Connecticut Institute of Water Resources
Annual Technical Report
FY 2010

Introduction

The Connecticut Institute of Water Resources is located at the University of Connecticut (UCONN) and reports to the head of the Department of Natural Resources Management and Engineering, in the College of Agriculture and Natural Resources. The current Director is Dr. Glenn Warner, and the Associate Director is Dr. Patricia Bresnahan.

Although located at UCONN, the Institute serves the water resource community throughout the state. It works with all of Connecticut's water resource professionals, managers and academics to resolve state and regional water related problems and to provide a strong connection between water resource managers and the academic community.

The foundation for this connection is our Advisory Board, whose composition reflects the main water resource constituency groups in the state. IWR staff also participates on statewide water-related committees whenever possible, enabling our Institute to establish good working relationships with agencies, environmental groups, the water industry and academics.

The USGS 104B program is the financial core of the CT IWR. The Institute does not receive discretionary funding from the state or the university, although it does receive approximately one third of the Associate Director's salary per year as match for our program administration and other activities.

Research Program Introduction

The majority of our 104B funds are given out as grants initiated in response to our annual RFP, with the majority of those funds going to research projects. When selecting projects for funding, the Institute considers three main areas: 1. technical merit, 2. state needs and 3. CT IWR priorities (use of students, new faculty, seed money for innovative ideas).

In addition to its 104B program, the Institute conducts externally funded projects, the majority of which are sponsored by state agencies.

Optimization of Acidogenic Anaerobic Wastewater Treatment with The Potential for Water Reclamation

Basic Information

Title:	Optimization of Acidogenic Anaerobic Wastewater Treatment with The Potential for Water Reclamation
Project Number:	2008CT177B
Start Date:	3/1/2008
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2nd
Research Category:	Engineering
Focus Category:	Acid Deposition, Water Quality, None
Descriptors:	
Principal Investigators:	Baikun Li

Publications

1. Y. Sharma, and B.Li. Hydrogen production from organic contaminants in batch-mode and continuous mode. Bioresource Technology (In review). Submitted: November 2008.
2. Y. Sharma , B. Li. Optimization of hydrogen production from organic wastewaters from experimental and kinetic approaches. International Journal of Hydrogen Energy (In press).
3. Y. Sharma, and B.Li. Optimization of hydrogen production treating organic contaminants. Water Environmental Federation Technical Exhibition and Conference (WEF-TEC), Chicago IL, Oct. 2008. (Won the First-Prize in Poster Session).
4. D. Jiang, Y. Sharma, B. Li, M. Curtis. Bioenergy production from wastewater treatment. Water Environmental Federation (WEF) Sustainability Conference, DC. June 2008.
5. Y. Sharma, and B.Li. Optimization of hydrogen production in anaerobic acidogenic phase and electricity generation in MFCs. ACS Annual Conference. March 2010.
6. Y. Sharma, and B.Li. Co-metablism of biodiesel waste to clean energy. Water Environmental Federation Technical Exhibition and Conference (WEF-TEC), Oct. 2010.
7. Li, F., Sharma, Y., Lei, Y., Zhou, Q., B. Li. “Microbial Fuel Cells: The Effects of Configurations, Electrolyte Solutions, and Electrode Materials”. Applied Biochemistry Biotechnology. DOI 10.1007/s12010-008-8516-5. 2009.
8. Sharma, Y. B. Li. “The variation of power generation with organic substrates in single-chamber microbial fuel cells (SCMFCs)”. Bioresource Technology. 101 (6): 1884-1850. 2009.
9. Sharma, Y., B. Li. “Optimization of hydrogen production from wastewater in batch reactors through experimental and kinetic analysis”. International Journal of Hydrogen Energy. 34 (15): 6171-6180. 2010.
10. Sharma, Y., B. Li. “Optimizing energy harvest in wastewater treatment by combining anaerobic hydrogen producing biofermentor (HPB) and microbial fuel cell (MFC)”. International Journal of Hydrogen Energy. 35 (8): 3789-3797. 2010.
11. Sharma, Y., Parnas, R., B.Li. “Bioenergy production from glycerol in hydrogen producing bioreactors (HPBs) and microbial fuel cells (MFCs)”. International Journal Hydrogen Energy, 36 (6). 3853-3861. 2011.

Products and outcomes of the Connecticut Water Resource Center Project "Optimization of Acidogenic Anaerobic Wastewater Treatment with The Potential for Water Reclamation"

(**Baikun Li** PI, **Yogesh Sharma**, Graduate student)

Research: The research project focused on the optimization of acidogenic anaerobic wastewater treatment, wastewater effluent quality and the bioenergy production from wastewater treatment. Anaerobic treatment has been extensively tested in batch-mode (100 mL) and continuous-mode (2L). The effects of contaminant concentration, pH, and temperature on wastewater treatment and hydrogen production have been elucidated. The correlation between biogas production and liquid fermentation products has been determined. The microbial communities under different operational conditions have been analyzed. In addition, acidogenic wastewater treatment process is also connected with microbial fuel cell (MFCs) to further treat the anaerobic effluent for water reclamation.

The research has provided significant value for the professional development of Mr. Yogesh Sharma. He has presented at several conferences and won the Poster Award in WEFTEC 2009. Yogesh also presented the research in the WEFTEC 2010 Annual Conferences. He also submitted five journal papers based on the research project. In 2009, Yogesh won the Outstanding Environmental Engineering Graduate Student Award In NEWEA.

Research conducted in 2010: Due to the success of batch-mode tests and preliminary results of continuous-mode results, the optimization of continuous-mode systems has been conducted in 2010. The effects of contaminant concentration, pH and temperature on wastewater treatment efficiency, hydrogen production and liquid fermentation pathways will be extensively investigated in the continuous-flow systems, which is similar to the real-world treatment processes. Finally, the co-metablism of glycerol and glucose in anaerobic biofermentor was conducted to convert the biodiesel waste to clean energy source.

Presentation delivered from the project.

1. Y. Sharma, and B.Li. Optimization of hydrogen production in anaerobic acidogenic phase and electricity generation in MFCs. *ACS Annual Conference. March 2010.*
2. Y. Sharma, and B.Li. Co-metablism of biodiesel waste to clean energy. W*ater Environmental Federation Technical Exhibition and Conference (WEF-TEC)*, Oct. 2010.

Journal paper submitted from the project.

1. Li, F., Sharma, Y., Lei, Y., Zhou, Q., B. Li. "Microbial Fuel Cells: The Effects of Configurations, Electrolyte Solutions, and Electrode Materials". *Applied Biochemistry Biotechnology.* DOI 10.1007/s12010-008-8516-5. 2009.
2. Sharma, Y. B. Li. "The variation of power generation with organic substrates in single-chamber microbial fuel cells (SCMFCs)". *Bioresource Technology.* 101 (6): 1884-1850. 2009.
3. Sharma, Y., B. Li. **"**Optimization of hydrogen production from wastewater in batch reactors through experimental and kinetic analysis". *International Journal of Hydrogen Energy.* 34 (15): 6171-6180. 2010.
4. Sharma, Y., B. Li. "Optimizing energy harvest in wastewater treatment by combining anaerobic hydrogen producing biofermentor (HPB) and microbial fuel cell (MFC)". *International Journal of Hydrogen Energy.* 35 (8): 3789-3797. 2010.

5. Sharma, Y., Parnas, R., B.Li. “Bioenergy production from glycerol in hydrogen producing bioreactors (HPBs) and microbial fuel cells (MFCs)”. *International Journal Hydrogen Energy*, 36 (6). 3853-3861. 2011.

Evaluation of Turbidity Acidification During Sampling and Analytical Preparation as the Cause of Observed Manganese Anomalies in Drinking Water Wells

Basic Information

Title:	Evaluation of Turbidity Acidification During Sampling and Analytical Preparation as the Cause of Observed Manganese Anomalies in Drinking Water Wells
Project Number:	2009CT202B
Start Date:	3/1/2009
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2
Research Category:	Ground-water Flow and Transport
Focus Category:	Hydrogeochemistry, Toxic Substances, Geochemical Processes
Descriptors:	None
Principal Investigators:	Gary A. a Robbins

Publications

1. Suarez, L, 2010, Evaluation of Turbidity Acidification During Sampling and Analytical Preparation as the Cause of Observed Manganese Anomalies in Drinking Water Wells, Final report for M.S. research project, U. Connecticut.
2. Robbins, G. 2008, Geochemical Linkages Between Increasing Rural Development and Elevated Manganese Levels in Domestic Wells in Fractured Crystalline Bedrock, seminar presentation at New Mexico, Tech U., Socorro, NM, April 3.

Project: Evaluation of Turbidity Acidification During Sampling and Analytical Preparation as the Cause of Observed Manganese Anomalies in Drinking Water Wells

Principal Investigator: Gary A. Robbins, Professor of Geology, Dept. of Natural Resourcesand the Environment, U. Connecticut

Research Status: The study entailed conducting laboratory tests to simulate sample preservation with acid, with and without filtering, field sampling tests and sampling at bedrock wells at homes in different parts of the State that were identified as contaminated with dissolved manganese. All the research work is complete. We are currently developing a paper for publication to be submitted to ES&T.

Major Finding: High levels of manganese found in drinking water wells in crystalline bedrock in Connecticut have been found to be associated with anthropomorphic activities including septic effluent, mining, and degree of development. The increased manganese appears to be due to reduction in oxidation-reduction potential which could release manganese from soil, fracture surfaces or from oxidized steel casing. Acidification of water samples for preservation may result in false positive indications of manganese contamination or an increase in actual contamination levels, owing to leaching of suspended material.

Publications and Presentations:

Suarez, L, 2010, Evaluation of Turbidity Acidification During Sampling and Analytical Preparation as the Cause of Observed Manganese Anomalies in Drinking Water Wells, Final report for M.S. research project, U. Connecticut.

Robbins, G. 2008, Geochemical Linkages Between Increasing Rural Development and Elevated Manganese Levels in Domestic Wells in Fractured Crystalline Bedrock, seminar presentation at New Mexico, Tech U., Socorro, NM, April 3.

Students supported by the work

Lisandro (Lee) Suarez, Completed M.S. 2010

Helen Spera, M.S candidate (expected graduation summer 2011)

Stream chemical interactions within the urban environment: assessing the fate of nitrogen and mercury in a stream impacted by combined sewer overflows

Basic Information

Title:	Stream chemical interactions within the urban environment: assessing the fate of nitrogen and mercury in a stream impacted by combined sewer overflows
Project Number:	2009CT207B
Start Date:	3/1/2009
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2
Research Category:	Water Quality
Focus Category:	Nutrients, Surface Water, Wastewater
Descriptors:	None
Principal Investigators:	Joseph T Bushey

Publications

There are no publications.

CONNECTICUT INSTITUTE OF WATER RESOURCES

Project Title: Dynamics of nitrogen loading and speciation in urban combined sewer catchments: An assessment of the effects of flow conditions

QUARTERLY REPORT

Period: April 2010 – May 2011
Submitted: June 2, 2011

PRINCIPAL INVESTIGATOR

Joseph T. Bushey
Department of Civil & Environmental Engineering, University of Connecticut

ADDITIONAL PROJECT PARTICIPANTS

Graduate Student, Mykel Mendes, MS

OVERVIEW:

Due to challenges encountered with the pore water samplers in the Park River, efforts during the second year of the project (April 2010 – May 2011) have focused on characterizing shifts in DOC quality according to source and then to assess the influence of those DOC shifts on mercury (Hg) binding. The nature of the bed sediment in the North Park River and vandalism prevented accurate collection of pore water samples from the range of sits. Field equipment vandalism combined with graduate student interest in DOC quality led to the shift in emphasis. Monthly stream water samples are still being collected to assess base flow changes along with event sample collection associated with separate project. Regarding DOC quality characterization, $SUVA_{254}$ is being used as a surrogate for quality during events. This is to be supplemented by fluorescence and electron emission spectroscopy (EEMS) on select samples. Finally, DOC hydrophilic and hydrophobic fractions have been isolated for characterization and will be utilized in laboratory sorption experiments to assess potential shifts in Hg mobilization and bioavailability with source.

While the focus of the project has shifted towards DOC characterization, a methodology has been developed by another student for laboratory assessment of denitrification potential for the sediments in the North Park River and to examine the potential influence of shifts in N-source on denitrification in a laboratory setting. To date, materials have been ordered and a methodology is being established to perform laboratory work and to assess shifts in microbial populations.

Accomplishments to date:

- Finalized sampling site selection
- Obtained site access
- Hired and trained a graduate student to execute sampling and chemical analysis
- Established method for DOC characterization and fractionation
- Collection of monthly stream water samples (November 2009)
- Collected sediment samples (May 2010)
- Installed water level loggers (June 2010)
- Set up sorption experiments for Hg-DOC interactions (June 2011)

RESEARCH AND EDUCATIONAL ACTIVITIES:

Field Deployment*:*

Dr. Bushey and Mr. Perkins from the University of Connecticut Center for Environmental Sciences and Engineering made an initial evaluation of perspective field sites in April 2009 in association with a related project for The Metropolitan District Commission. This was followed by two additional site visits by Dr. Bushey during Summer 2009 and by Dr. Bushey and Ms. Mendes in November 2009. Based on these initial discussions regarding The MDC study, a stream reach was selected to bracket the influence of combined sewer overflows (CSOs) and untreated wastewater on water quality in the North Park River (NPR), in Northwestern Hartford (CT). Concerns remained regarding the suitability of the field sampling sites relative to (1) the CT IWR study objectives, (2) the physical potential to install and maintain porewater samplers, and (3) site access approval. Based on preliminary site visits, four sites were selected within the initial stream reach for stream water sampling: UConn Law School, Albany Avenue, University of Hartford and Portage Road moving upstream, respectively (Figure 1). These four sites were approximately equally-distributed along the reach with two each above and below the uppermost CSO. Site access for the respective sites was obtained in Fall 2009 during discussions with homeowners (Portage Rd), the University of Hartford, the University of Connecticut Law School and Hartford and MDC personnel (Albany Ave). Additional site selection for DOC characterization was finalized in Fall 2010 to include the Hartford WPCF influent and effluent streams, impervious surface runoff and a forested site in the headwaters of the NPR.

Equipment

Following site selection, the samplers and flow monitoring devices were ordered. Equipment was ordered and porewater samplers were designed based on an installation approach. The installation approach was selected over composite sampling using a temporary pumping probe due to the consistent potential for the permanent devices. A sediment sampler, flow-meter and two water chemistry probes were ordered and prepared for use. Sufficient 1-ft and 2-ft plastic sediment core sleeves were ordered to collect the proposed number of sediment cores from the sites.

For porewater sampling, 30 mL Teflon vials were ordered with one transfer port on the tip. Holes were drilled into the sides of the vials to allow for uniform water flow into the vials during sampling. The smallest possible drill bit was used to minimize the entrainment of solids during sampling. Additionally, the sediment corer was retrofitted to enable easy installation of the porewater samples at the appropriate depth (Figure 2). A prototype temporary porewater sampling device also was explored and constructed due to potential issues with the permanent installations and site channel sediment composition and security as discussed below.

Student Training

In addition to the set up of instrumentation, a graduate student, Mykel Mendes, has been hired and trained. Due to the timing of the grant, the student did not begin until August 2009. However, in this short time frame, the student has been trained by Dr. Bushey and CESE personnel on laboratory protocol as well as the analysis of dissolved organic carbon (DOC), anions and mercury (Hg). Ms. Mendes has also investigated DOC characterization techniques and set up instrumentation for fractionating and isolating DOC in the UConn laboratory. As with N speciation shifts, the investigation of DOC quality in an urban setting is lacking. Additionally, Ms. Mendes (MS) has become familiar with sampling and field work as well as obtained knowledge of the relevant research in the field.

A second student (Nakita Horrell, MS) was hired in association with the MDC/DEP project and has established a methodology for examining the influence of N shifts on denitrification in a laboratory setting. The lack of suitability of the NPR for in-situ sediment assessment required a shift in the approach towards a laboratory setting, particularly a microbiological assessment. However, the cores previously collected in association with the CTIWR project will be utilized to assess denitrification potential via microbial population dynamics.

Sampling and piezometers installation

Stream water sampling was initiated in November 2009 following the granting of site access. Samples were collected at each of the four sampling sites for Hg speciation, DOC characterization, anions and metals. Monthly stream samples have been collected through April 2011 and are planned to continue to establish a seasonal baseline for the watershed.

Bed type and suitability were examined for porewater samplers during the initial stream water sampling at the four sites in November 2009 (Figure 1). The Portage Road site was eliminated for porewater samplers due to the bedrock stream bed characteristics. At the UConn Law School site, the stream channel is composed of a thick clay layer. However, a sandy layer exists near rip-rap installed to protect a recently modified MDC sewer pipe crossing beneath the channel. Three samplers were installed in this sandy layer as these relatively exchangeable sites are Denitrification and methylation hotspots. The transect of three porewater samplers at the Albany Avenue site was installed perpendicular to the channel (Figure 3) at an approximate depth of 4 in to the top of the sampler. This depth was deeper than initially intended but necessary to prevent the sampler from washing downstream during high flow. The two transects at the University of Hartford site included two samplers in the stream channel at 4 in depth with four samplers installed in sand/gravel bar on a bend in the river (Figure 4). Two samplers were installed at different depths of the bar, one shallow (8 in below surface) and one deep (22 in below surface). The transects at the UConn Law School stream channel site were installed similarly to those at Albany Ave.

At the UConn Law School, a small side channel which floods during elevated discharge conditions was instrumented with porewater samplers as a thick littoral layer existed over the clay layer. However, two of the lysimeter tubes were vandalized in the month following installation while the others filled with clay making pumping difficult. The stream bank samplers and one of the stream transects at the University of Hartford location were also vandalized. Finally, a decision was made not to install porewater samplers in the small pond on the University of Hartford campus in lieu of sediment core collection. Due to vandalism we are re-exploring the temporary porewater collection device as described by the USGS. Permanent samplers are difficult and costly to install particularly given the lack of protection from vandalism afforded at the urbanized sites. However, initial pumping tests in April-May 2010 also demonstrated the difficulty in obtaining accurate porewater samples from the installed lysimeters. Due to the clay lens dominating the stream bed we had selected relatively rocky locations in which to install our samplers. In each case, surface water quickly is drawn into the porewater samplers during pumping. Therefore, we have since shifted to a laboratory-based microbial assessment of the influence of shifts in N speciation.

Initial discharge readings were to be calculated from readings across the channel, with channel morphology noted. However, this has proved difficult and inconsistent. A set of water level loggers was installed in June 2010 at the Portage Rd and the UConn Law School sites. These will be calibrated during multiple events to discharge using ISCO® discharge recorders in Summer 2011.

Additional sediment samplers are being installed in June 2011 to collect solids mobilized during events. These will be characterized for OC content as well as for CHNS, trace metals and anthropogenic organic compounds.

Dissolved Organic Carbon Characterization

A column was set up and utilized to separate the humic acid, fulvic acid, hydrophobic acid and hydrophilic acid fractions from 5 water sources: WPCF influent, WPCF effluent, impervious surface runoff, forested stream water and a sample collected at peak discharge at the UConn Law School site in late February 2011. Organic characteristics have been documented to reflect source contributions to the watershed and also to influence contaminant, particularly trace metal, mobilization. The DOC from each sample has been characterized according to $SUVA_{254,}$ fluorescence, EEMS, size and characteristic fractionation. We are currently lyophilizing the final runoff sample collected in May 2011. Once finalized, we will analyze each DOC via NMR for basic characteristics (e.g., amino acid fraction) as well as for CHNS with a particular focus on the S content.

A 100 L sample was collected from each site, and filtered through precombusted Whatman GF/C glass fiber 0.45 µm filters into 50 L carboys and were acidified to a pH of 2.0 with hydrochloric acid. These samples were fractionated into hydrophobic (humic) and hydrophilic (non humic) fractions of DOC using analytical-scale column chromatography with DAX-8 Supelite resin (40-60 mesh) and XAD-4 Amberlite resin (20-60 mesh) according to published methods (Thurman and Malcolm, 1981; Aiken et al, 1992; Hood et al, 2003; Wang et al, 2009). The organic matter isolates were desalted, proton saturated, and lyophilized for use in the Hg-DOC sorption experiments. Total dissolved organic carbon was determined with a Tekmar Apollo 900 TOC analyzer. Additional surface water samples were collected in 500 ml trace-clean Teflon® bottles, filtered through precombusted Whatman GF/C glass fiber 0.45 µm filters and analyzed for total dissolved mercury via oxidation, purge, and trap, cold vapor atomic fluorescence spectroscopy (CVAFS; EPA Method 1631). A spectral analysis of each sample and its isolates was obtained by measuring $SUVA_{254}$ and fluorescence. Fluorescence was determined on a spectrofluorometer equipped with a xenon arc lamp as the excitation source. A Matlab code was developed (M. Quaranta, personal communication) to separated the excitation emission matrix into contour plots using the Ex/Em and intensities of fluorescence maxima for characterization. High performance size exclusion chromatography (HPSEC) measured estimates of the molecular size of the DOC and an elemental analyzer will be used to estimate the percentages of carbon, nitrogen, hydrogen, and sulfur content of the DOC source.

Hg-DOC Sorption Analysis

An equilibrium dialysis ligand exchange (EDLE) experiment will be performed on each sample to observe the complexation potential of ionic mercury (Hg^{2+}) to the hydrophilic and hydrophobic fractions of freshwater DOC isolates (Hintelmann et al, 1997; Haitzer et al, 2002; 2003; Waples et al 2003). Dialysis CE 500 MWCO membranes were cleaned by immersing the membrane in DI water overnight and then rinsing several times with DI water. The membrane was stored at 4°C in DI water. Using about 20 cm length of dialysis tubing as the inner membrane (bag), 1.0 mg/L of the freeze dried organic matter was reconcentrated in 0.1 M $KClO_4$ and 0.01 M EDTA. This membrane was placed in an outside solution which is spiked with Hg^{2+} in 10% HCl in a 250 ml Teflon bottle. The outside solution was spiked with Hg^{2+} at concentrations from 1.0 to 25 ng/L. The bottles were placed on an end-over-end rotator for 24 hours in a dark room to reduce photo degradation of the organic matter. Sample aliquots were taken from inside and outside of the bag and analyzed for Hg^{2+} by EPA Method 1631 for cold vapor atomic fluorescence spectroscopy (CVAFS) and DOC from a Teledyne Tekmar Apollo 9000 TOC analyzer. Experiments were completed in triplicate for each type of DOM source with a control containing only EDTA and Hg^{2+}. The Hg^{2+} concentration inside the bag indicated the amount of Hg^{2+} bound to the organic matter and the Hg^{2+} outside represents the amount of the total (bound and unbound) Hg.

Laboratory Nitrogen Speciation Shift Impacts

The Park River sites are being assessed for potential shifts in microbial community diversity and function in response to shifting N species contributions. CSOs and impervious surface runoff contribute significantly to N flux during precipitation events. The overarching objective of Ms. Horrell's project will be to determine potential impacts on microbial nitrogen cycling with urbanization. To address this objective she has developed a microfluidic device to directly assess microbial communities in the natural systems. We propose to deploy the microfluidic devices in the natural environment along the urbanization gradient of the NPR to assess impacts on the microbial community as well as to harvest microbial communities to conduct chemical assays in the laboratory. These will allow us to characterize the impact of chloride loading and to assess potential shifts due to N species shifts. Devices will be deployed for various time intervals to establish how long the device needs to be deployed in order to recruit enough microbes and the chloride gradient stability will be tested. This will be tested at an individual vernal pool location prior to deployment at other locations. Devices will be deployed at three Park River sites.

Nitrogen utilization assays

A technique also has been developed to assess the ability of microbial communities to utilize various N chemical species. The microbial community collected from the upstream Park River location theoretically represents a community that is primarily influenced by forested inputs with sporadic stormwater runoff from impervious surfaces. Downstream locations receive CSO inputs. Batch systems will be prepared using sediments from upstream and downstream locations with N as the limiting nutrient. The solutions will be spiked with various N species, either reduced or oxidized, and monitored for chemical speciation of N. This will provide a measure of N conversion and utilization in the sediments similar to that proposed using the in-stream sediment pore water devices. The sediments can be brought back to the lab and incubated with 40 mL stream water collected from various levels of the urban gradient in Park River. Initial samples of the water will be analyzed for N species (NO_3^-, NO_2^-, NH_4^+, and N_{org}) and dissolved organic carbon (DOC). The carbon content will be measured and additional carbon added to satisfy the Redfield ratio of 16:1 (C:N) so that N is the limiting nutrient for microbial respiration. The incubations will be carried out in mason jars and lids will be fitted with septa for sampling gas (N_2, CO_2, and O_2). Denitrification will be determined by monitoring the production of N_2. The total duration for the incubations will be 30 days with samples collected at days 0, 10, 20, and 30. This will include water samples for N species and gas samples as described above. On days 0 and 30, the microbial community will be extracted from the sediment samples using commercially available kits and compared to the community structure that is present in the control sample. We will then be able to determine if the change in source impacts community structure and if this influences the N transformations.

Microbial community analysis

Microbial DNA will be extracted using commercially available kits and PCR used to amplify genetic material. The 16s rRNA gene from each genome will be sequenced and a comparison will be made between microbial communities as a function of the chloride gradient. This method will allow us to determine the abundance of the species present in the sample, but not specific species. This is a simple method that allows researchers to make relative comparisons between different communities. In this case, we are interested in the change in community diversity and this method is appropriate.

Future Work

- Collect stream water samples monthly
    - Analyze for Hg speciation, N speciation, metals, DOC characterization and ancillary parameters
- Perform Hg-DOC sorption experiments (June 2011)
- Analyze sediment samples for Hg speciation, metals, POC characterization, organic content and ancillary parameters (Fall 2011)
- Assess changes in microbial diversity due to shifting nitrogen sources (Summer 2011)
- Evaluate potential impact of shifting source on denitrification potential (Summer 2011)

Anticipated output:

- MS thesis
    - Mykel Mendes, "Evaluation of changes in Hg-DOC binding in various contributing sources to streams in developed ecosystems" (*August 2011*)
    - Nakita Horrell, "Potential shifts in microbial population diversity and denitrification potential due to alterations in N species contributions and chloride levels" (*December 2011*)

- Manuscripts
    - Hg-DOC sorption in urban stream water sources (*anticipated submission September 2011*)
    - Hg-DOC relationships during events: contributions from potential sources relative to base flow (*anticipated submission December 2011*)
    - Alterations in denitrification potential due to shifts in nitrogen speciation and chloride concentrations in developed ecosystems (*anticipated submission December 2011*)

Multi-temporal Assessment of Connecticut Lake Water Clarity Using Landsat Satellite Imagery

Basic Information

Title:	Multi-temporal Assessment of Connecticut Lake Water Clarity Using Landsat Satellite Imagery
Project Number:	2010CT208B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	District 2
Research Category:	Water Quality
Focus Category:	Water Quality, Surface Water, None
Descriptors:	None
Principal Investigators:	Daniel Civco, James D Hurd

Publications

There are no publications.

Multi-temporal Assessment of Connecticut Lake Water Clarity Using Landsat Satellite Imagery

Progress Report
May 2011

Daniel Civco – Principal Investigator
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RESEARCH PROBLEM

Connecticut has over 1,000 lakes and ponds larger than 5 acres in area. These water bodies provide important recreational opportunities, aesthetic values, and ecosystem services that contribute to the quality of life, environment, and economy of the state. Over the past 400 years, Connecticut has undergone significant alterations to its landscape. As a result of these mostly anthropogenic activities, including clearing of forests, agriculture, and urban and rural development, there have been significant impacts to the water quality of Connecticut's lakes and ponds. While a natural process, the eutrophication of lakes caused by excess nutrient export in runoff has been, and continues to be, a pervasive problem (Siver *et al.*, 1996). These conditions limit recreation opportunities, reduce the economical value of property, and diminish the ecological integrity of lakes" (CT DEP Lake Water Quality Management Program). An analysis conducted in Connecticut by Siver *et al.* (1996) found that 33 out of 35 lakes studied had shown a decline in water clarity, an indicator of water quality, since the 1930's.

Protecting lake water quality is a major concern for local, regional, and state agencies as well as citizens and non-profit organizations. Comprehensive water quality data are essential for improved management and policy decisions. It is, however, prohibitively expensive to monitor water quality for a significant number of lakes and ponds using conventional methods. As such, many lakes and ponds are not sampled throughout the region (missing potentially low water quality lakes and ponds), or under-sampled within the lake (missing the full, within lake, spatial extent of algal blooms and other phenomenon associated with the identification of lake trophic levels) resulting in the under-representation of the full extent of water quality issues (Mancino *et al.*, 2009). Over the years, several surveys have been undertaken to assess water quality in Connecticut, but the number of lakes and ponds included are minimal (Deevey, 1941; Norvell and Frink, 1975; Frink and Norvell, 1984; Canavan and Siver, 1994; 1995). Additionally, the U.S. EPA, USGS, Connecticut Agricultural Experiment Station (CAES), Connecticut DEP (CT DEP), academic and research institutions, and non-profit organizations periodically conduct water quality analysis. Although these surveys provide a hint at statewide water quality, no complete assessment has been conducted. Satellite remote sensing provides an efficient means by which to get at the *big* picture of statewide lake and pond water quality by enhancing *in situ* limnological measurements which can be applied to other lakes within the same satellite image and allow for the extension of the measured parameters collected from point locations within a lake to be applied to the entire lake surface (Mancino *et al.*, 2009).

INTRODUCTION

The primary goal of this project was to ***derive a multi-temporal assessment of lake water clarity at the state level from available Secchi Disk Transparency (SDT) data and archived Landsat satellite imagery dating back to the mid-1970s.*** To achieve this, we adopted the regression analysis procedures used successfully in the Northern Plains region of the United States (Lillesand *et al.*, 1983; Lathrop and Lillesand, 1986; Fuller *et al.*, 2002; Kloiber *et al.*, 2002a; 2002b). Ninty-five Landsat scenes covering portions of the years 1973-2010 for Connecticut were reviewed for applicability and numerous years of SDT data of Connecticut lakes were collected from the literature. Additionally, physical collection of SDT data was conducted from late July through August 2010 and applied to a 2010 estimation of Connecticut lake water clarity. Based on these data, four dates of water clarity were estimated for the years 1980, 1993, 2005 and 2010.

DATA

Secchi Disk Transperency Data: Lake water clarity is typically measured by Secchi disk and the Secchi Disk Transparency (SDT) result serves as an indirect measure of a lake's trophic state. This data is directly comparable to the reflectance information collected by satellite imagery. For this project, transparency data was collected from the literature for lakes in Connecticut (Norvell and Frink, 1975; Frink and Norvell, 1984; Canavan and Siver, 1994; 1995; CAES, 2010). Data ranged from the years 1973 – 2009 which corresponds closely with the launch of the first Landsat satellite in 1972. All SDT data collected for this project are reported in Appendix A. Additionally, a team of students physically collected SDT data during the late July – August 2010 season. This data was used for the 2010 water clarity estimate.

Landsat Satellite Imagery: Connecticut is covered almost entirely by Landsat scene WRS Path 13 Row 31. This path row was, therefore, the only scene examined for this project dating back to 1973. The objective was to find cloud free imagery that corresponded closely with the available SDT data collection. A list of all Landsat data examined are provided in Appendix B. The preference is to have SDT data collected within plus or minus seven days of the Landsat image. Examining 95 satellite images, it was determined that the best dates for producing water clarity estimates would be August 29, 2010 (Landsat 7 ETM), August 21, 2010 (Landsat 5 TM), September 9, 2005 (Landsat 5 TM), August 22, 1993 (Landsat 5 TM), and April 6, 1980 (Landsat 3 MSS) although some of these dates resulted in extending beyond the preferred seven day span of SDT collection (see Appendix C). Some misregistration was identified in the 1980 and 1993 imagery which was shifted to match that found in the 2010 (Table 1).

Table 1. Required shift in the X and Y direction to geographically align with the 2010 Landsat image.

DATE	X SHIFT (meters)	Y SHIFT (meters)
6 April, 1980	-1667	-603
22 August, 1993	+ 3180	+17790

METHODOLOGY

Once the appropriate SDT and Landsat data had been acquired, the follow steps were performed to derive lake water clarity estimates.

Water Extraction: An unsupervised classification process (ISODATA in ERDAS IMAGINE) is applied to the Landsat imagery to identify water and other land cover pixels. Since water is spectrally unique from most other land cover features it tends to be easily identifiable. Thirty clusters are specified and labeled into water or non-water categories. These clusters are recoded into non-water (class 0) and water (class 1). A clump process is applied to the water pixels to identify groups of adjacent water pixels which represent waterbody features. Water clumps less than 3 acres in area are sieved from the clump layer to produce a feature layer of waterbodies greater than three acres. This waterbody feature layer is used to extract water pixels from the original Landsat image which is then used in the regression model process.

Cloud and Cloud Shadow Removal: Some cloud and cloud shadow existed in the 1993 and 2005 Landsat TM images, however, these were minimal and did not significantly impact the identification of water pixels during the water extraction process. The August 21, 2010 Landsat TM image had significant cloud cover over the western half of the scene and could not be used for water clarity estimation. This area was substituted with the August 29, 2010 Landsat ETM image to derive the water clarity estimation. The April 6, 1980 Landsat MSS scene had no cloud issues.

Prepare Regression Model: Following recommendations found in the literature, the extracted water pixels from Landsat band 1 (blue) and band 3 (red) from the Thematic Mapper Sensor (2010, 2005, 1993) and band 1 (blue/green) and band2 (red) from the Multispectral Scanner (1980) are used to build the regression model. Using a statewide water polygon layer, the average response of each lake in band 1 and the ratio band 1/band3 is determined. Figure 1 provides examples of the derived Landsat data used to derive the data used in the regression model.

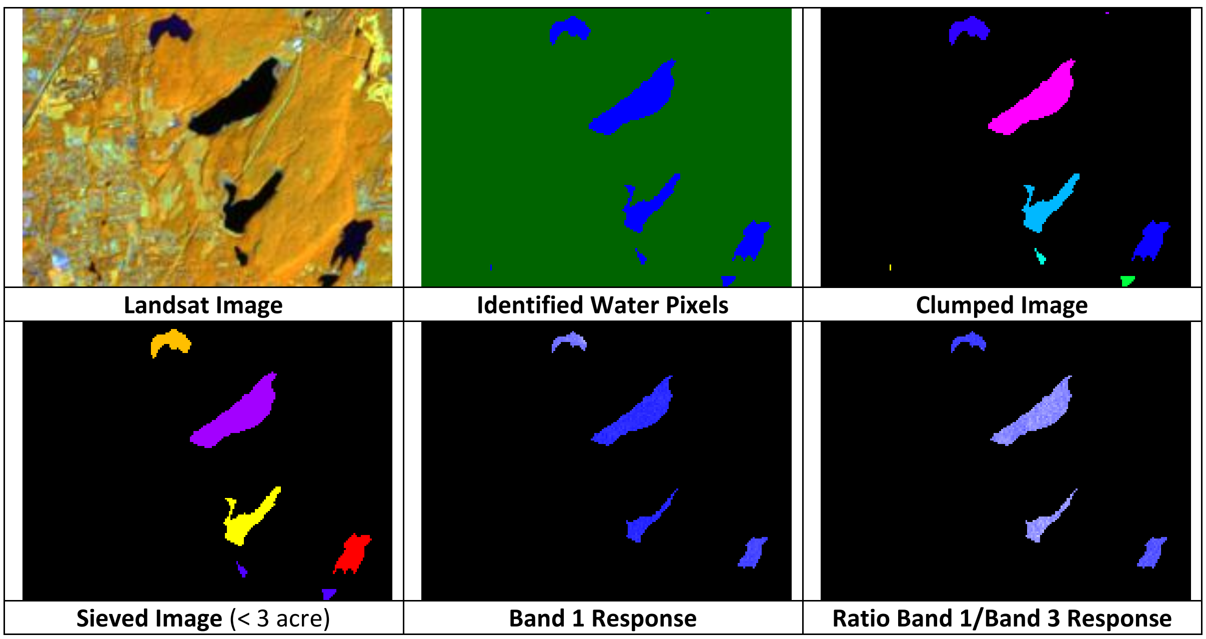

Figure 1. Example data layers created to build regression model.

Regression Model: The Landsat band 1 and the ratio of band 1/band 3 are used as the two independent variables in the model. The SDT data of sampled lakes for a given analysis year, log-transformed, serve as the dependent variable. The general predictive multiple regression equation used for the water clarity estimation is:

$$In(SD) = a(TM1/TM3) + b(TM1) + c$$

The resulting multiple regression equations independently derived for each analysis date are provided in Table 2. These models are applied, for each respective date, to the averaged band 1 and ration of band 1/band 3 Landsat data to derive the final lake water clarity estimate.

Table 2. Resulting multiple regression equations used for prediction of water clarity for each analysis date.

Estimation Date	Regression Equations
August 29, 2010	ln(SD)=1.29535(TM3/TM1) + (-0.04106)(TM1) + 0.69188
August 21, 2010	ln(SD)=0.40901(TM3/TM1) + 0.03047(TM1) + (-6.30695)
September 9, 2005	ln(SD)=0.13905(TM3/TM1) + 0.01899(TM1) + (-6.01691)
August 22, 1993	ln(SD)=0.07276(TM3/TM1) + 0.01722(TM1) + (-3.91417)
April 6, 1980	ln(SD)=0.55905(TM3/TM1) + (-0.03638)(TM1) + (-0.42668)

RESULTS AND DISCUSSION

An example of the final result of the water clarity estimation for 2010 is provided in Figure 2. For this particular date, 511 lakes are reported. For 2005, 1993 and 1980, 607 lakes, 550 lakes, and 459 lakes respectively were estimated. The number of lakes, and specific lakes, varied for each date depending on the amount of water pixels identified from the Landsat imagery for

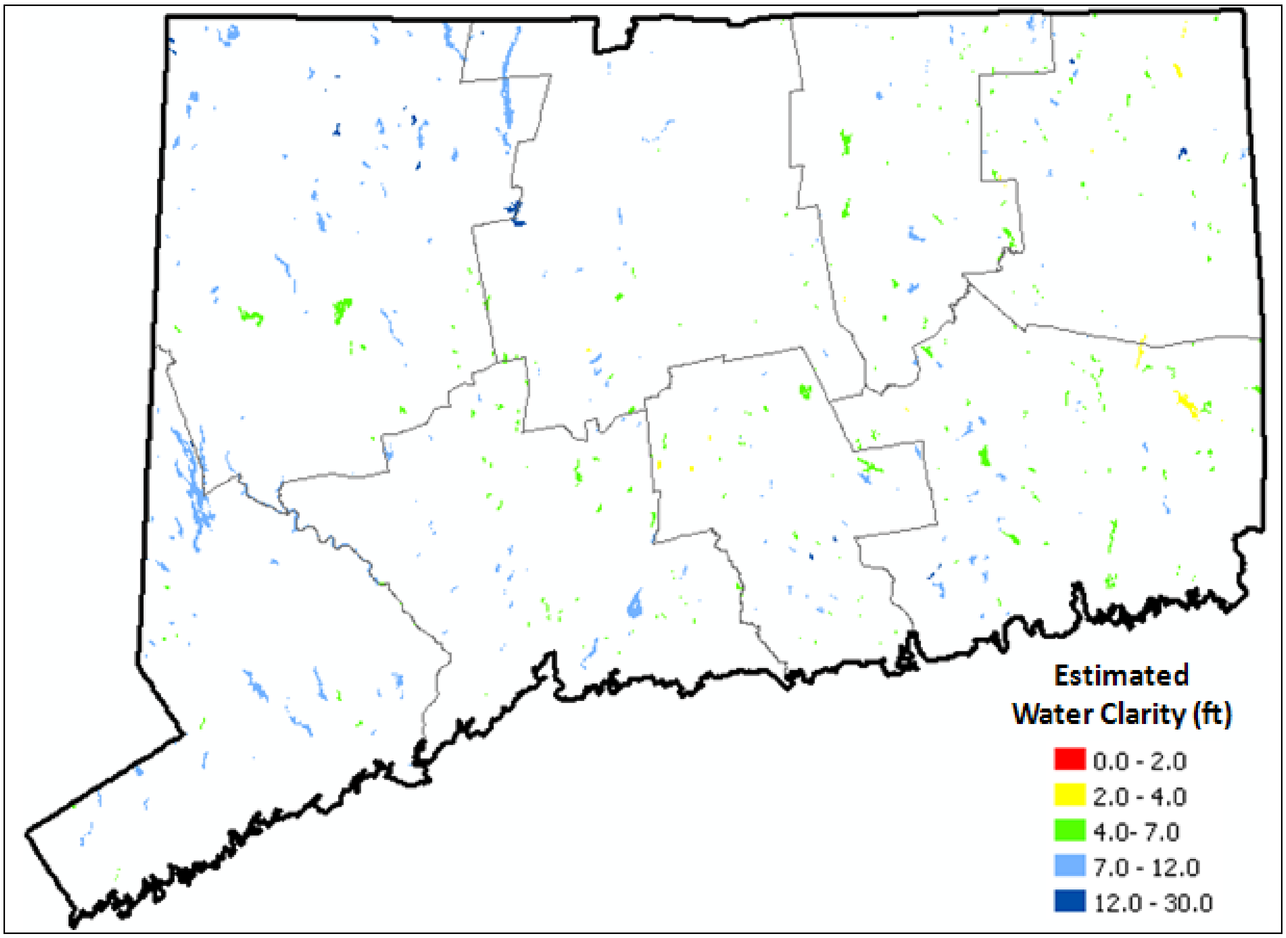

Figure 2. 2010 lake water clarity estimate. 511 lakes reported.

each date assessed. The map indicates differences in water clarity among lakes within the state, and the difference in water clarity is distributed throughout the state. The other dates of resulting water clarity estimation show similar trends. These will be made available online at the Center for Landuse Education and Research (CLEAR) website at http://clear.uconn.edu. Along with tablulature data for direct comparison among dates.

Additional statistical analysis provided in Figure 3 and Figure 4 seems to indicate a trend of decreasing water clarity overall from 1980 to 2010. In Figure 3, the median water clarity from 1980 is 8.44 feet (based on estimation of a springtime MSS Landsat image), 8.87 feet in 1993, 7.19 feet in 2005, and 6.83 feet for 2010. In addition, the maximum water clarity decreases as does the overall range. In Figure 4, most lakes have a slightly deeper water clarity of 7-12 feet in 1980 with this shifting to more lakes having a water clarity depth of 4-7 feet by 2010. Statistical analysis of the quality of the estimates still needs to be performed to determine if these are true trends or just artifacts of the models and imagery used. During the regression model development, 25 percent of the SDT samples, randomly selected, were maintained for validation purposes.

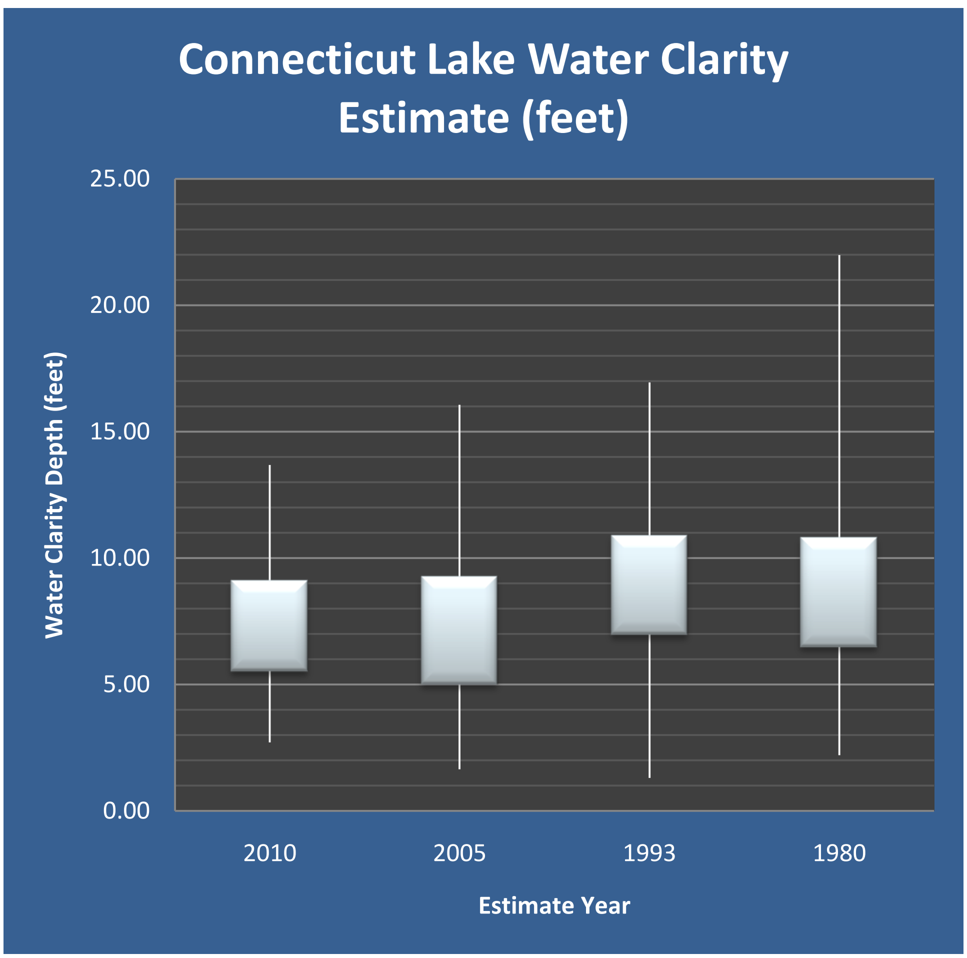

Figure 3. Box plot showing the median water clarity results, 25th and 75th percentile and minimum and maximum results for all lakes for each date assessed.

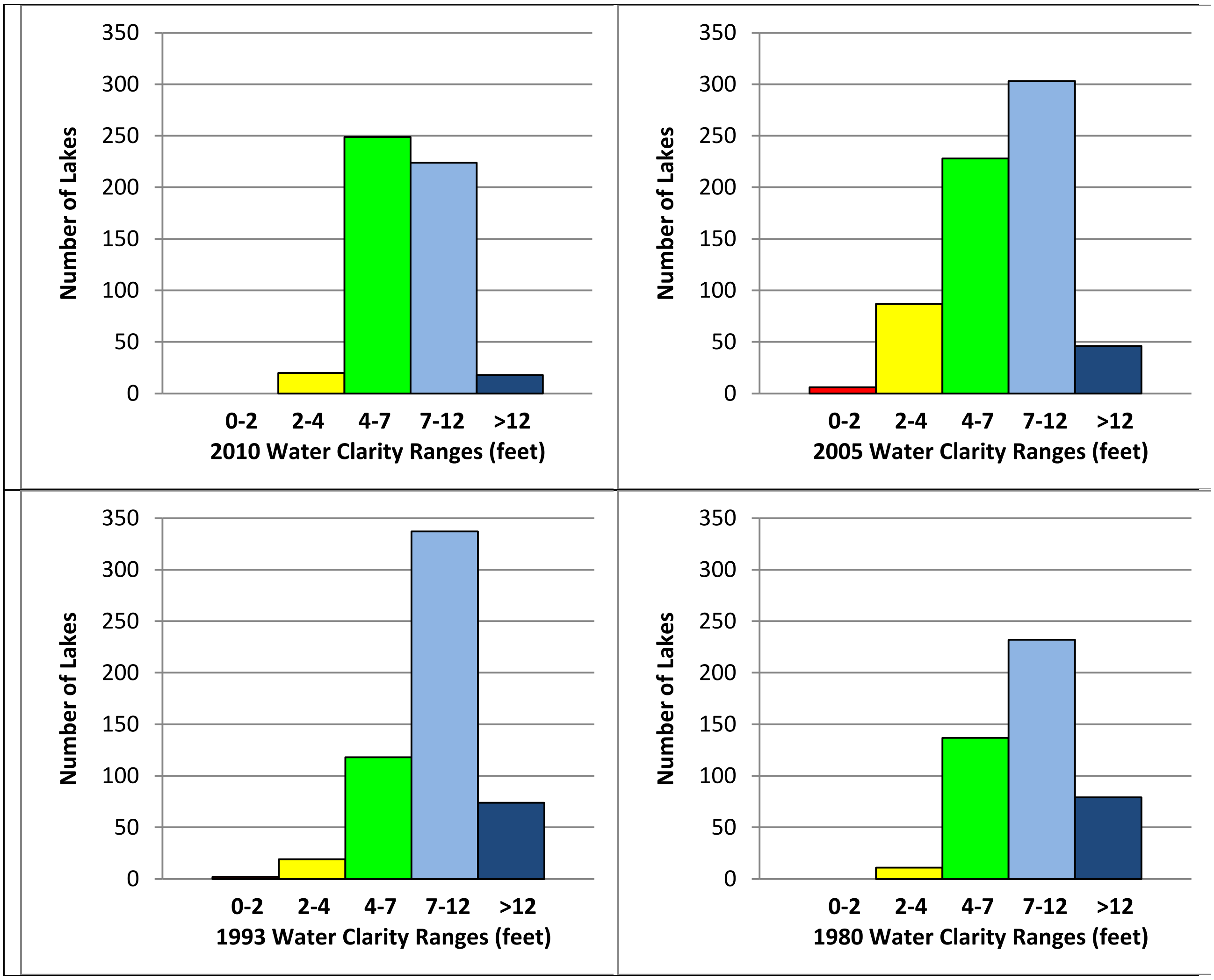

Figure 4. Water quality distribution of lakes in Connecticut for each of the four dates assessed.

FUTURE RECOMMENDATIONS

The following is a list of future research activities and needs:

- Comprehensive set of lake transparency data collected during the mid-July through mid-September time period as near the date of Landsat collection as possible. This can be problematic since we are unable to determine cloud cover until the day of the Landsat satellite overpass. If we can organize a large enough and active group of volunteers to be prepared to collect SDT data, we believe we can be successful at improving the lake water clarity estimates.
- Knowing specific coordinate location of lake transparency data collection will allow for more precision in model development. Currently point transparence data is applied to all water pixels making up the water body as opposed to just the single pixel and/or

immediate eight surrounding neighbors surrounding the area of data collection. Variability within the lake is likely to skew model results.

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APPENDIX A

Secchi Disk Transparency Data Collected

YEAR: 2010					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Wangumbaug Lake	3.7	7/22/2010	Long Pond	3.5	8/16/2010
Little Pond	1.6	7/29/2010	Dodge Pond	3.2	8/17/2010
Mansfield Hollow	2.2	7/30/2010	Gorton Pond	2.1	8/17/2010
Lower Bolton Lake	1.35	8/2/2010	Norwich Pond	2.4	8/17/2010
Middle Bolton	1.8	8/2/2010	Pattagansett Lake	2.7	8/17/2010
Bigelow Pond	2.3	8/4/2010	Powers Lake	4.1	8/17/2010
Black Pond	3.4	8/4/2010	Beseck Lake	0.8	8/19/2010
Mashapaug Pond	4.4	8/4/2010	Black Pond	2.6	8/19/2010
Lake Hayward	2.7	8/10/2010	North Farms Reservoir	1.25	8/19/2010
Moodus Reservoir	1.3	8/10/2010	Silver Lake	0.7	8/19/2010
Pickerel Lake	1.4	8/10/2010	Avery Lake	1.4	8/26/2010
Beach Pond	3.4	8/12/2010	Lantern Hill	2.5	8/26/2010
Glasgo Pond	1.3	8/12/2010	Gardner Lake	2.4	8/27/2010
Hopeville Pond	2.3	8/12/2010	Rogers Lake	3.5	8/27/2010
Pachaug Pond	1.9	8/12/2010	Uncas Pond	3.6	8/27/2010
Lake of Isles	2.4	8/16/2010			

YEAR: 2009					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Taunton Lake	1.5	6/10/2009	Gables Pond	2.6	8/3/2009
Rolling Ridge Pond	0.7	6/12/2009	Indian Lake	2	8/10/2009
Williams Pond	2.3	6/23/2009	Mill Pond Park	1.2	9/4/2009
Basserman Pond	1	6/25/2009	Cusick Pond	2	9/9/2009
Youngs Pond	0.3	7/1/2009	North Farms Rerervoir	1.1	9/9/2009
Redwing Pond	1.1	7/13/2009	Deer Lake	1.3	9/14/2009
Crystal Pond	2.3	7/16/2009	Deer Lake Reservoir	3.7	9/14/2009
Chaffee Lake	2.3	7/20/2009	Fall Mountain Lake	1.7	9/15/2009
Crystal Lake	1	7/20/2009	Fence Rock Lake	2	9/17/2009
Lower Moodus	1.5	7/20/2009	Wah Wah Taysee Pond	2	9/21/2009
Beaver Dam Lake	2	7/22/2009	Spring Lake	1.3	9/24/2009
H-H Camp Pond	1.5	7/23/2009	Hospital reservoir #3	4	9/30/2009
Town Mill Pond	2	7/30/2009			

YEAR: 2008					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Silver Lake	1	7/8/2008	Upper Guilford Lake	0.6	8/5/2008
Coventry Lake	3.3	7/15/2008	Andover Lake	2	8/14/2008
Moosup Pond	3.9	7/23/2008	Williamson Pond	1.8	8/18/2008

Beach Pond	5	7/31/2008			

YEAR: 2007					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Powers Lake	3	7/6/2007	Quaddick Reservoir	2.8	9/6/2007
Rolling Ridge Pond	0.5	7/20/2007	Forest Lake	1.8	9/13/2007
Winchester Lake	3	9/5/2007			

YEAR: 2006					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Ashford Lake	1.1	7/12/2006	Keley (Kelsey) Pond	0.75	8/8/2006
Rogers Lake	2.3	7/13/2006	Gladstone Pond	0.8	8/10/2006
Diamond Lake	2.5	7/14/2006	Pocotopaug Lake	0.5	8/16/2006
Oakwood Pond	1	7/14/2006	Ivoryton Pond	2	8/21/2006
Pattaganset Lake	2.3	7/18/2006	Amston Lake	3.5	8/22/2006
Clear Lake	3	7/19/2006	Bissonette Pond	1	8/28/2006
Gardner Lake	2	7/24/2006	Timbe Lake	2.7	9/7/2006
Amos Lake	2.3	8/1/2006	Mystic Seaport Pond	1.5	9/8/2006
Indian Lake	1	8/3/2006	Lower Pond	1.5	9/13/2006

YEAR: 2005					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Nichols Pond	0.9	6/29/2005	Chase Reservoir	2.7	8/8/2005
Pistapaug Pond	3.2	6/29/2005	Hayward Lake	2.2	8/9/2005
Mackenzie Reservoir	0.9	6/30/2005	Staffordville Rerervoir	3.2	8/11/2005
Long Meadow Pond	1.6	7/5/2005	Howells Pond	1.2	8/12/2005
Talmadge Ice Pond	1	7/7/2005	Mamanasco Lake	0.8	8/15/2005
Dayton Pond	1.4	7/8/2005	Messerschmidt Pond	2.8	8/16/2005
Lucky Pond	0.7	7/8/2005	Ball Pond	2	8/17/2005
Hidden Lake	1.9	7/11/2005	Black Hall Pond	2.8	8/18/2005
Housantonic Lake	2	7/12/2005	Millers Pond	4	8/22/2005
Alexander Lake	5.8	7/13/2005	Morey Pond	3.5	8/23/2005
Bigelow Pond	2.5	7/14/2005	Hamlin Pond	1.2	8/24/2005
Shelton Rerervoir #2	2.2	7/15/2005	Paderewski Park Pond	0.9	8/24/2005
Shelton Rerervoir #3	3	7/15/2005	Crystal Lake	2.9	8/25/2005
Ulbrich Rerervoir	2.6	7/18/2005	West Lake	2.5	8/25/2005
Upper Bolton Lake	0.8	7/18/2005	Tyler Lake	2.1	8/30/2005
Lower Bolton Lake	3.2	7/19/2005	Birch Pond	0.4	9/1/2005
Middle Bolton Lake	2.9	7/19/2005	Dunlop Pond	1.4	9/1/2005
Chalkers Mill Pond	0.5	7/22/2005	Tilleys Pond	0.8	9/1/2005
Crystal Lake	0.6	7/22/2005	Williams Brook (Highland Lake)	1.5	9/2/2005
Black Pond	3.8	7/25/2005	Winnemaug Lake	1.1	9/6/2005
Burr Pond	2.4	7/25/2005	Echo Lake	1.2	9/7/2005

Spring Lake	0.8	7/26/2005	Merriman Pond	1.5	9/8/2005
Cescent Lake	1	7/27/2005	Sylvan Lake	1.4	9/8/2005
Mills Pond, Lower	1	7/27/2005	Wampum Hill Pond	0.7	9/9/2005
Mills Pond, Upper	1	7/27/2005	West Side Pond	5.1	9/12/2005
Hummers Pond	1.5	7/28/2005	Mohawk Pond	5.4	9/13/2005
Schreeder Pond	1.7	7/28/2005	West Hill Pond	10.2	9/14/2005
Branford Suppy Pond (East)	1.5	8/1/2005	Billings Lake	5.4	9/22/2005
Halls Pond	3	8/1/2005	North Pond	1.3	9/23/2005
Cedar Pond	2.3	8/1/2005	Silvias Pond	1.1	9/26/2005
Great Hill Pond	2.4	8/1/2005	Bantam Pond	1.4	9/27/2005
Green Falls Reservoir	5.6	8/2/2005	Quonnipaug Lake	3.9	9/28/2005
Angus Park Pond	1.2	8/4/2005	Waubeeka Lake	2.4	9/28/2005
Horse Pond	2.6	8/4/2005	Avery Pond	1.2	9/30/2005
Salmon Brook	0.7	8/4/2005	Blissville Pond	1.7	9/30/2005
Dog Pond	2.5	8/5/2005			

YEAR: 2004					
LAKE NAME	**DEPTH (ft)**	**DATE COLLECTED**	**LAKE NAME**	**DEPTH (ft)**	**DATE COLLECTED**
Graniss Lake	4	5/11/2004	Terramuggus Lake	5.3	7/29/2004
Dooley Pond	1.7	6/18/2004	Kenosia Lake	2	8/2/2004
North Farms Rerervoir	0.5	6/21/2004	Crystal Lake	1.8	8/6/2004
Beseck Lake	2.5	6/24/2004	Wintergreen Lake	3.7	8/9/2004
Black Pond	4	6/25/2004	Highland Lake	3.25	8/10/2004
Cedar Lake	3	6/29/2004	Hammonasset Lake	1.8	8/11/2004
Higganum Reservoir	1.5	7/1/2004	Anderson Pond	1.4	8/12/2004
Silver Lake	1.8	7/6/2004	Batterson Park Pond	1.4	8/13/2004
Uncas Lake	3.3	7/7/2004	Canoe Brook Lake	3.6	8/18/2004
Norwich Pond	1.7	7/8/2004	Pinewood Lake	1.6	8/25/2004
Dodge Pond	2.2	7/9/2004	Bashan Lake	4.2	8/27/2004
Gorton Pond	1.6	7/12/2004	Maltby Lake #3	5.4	8/27/2004
Pickerel Lake	2	7/16/2004	Maltby Lake #1	2.8	9/2/2004
Manitook Lake	3.4	7/19/2004	Maltby Lake #2	8.3	9/2/2004
Saltonstall Lake	2.1	7/23/2004	Wononscopomuc Lake	4.2	9/15/2004
Holbrook Pond	1	7/27/2004			

YEAR: 1993					
LAKE NAME	**DEPTH (ft)**	**DATE COLLECTED**	**LAKE NAME**	**DEPTH (ft)**	**DATE COLLECTED**
Norwich Pond	2.4	6/1/1993	Beseck Lake	2.1	7/9/1993
Pataganset Lake	3.4	6/1/1993	Black Pond	3.8	7/9/1993
Powers Lake	3.2	6/1/1993	Amos Lake	2.3	7/13/1993
Rogers Lake	2.9	6/1/1993	Lantern Hill Pond	2.6	7/13/1993
Uncas Pond	3.5	6/1/1993	Long Pond	4.8	7/13/1993
Anderson Pond	1.4	6/2/1993	Norwich Pond	3.1	7/14/1993
Beach Pond	3.9	6/2/1993	Pataganset Lake	2.9	7/14/1993
Beachdale Pond	1.5	6/2/1993	Rogers Lake	4.6	7/14/1993

Billings Lake	3.6	6/2/1993	Uncas Pond	5.3	7/14/1993
Green Falls Reservoir	6.9	6/2/1993	Alexander Lake	5.6	7/16/1993
Pachaug Pond	2	6/2/1993	Killingly Pond	5.5	7/16/1993
Amos Lake	2.4	6/3/1993	Beach Pond	4.3	7/20/1993
Avery Pond	2.2	6/3/1993	Beachdale Pond	2	7/20/1993
Lantern Hill Pond	3	6/3/1993	Green Falls Reservoir	6.2	7/20/1993
Long Pond	3.2	6/3/1993	Pachaug Pond	2	7/20/1993
Wyassup Lake	4.3	6/3/1993	Linsley Pond	2.1	7/21/1993
Bashan Lake	5.8	6/8/1993	Crystal Lake	4.1	7/22/1993
Silver Lake	1.1	6/8/1993	Gardner Lake	2.6	7/22/1993
Crystal Lake	2.1	6/9/1993	Wamgumbaug Lake	2.8	7/22/1993
Gardner Lake	2.8	6/9/1993	Ball Pond	2.1	7/26/1993
Lake Hayward	4	6/9/1993	Kenoxia Lake	1.9	7/26/1993
Alexander Lake	5.6	6/11/1993	Bantam Lake	0.9	7/27/1993
Black Pond	4.2	6/11/1993	Lake Quassapaug	4.6	7/27/1993
Mashapaug Lake	3.3	6/11/1993	Lake Waramaug	2.3	7/27/1993
Ball Pond	3.1	6/13/1993	Tyler Lake	2.2	7/27/1993
State Lind Pond	1.6	6/14/1993	West Side Pond	4.7	7/27/1993
Beseck Lake	2.7	6/15/1993	Bigelow Pond	3.4	7/28/1993
Black Pond	3.6	6/15/1993	Black Pond	4.2	7/28/1993
Kenoxia Lake	2.4	6/16/1993	Mashapaug Lake	6.7	7/28/1993
Bantam Lake	3.3	6/22/1993	Highland Lake	4.2	8/2/1993
Lake Quassapaug	3.6	6/22/1993	Lake Winchester	3	8/2/1993
Lake Waramaug	1.4	6/22/1993	West Hill Pond	6.4	8/2/1993
Mohawk Pond	3.8	6/22/1993	Dog Pond	2.2	8/3/1993
Mount Tom Pond	4.9	6/22/1993	East Twin Lake	4	8/3/1993
East Twin Lake	4.3	6/23/1993	Mohawk Pond	4.9	8/3/1993
Emmons Pond	1.7	6/23/1993	Mount Tom Pond	3.8	8/3/1993
Highland Lake	4.4	6/23/1993	Wonoscopomuc Lake	4.9	8/3/1993
Lake Winchester	3.7	6/23/1993	Avery Pond	0.9	8/10/1993
Tyler Lake	2.5	6/23/1993	Lake Hayward	3.5	8/10/1993
West Hill Pond	9.4	6/23/1993	Anderson Pond	1.6	8/11/1993
West Side Pond	3.3	6/23/1993	Billings Lake	4.6	8/11/1993
Wonoscopomuc Lake	4.2	6/23/1993	Wyassup Lake	3.3	8/11/1993
Roseland Lake	0.6	6/28/1993	Squantz Pond	2.9	8/25/1993
Wamgumbaug Lake	4.8	6/28/1993	Candlewood Lake	2.7	8/27/1993
Quonnipaug Lake	4.6	6/29/1993	Linsley Pond	1.6	9/8/1993
Terramuggus Lake	4.8	6/29/1993	Quonnipaug Lake	3.4	9/8/1993
State Lind Pond	1.4	7/8/1993	Terramuggus Lake	5.6	9/8/1993
Bashan Lake	6.2	7/9/1993			

YEAR: 1992					
LAKE NAME	**DEPTH (ft)**	**DATE COLLECTED**	**LAKE NAME**	**DEPTH (ft)**	**DATE COLLECTED**
Gardner Lake	3.4	6/3/1992	Killingly Pond	5.2	6/30/1992
Lake Hayward	3.9	6/3/1992	Beseck Lake	2.6	7/10/1992
Pataganset Lake	2.8	6/3/1992	Black Pond	3.2	7/10/1992
Norwich Pond	2.7	6/4/1992	Crystal Lake	1.1	7/10/1992
Rogers Lake	2.8	6/4/1992	Silver Lake	1.7	7/10/1992

Uncas Pond	3.7	6/4/1992	East Twin Lake	2.9	7/20/1992
Lantern Hill Pond	1.9	6/5/1992	Lake Winchester	2.9	7/20/1992
Long Pond	3.1	6/5/1992	West Hill Pond	7.3	7/20/1992
Pataganset Lake	2.7	6/10/1992	Wonoscopomuc Lake	4.4	7/20/1992
Roseland Lake	1.2	6/11/1992	Candlewood Lake	2.1	7/21/1992
Bigelow Pond	2.1	6/12/1992	Lake Waramaug	1.8	7/21/1992
Mashapaug Lake	3.5	6/12/1992	Squantz Pond	4	7/21/1992
Black Pond	4.3	6/13/1992	Bantam Lake	2.3	7/22/1992
Amos Lake	1.9	6/16/1992	Dog Pond	2.1	7/22/1992
Avery Pond	1.6	6/16/1992	Mohawk Pond	4.3	7/22/1992
Beach Pond	4	6/23/1992	Mount Tom Pond	3.8	7/22/1992
Billings Lake	4.4	6/23/1992	Tyler Lake	3.4	7/22/1992
Pachaug Pond	1.8	6/23/1992	West Side Pond	3	7/22/1992
Wyassup Lake	3.4	6/23/1992	Dog Pond	2.8	7/30/1992
Bashan Lake	4.9	6/26/1992	Rogers Lake	3.4	9/4/1992
Crystal Lake	2.6	6/26/1992	Long Pond	4.2	9/10/1992
State Lind Pond	1.3	6/26/1992	Wamgumbaug Lake	3.5	9/17/1992
Wamgumbaug Lake	4.1	6/26/1992	Beach Pond	5.3	9/19/1992
Alexander Lake	6.2	6/30/1992	Bashan Lake	6.7	10/5/1992
Anderson Pond	1.3	6/30/1992	Pataganset Lake	2.4	10/5/1992
Beachdale Pond	1	6/30/1992	Long Pond	3.8	10/29/1992

YEAR: 1991

LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Beseck Lake	1.9	4/12/1989	Beseck Lake	1.5	8/1/1989
Crystal Lake	2.3	4/12/1989	Gardner Lake	1.5	8/3/1989
Gardner Lake	1.7	4/14/1989	Dog Pond	1.8	8/9/1989
Lake Hayward	3.5	4/14/1989	Lake Winchester	2.1	8/9/1989
Lake Quassapaug	2.3	4/19/1989	Lake Quassapaug	1.5	8/10/1989
West Hill Pond	4.9	4/21/1989	West Hill Pond	7	8/17/1989
Alexander Lake	6.7	4/25/1989	Crystal Lake	2.4	8/21/1989
Killingly Pond	4.6	4/25/1989	East Twin Lake	4.6	8/24/1989
Avery Pond	2.3	4/26/1989	Wonoscopomuc Lake	6.1	8/25/1989
Beachdale Pond	1.5	4/26/1989	Alexander Lake	6.1	8/28/1989
Lake of Isles	3	4/26/1989	Killingly Pond	4.6	8/28/1989
Long Pond	3	4/26/1989	Lake Hayward	3.2	8/29/1989
Green Falls Reservoir	5.2	5/11/1989	Beachdale Pond	1.1	9/1/1989
Dog Pond	1.5	5/12/1989	Long Pond	4.1	9/5/1989
Lake Winchester	3.4	5/12/1989	Avery Pond	0.9	9/6/1989
East Twin Lake	4.3	5/17/1989	Green Falls Reservoir	7.5	9/6/1989
Wonoscopomuc Lake	3	5/17/1989	Lake of Isles	2.1	9/6/1989

YEAR: 1990

LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Anderson Pond	1.1	5/9/1990	Dog Pond	2.9	6/15/1990
Lantern Hill Pond	3	5/9/1990	Lake Waramaug	2.7	6/15/1990

Red Cedar Lake	2.6	5/10/1990	Tyler Lake	4	6/15/1990
Lake Waramaug	1.7	6/5/1990	East Twin Lake	6	6/26/1990
Beach Pond	4.9	6/11/1990	Wonoscopomuc Lake	6	6/26/1990
Beachdale Pond	1.3	6/12/1990	Lake Waramaug	2.1	7/31/1990
Green Falls Reservoir	5.4	6/12/1990	Red Cedar Lake	2	8/9/1990
Pachaug Pond	1.5	6/12/1990	Mohawk Pond	5	8/17/1990
Avery Pond	1.9	6/13/1990	Anderson Pond	0.9	8/21/1990
Mohawk Pond	5.1	6/13/1990	Lantern Hill Pond	1.5	8/21/1990
West Side Pond	3.2	6/13/1990	West Side Pond	2.4	8/23/1990
West Side Pond	3.5	6/14/1990	Lake Waramaug	1.8	8/31/1990

YEAR: 1989

LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Beseck Lake	1.9	4/12/1989	Beseck Lake	1.5	8/1/1989
Crystal Lake	2.3	4/12/1989	Gardner Lake	1.5	8/3/1989
Gardner Lake	1.7	4/14/1989	Dog Pond	1.8	8/9/1989
Lake Hayward	3.5	4/14/1989	Lake Winchester	2.1	8/9/1989
Lake Quassapaug	2.3	4/19/1989	Lake Quassapaug	1.5	8/10/1989
West Hill Pond	4.9	4/21/1989	West Hill Pond	7	8/17/1989
Alexander Lake	6.7	4/25/1989	Crystal Lake	2.4	8/21/1989
Killingly Pond	4.6	4/25/1989	East Twin Lake	4.6	8/24/1989
Avery Pond	2.3	4/26/1989	Wonoscopomuc Lake	6.1	8/25/1989
Beachdale Pond	1.5	4/26/1989	Alexander Lake	6.1	8/28/1989
Lake of Isles	3	4/26/1989	Killingly Pond	4.6	8/28/1989
Long Pond	3	4/26/1989	Lake Hayward	3.2	8/29/1989
Green Falls Reservoir	5.2	5/11/1989	Beachdale Pond	1.1	9/1/1989
Dog Pond	1.5	5/12/1989	Long Pond	4.1	9/5/1989
Lake Winchester	3.4	5/12/1989	Avery Pond	0.9	9/6/1989
East Twin Lake	4.3	5/17/1989	Green Falls Reservoir	7.5	9/6/1989
Wonoscopomuc Lake	3	5/17/1989	Lake of Isles	2.1	9/6/1989

YEAR: 1980

LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Quonnipaug	3	4/1/1980	Quonnipaug	4.4	7/16/1980
Norwich	3.2	4/2/1980	Winnemaug	1.3	7/18/1980
Powers	3.5	4/2/1980	Powers	3.2	7/21/1980
Uncas	5.2	4/2/1980	Bashan	5.5	7/22/1980
Amos	2.6	4/3/1980	Ball	2.5	7/24/1980
Billings	5.2	4/3/1980	Moodus	2	7/25/1980
Bashan	6	4/7/1980	Long Meadow	1.3	7/28/1980
Moodus	2.1	4/7/1980	Norwich	3	7/30/1980
Columbia	3	4/8/1980	Uncas	5.4	7/30/1980
Waumgumbaug	3.6	4/8/1980	Kenosia	1.8	7/31/1980
Glasgo	2.8	4/9/1980	Columbia	5	8/5/1980
Ball	1.3	4/11/1980	Waumgumbaug	6.1	8/5/1980
Winnemaug	1.3	4/11/1980	Eagleville	1.5	8/6/1980

Long Meadow	1.1	4/14/1980	Squantz	3.4	8/7/1980
Kenosia	1	4/15/1980	Burr	2.7	8/8/1980
Squantz	5.2	4/15/1980	Amos	3.7	8/18/1980
Little	3.1	4/17/1980	Bigelow	2.5	8/19/1980
Quaddick	5.1	4/17/1980	Black (Woodstock)	3	8/19/1980
Bigelow	5.2	4/18/1980	Billings	4.5	8/20/1980
Black (Woodstock)	5.2	4/18/1980	Glasgo	2	8/22/1980
Burr	3.7	4/21/1980	Little	3	8/25/1980
Housatonic	2.1	5/5/1980	Quaddick	2.3	8/25/1980
Eagleville	2.3	5/9/1980	Housatonic	2	8/28/1980

YEAR: 1979					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Black (Meriden)	2.3	3/26/1979	Highland	6	8/2/1979
North Farms	1.5	3/26/1979	Beach	7.2	8/3/1979
Silver(Berlin)	2.5	3/26/1979	Dodge	4	8/7/1979
Cedar Lake	4.3	3/27/1979	Gorton	2	8/7/1979
Gorton	2.5	3/27/1979	Crystal(Ellington)	4	8/13/1979
Beach	6	4/4/1979	Mashapaug	8.2	8/13/1979
Wyassup	4.3	4/4/1979	Pachaug	3.5	8/14/1979
Mount Tom	3.5	4/5/1979	Cedar Lake	4.1	8/15/1979
Crystal(Ellington)	3.5	4/10/1979	Wyassup	4.3	8/16/1979
Mashapaug	6	4/10/1979	Tyler	3.8	8/17/1979
Highland	4.3	4/11/1979	Mount Tom	4.5	8/20/1979
Tyler	3.3	4/11/1979	Middle Bolton	2.5	8/21/1979
Lower Bolton	3.3	4/17/1979	Hitchcock	2	8/28/1979
Mamanasco	3	4/20/1979	Batterson Park	1.5	8/29/1979
1860 Reservoir	1	4/24/1979	Mamanasco	1.8	8/29/1979
Batterson Park	2.3	4/24/1979	Black (Meriden)	2.5	8/30/1979
Middle Bolton	2.5	4/24/1979	Silver(Berlin)	1.8	8/30/1979
Dodge	4.8	4/30/1979	Lower Bolton	2.3	9/1/1979
Pachaug	3	5/2/1979	North Farms	1	9/1/1979
Hitchcock	3	5/7/1979	1860 Reservoir	1	10/1/1979

YEAR: 1974					
LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Beseck Lake	2.2	4/3/1974	Candlewood Lake	5.7	7/15/1974
Cedar Pond	1.1	4/3/1974	Alexander Lake	6.3	7/17/1974
Linsley Pond	1.1	4/3/1974	Roseland Lake	2.5	7/17/1974
Long Pond	3.2	4/10/1974	Bantam Lake	1.5	7/23/1974
Pataganset Lake	3	4/10/1974	Beseck Lake	2.5	7/23/1974
Lake Pocotopaug	2.5	4/15/1974	Cedar Pond	0.9	7/23/1974
Terramuggus Lake	4.4	4/15/1974	Quassapaug Lake	7.5	7/23/1974
Quassapaug Lake	2.5	4/22/1974	Lake Lillinonah	2.5	7/25/1974
Shenipsit Lake	3	4/22/1974	Lake Hayward	3.3	7/29/1974
West Hill Pond	5.5	4/23/1974	East Twin Lake	6	7/30/1974

Bantam Lake	3	4/24/1974	Mudge Pond	3.8	7/30/1974
Gardner Lake	3.5	4/25/1974	Lake Zoar	2.5	7/31/1974
Lake Hayward	4.8	4/25/1974	Roseland Lake	3	8/1/1974
Taunton Pond	3.5	4/29/1974	Long Pond	4.8	8/6/1974
Mudge Pond	2.5	4/30/1974	Lake Pocotopaug	4.3	8/8/1974
Waramaug Lake	2	4/30/1974	Terramuggus Lake	6	8/8/1974
Roseland Lake	2	5/2/1974	Linsley Pond	3.5	8/9/1974
Alexander Lake	9.7	5/5/1974	Candlewood Lake	4.5	8/13/1974
East Twin Lake	5.3	5/7/1974	Taunton Pond	3.3	8/13/1974
Wononscopomuc Lake	1	5/7/1974	Shenipsit Lake	3.5	8/20/1974
Candlewood Lake	5.3	5/8/1974	Gardner Lake	4.8	8/21/1974
Lake Lillinonah	3.2	5/31/1974	Pataganset Lake	3	8/21/1974
Lake Zoar	2.2	5/31/1974	Bantam Lake	2.2	8/22/1974
Beseck Lake	4	6/21/1974	Waramaug Lake	3.2	8/22/1974
Bantam Lake	1.8	6/24/1974	West Hill Pond	7.2	8/22/1974
Quassapaug Lake	6.8	6/27/1974	Beseck Lake	2	8/26/1974
Shenipsit Lake	4.5	6/28/1974	Quassapaug Lake	6	8/26/1974
Gardner Lake	3.5	7/1/1974	Alexander Lake	8.2	8/27/1974
Pataganset Lake	2.5	7/1/1974	Mudge Pond	4	8/28/1974
Waramaug Lake	2.3	7/2/1974	Lake Zoar	2.1	8/29/1974
West Hill Pond	6.8	7/2/1974	East Twin Lake	5	9/4/1974
Lake Zoar	1	7/3/1974	Wononscopomuc Lake	8.2	9/4/1974
Lake Lillinonah	1.3	7/8/1974	Lake Pocotopaug	2	9/5/1974
Lake Pocotopaug	4.5	7/9/1974	Candlewood Lake	5.3	9/10/1974
East Twin Lake	5	7/10/1974	Lake Lillinonah	1.9	9/12/1974
Mudge Pond	4.5	7/11/1974	Lake Hayward	3.3	11/20/1974
Wononscopomuc Lake	7.3	7/11/1974			

YEAR: 1973

LAKE NAME	DEPTH (ft)	DATE COLLECTED	LAKE NAME	DEPTH (ft)	DATE COLLECTED
Bantam Lake	2	9/26/1973	Waramaug Lake	2	11/5/1973
Lake Zoar	1.5	10/4/1973	Mudge Pond	2.5	11/7/1973
East Twin Lake	6.2	10/17/1973	Cedar Pond	2	11/9/1973
Wononscopomuc Lake	4.3	10/17/1973	Linsley Pond	1.5	11/9/1973
Lake Lillinonah	2	10/19/1973	Gardner Lake	3.3	11/13/1973
Alexander Lake	5.7	10/23/1973	Pataganset Lake	3	11/13/1973
Shenipsit Lake	2.5	10/25/1973	Lake Pocotopaug	4.5	11/15/1973
Beseck Lake	2	10/31/1973	Terramuggus Lake	5.5	11/15/1973
Taunton Pond	4.5	11/2/1973	Candlewood Lake	5.2	11/20/1973
Quassapaug Lake	2.2	11/5/1973	Long Pond	3.2	11/20/1973

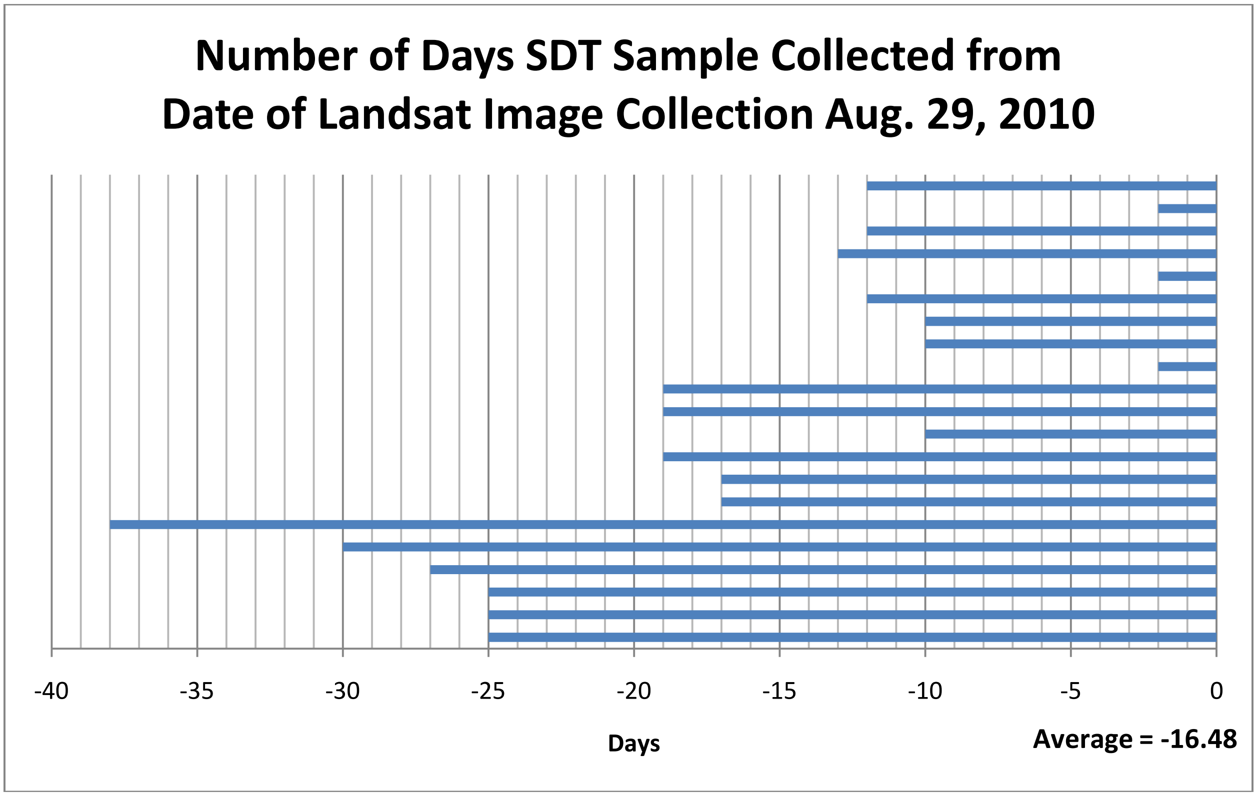
APPENDIX B

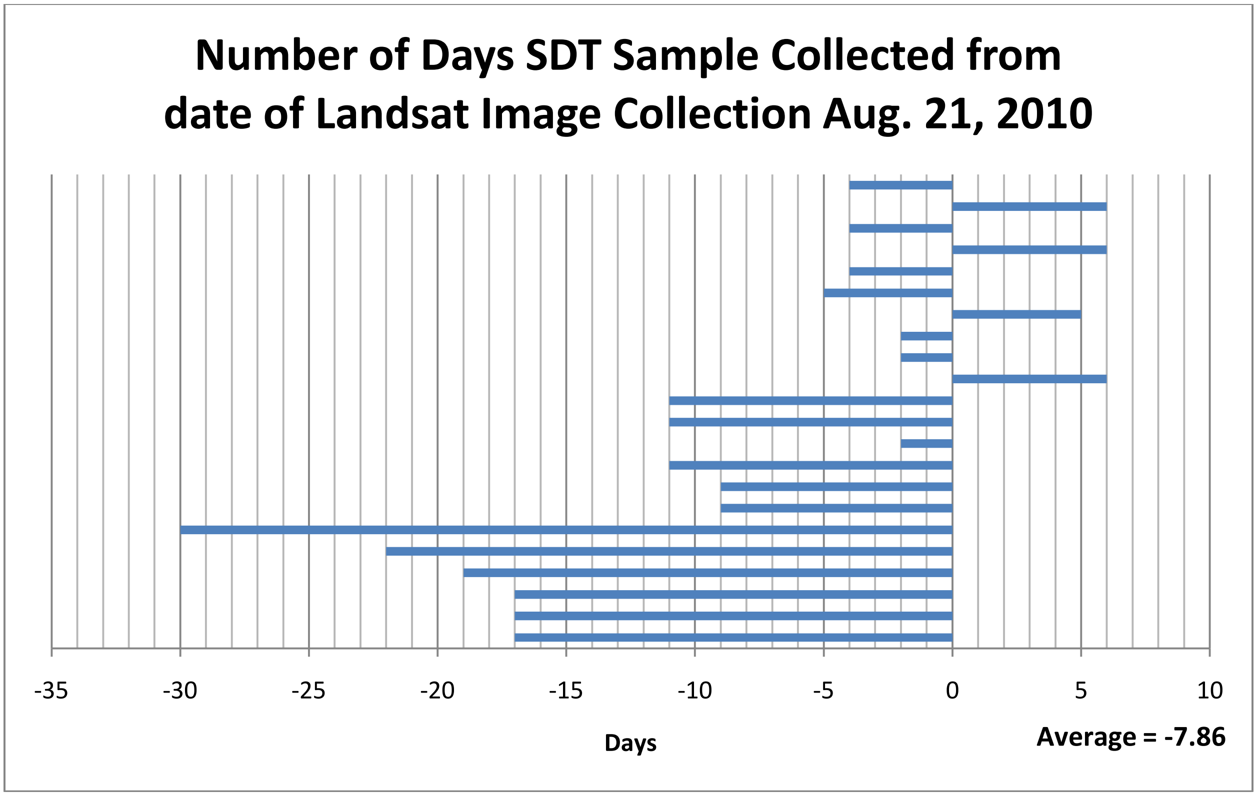
Landsat Satellite Imagery Examined

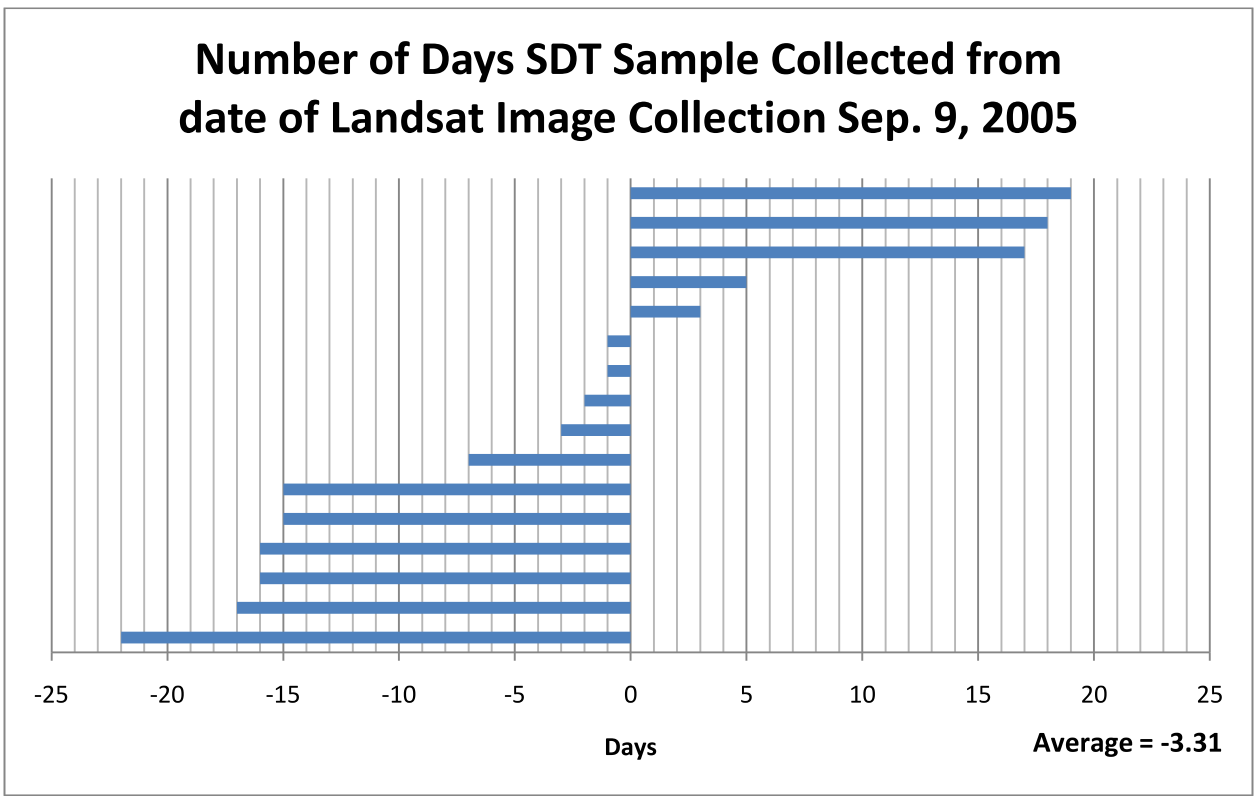
PLATFORM AND SENSOR	COLLECTION DATE	PLATFORM AND SENSOR	COLLECTION DATE	PLATFORM AND SENSOR	COLLECTION DATE
Landsat 5, TM	August 30, 2010	Landsat 7, ETM	October 26, 2007	Landsat 7, ETM	April 9, 2005
Landsat 7, ETM	August 29, 2010	Landsat 5, TM	September 30, 2007	Landsat 5, TM	October 7, 2004
Landsat 5, TM	August 21, 2010	Landsat 5, TM	September 7, 2007	Landsat 5, TM	August 29, 2004
Landsat 5, TM	August 14, 2010	Landsat 7, ETM	August 30, 2007	Landsat 7, ETM	August 28, 2004
Landsat 7, ETM	August 13, 2010	Landsat 5, TM	August 29, 2007	Landsat 5, TM	August 20, 2004
Landsat 7, ETM	August 6, 2010	Landsat 7, ETM	August 14, 2007	Landsat 5, TM	August 4, 2004
Landsat 5, TM	August 5, 2010	Landsat 7, ETM	August 5, 2007	Landsat 7, ETM	July 11, 2004
Landsat 7, ETM	July 28, 2010	Landsat 5, TM	July 12, 2007	Landsat 7, ETM	July 4, 2004
Landsat 7, ETM	July 21, 2010	Landsat 5, TM	June 26, 2007	Landsat 5, TM	July 3, 2004
Landsat 5, TM	July 20, 2010	Landsat 7, ETM	June 2, 2007	Landsat 5, TM	August 20, 2004
Landsat 5, TM	July 13, 2010	Landsat 5, TM	April 23, 2007	Landsat 7, ETM	June 9, 2004
Landsat 7, ETM	July 12, 2010	Landsat 5, TM	October 13, 2006	Landsat 7, ETM	May 8, 2004
Landsat 5, TM	July 2, 2010	Landsat 5, TM	September 11, 2006	Landsat 5, TM	August 22, 1993
Landsat 7, ETM	May 25, 2010	Landsat 5, TM	August 10, 2006	Landsat 5, TM	July 21, 1993
Landsat 5, TM	May 1, 2010	Landsat 5, TM	August 3, 2006	Landsat 5, TM	June 3, 1993
Landsat 5, TM	April 15, 2010	Landsat 7, ETM	August 2, 2006	Landsat 5, TM	September 20, 1992
Landsat 7, ETM	September 20, 2009	Landsat 7, ETM	August 2, 2006	Landsat 5, TM	August 19, 1992
Landsat 5, TM	September 19, 2009	Landsat 7, ETM	July 26, 2006	Landsat 5, TM	June 16, 1992
Landsat 7, ETM	September 4, 2009	Landsat 5, TM	July 25, 2006	Landsat 5, TM	October 4, 1991
Landsat 7, ETM	August 19, 2009	Landsat 5, TM	July 18, 2006	Landsat 5, TM	September 2, 1991
Landsat 5, TM	August 18, 2009	Landsat 7, ETM	July 17, 2006	Landsat 5, TM	August 17, 1991
Landsat 7, ETM	August 3, 2009	Landsat 5, TM	July 9, 2006	Landsat 5, TM	August 2, 1991
Landsat 7, ETM	July 25, 2009	Landsat 7, ETM	July 1, 2006	Landsat 5, TM	August 1, 1991
Landsat 5, TM	July 10, 2009	Landsat 5, TM	April 20, 2006	Landsat 5, TM	July 16, 1991
Landsat 5, TM	April 12, 2009	Landsat 7, ETM	October 2, 2005	Landsat 5, TM	June 14, 1991
Landsat 7, ETM	September 24, 2008	Landsat 5, TM	September 9, 2005	Landsat 2, MSS	June 26, 1980
Landsat 5, TM	August 31, 2008	Landsat 5, TM	September 1, 2005	Landsat 3, MSS	April 6, 1980
Landsat 5, TM	July 30, 2008	Landsat 5, TM	August 23, 2005	Landsat 2, MSS	September 12, 1979
Landsat 5, TM	June 12, 2008	Landsat 5, TM	August 16, 2005	Landsat 3, MSS	August 16, 1979
Landsat 5, TM	May 11, 2008	Landsat 7, ETM	July 30, 2005	Landsat 2, MSS	May 9, 1979
Landsat 5, TM	April 25, 2008	Landsat 5, TM	July 22, 2005	Landsat 1, MSS	July 1, 1974
Landsat 7, ETM	November 25, 2007	Landsat 5, TM	April 17, 2005	Landsat 1, MSS	October 22, 1973

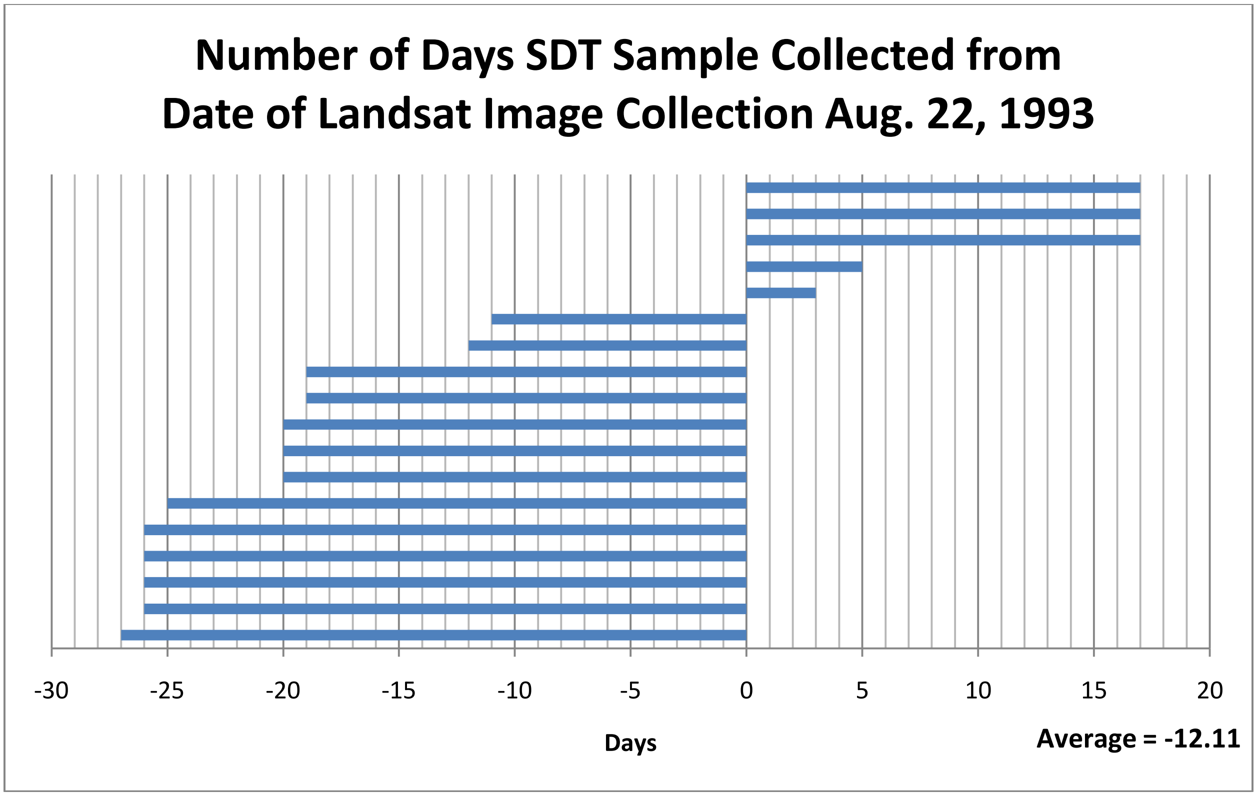
APPENDIX C

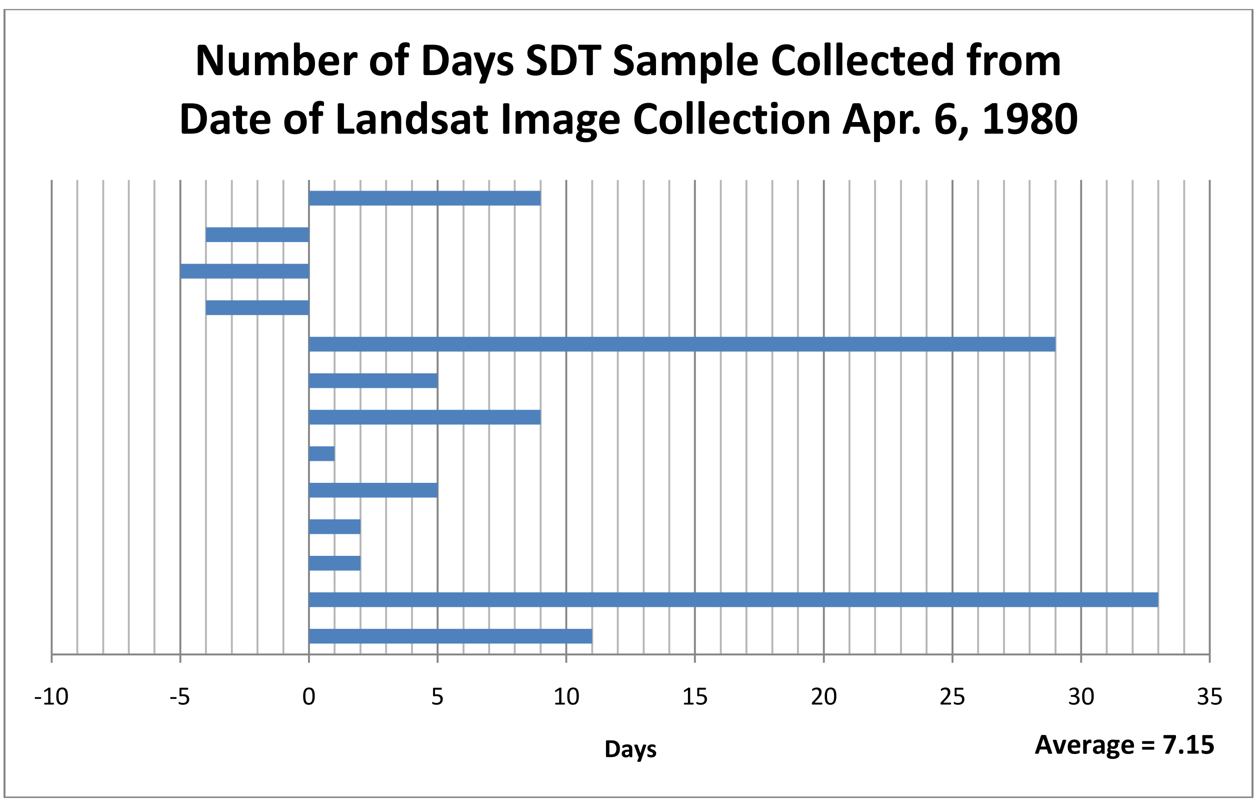
Number of Days between SDT Collection per Lake and Satellite Image Collection




Number of Days SDT Sample Collected from date of Landsat Image Collection Aug. 21, 2010
-35
-30
-25
-20
-15
-10
-5
0
5
10
Days
Average = -7.86


Number of Days SDT Sample Collected from date of Landsat Image Collection Sep. 9, 2005
-25
-20
-15
-10
-5
0
5
10
15
20
25
Days
Average = -3.31


Number of Days SDT Sample Collected from Date of Landsat Image Collection Aug. 22, 1993
-30
-25
-20
-15
-10
-5
0
5
10
15
20
Days
Average = -12.11


Number of Days SDT Sample Collected from Date of Landsat Image Collection Apr. 6, 1980
-10
-5
0
5
10
15
20
25
30
35
Days
Average = 7.15

Information Transfer Program Introduction

The Connecticut Institute of Water Resources information transfer program has several components: 1. CT IWR web site; 2. Publications; 3. Seminar Series; 4. Conferences and Workshops; 5. Service and Liaison Work. This work is supported through a separate 104B information transfer project, described below.

Our co-sponsorship of the Natural Resources and the Environment seminar series, a long-standing Connecticut IWR tradition, and our cosponsorship and involvement with the planning for the annual Connecticut Conference on Natural resources helps support the opportunity for the water resource professionals and interested members of the public in our small state to gather, be informed, and be come better acquainted.

Water Resources Technology Transfer Program

Basic Information

Title:	Water Resources Technology Transfer Program
Project Number:	2006CT128B
Start Date:	3/1/2009
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2nd
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	
Principal Investigators:	Glenn Warner, Patricia Bresnahan

Publications

1. Bresnahan, P., G.S. Warner, R.A. Jacobson and J.M. Stella. 2007. Modeling the effects of reservoir release practices on downstream flows. Connecticut Conference on Natural Resources. March 9, 2007. Storrs, CT
2. Warner, G.S., P. Bresnahan, R.A. Jacobson, J.M. Stella. 2007. Modeling the Effect of Reservoir Release Practices on Available Water Supply Using STELLA. Massachusetts Water Resources Conference. April 9, 2007. Amherst, MA.
3. Warner, G.S., P. Bresnahan, and R.A. Jacobson, 2007. Modeling Flows Downstream of Water Supply Reservoirs. Paper # 072092. Annual International Conference, ASABE. Minneapolis, MN; June 17-20, 2007.
4. Warner, G.S. and P.A. Bresnahan. 2007. Final Report for Project entitled: "Modeling Flows Downstream of Reservoirs" submitted to Connecticut Department of Environmental Protection, April 6, 2006.
5. Bresnahan, P., G.S. Warner, R.A. Jacobson and J.M. Stella. 2007. Modeling the effects of reservoir release practices on downstream flows. Connecticut Conference on Natural Resources. March 9, 2007. Storrs, CT
6. Warner, G.S., P. Bresnahan, R.A. Jacobson, J.M. Stella. 2007. Modeling the Effect of Reservoir Release Practices on Available Water Supply Using STELLA. Massachusetts Water Resources Conference. April 9, 2007. Amherst, MA.
7. Warner, G.S., P. Bresnahan, and R.A. Jacobson, 2007. Modeling Flows Downstream of Water Supply Reservoirs. Paper # 072092. Annual International Conference, ASABE. Minneapolis, MN; June 17-20, 2007.
8. Warner, G.S. and P.A. Bresnahan. 2007. Final Report for Project entitled: "Modeling Flows Downstream of Reservoirs" submitted to Connecticut Department of Environmental Protection, April 6, 2006.
9. Bresnahan, P.A.. 2008. Final Report for Project entitled: "Data Needs for Water Allocation Planning", submitted to Connecticut Department of Environmental Protection, June 30, 2008.
10. Bresnahan, P.A., and G.S. Warner. 2008. Final Report: Modeling the Effects of Reservoir Release Practices on Downstream Flows, Phase 2: Impact of Release Rules on Yield and Streamflow Metrics. Connecticut Institute of Water Resources, July 18, 2008; Storrs, CT
11. Reale-Munroe, Kynoch Regan. 2009. Reservoir Systems: An Integrated Modeling and Statistical Approach to Asses Variation in Stream Flow Statistics and Safe Yield. M.S. Thesis, Dept. Natural

Resources and the Environment, University of Connecticut.

12. Bresnahan, P., G.S. Warner, R.A. Jacobson and J.M. Stella. 2007. Modeling the effects of reservoir release practices on downstream flows. Connecticut Conference on Natural Resources. March 9, 2007. Storrs, CT
13. Warner, G.S., P. Bresnahan, R.A. Jacobson, J.M. Stella. 2007. Modeling the Effect of Reservoir Release Practices on Available Water Supply Using STELLA. Massachusetts Water Resources Conference. April 9, 2007. Amherst, MA.
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The Connecticut Institute of Water Resources information transfer program has several components: 1. CT IWR web site; 2. Publications; 3. Seminar Series; 4. Conferences and Workshops; 5. Service and Liaison Work.

In addition to the above more routine activities, this year Pat Bresnahan was awarded a $40,000 grant from the CT Department of Environmental Protection to coordinate the development of revisions to the state's Aquatic Nuisance Species Management Plan, and to begin some of the activities listed in that plan.

The review panel that conducted the recent five-year evaluation strongly suggested that our Institute improve its information transfer program, specifically by improving our web site and by developing joint efforts with the UCONN Department of Extension. Another area of concern, is the possibility of no funding for the WRI program in FY 2012-2013.

While we will continue to explore new information transfer options, we will also need to ensure that the legacy of the program is not lost, and that the projects and publications generated by this program are preserved, digitally archived when at all possible, and that they continue to remain available as a resource to water professionals and academics in the future.

Web Site: Our office maintains the CT IWR web site, which is updated on a quarterly basis (or as needed). It includes information about the WRI program, our institute and its board, a listing of the current year's seminars, a list of sponsored projects and publications, and access to electronic copies of our "Special Reports" series. We also use the web to announce special events and our RFP. We continue to cooperate with the University of Connecticut's digital archives department, which maintains our electronic reports as a part of its "Digital Commons @ University of Connecticut" project.

Seminar Series. The CTIWR co-sponsors the seminar series offered by the Department of Natural Resources Management and engineering, the administrative home for our Institute, instead of holding its own, separate series. Pat Bresnahan serves on the steering committee and actively seeks out speakers with a water interest. Each semester the CTIWR provides financial support to bring in one outside speaker as the "Kennard Water Resources Lecturer." Dr. William Kennard was the first Director of our Institute, and we honoring his contribution to our program in this way. This year's Kennard Lecturer was Jerome Delli Priscoli, the senior advisor on international water issues at the U.S. Army Corps of Engineers' Institute for Water Resources. The title of his talk was: "Water security, global water issues and climate change."

Conferences. The Institute co-sponsored and served on the steering committee for the annual. Connecticut Conference on Natural Resources. Steering Committee: Warner, co-chair, Bresnahan, Member. CTIWR also Contributed $500.

Service and Liaison Work. Both the Director and Associate Director actively serve on a number of water related panels.

- Scientific and Technical Standards Workgroup of the CT Stream Flow Advisory Group. Glenn Warner, invited member.

- The Nature Conservancy / Green Valley Institute's Conservation Action Planning for the Natchaug Basin. Pat Bresnahan and Glenn Warner participated on the panel.

- CT Governor's Steering Committee on Climate Change. Adaptation Subcommittee Workgroups. Glenn Warner serves on the Agriculture workgroup, and Pat Bresnahan serves on the infrastructure workgroup.

- Monitoring the Impact of Invasive Shrub Removal in a Riparian Corridor in Schoolhouse Brook Park, Mansfield, CT. Pat Bresnahan is working as a volunteer on this project, serving mainly as the field data coordinator, and is also contributing a few hours per month of CTIWR time to maintain the project's web site as a page off of the CTIWR site.

Baseline Study of Nutrient Loadings to Lake Kenosia

Basic Information

Title:	Baseline Study of Nutrient Loadings to Lake Kenosia
Project Number:	2010CT212B
Start Date:	3/1/2010
End Date:	1/31/2011
Funding Source:	104B
Congressional District:	Ct 005
Research Category:	Water Quality
Focus Category:	Ecology, Water Quality, Treatment
Descriptors:	None
Principal Investigators:	Theodora Pinou

Publications

There are no publications.

INVESTIGATION OF BASELINE STORMWATER LOADINGS OF NUTRIENTS TO LAKE KENOSIA

2010 – 2011 FINAL STATUS REPORT TO CTIWR

P.I. – THEODORA PINOU, ASSOCIATE PROFESSOR, DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES, WESTERN CONECTICUT STATE UNIVERSITY.

PROJECT MANAGER – JACK KOZUCHOWSKI, KOZUCHOWSKI ENVIRONMENTAL CONSULTING

GRADUATE STUDENT INTERNS – AARON FERRARO, NICOLE STITLER, DEPARTMENT OF BIOLOGICAL AND ENVIRONMENTAL SCIENCES, WESTERN CONNECTICUT STATE UNIVERSITY.

I. Introduction: The Big Picture

Western Connecticut State University is collaborating with the City of Danbury in the baseline monitoring of nutrient loadings to Lake Kenosia, an impaired lake in western Connecticut. The Connecticut Institute of Water Resources (IWR) funded an initial baseline study of stormwater pollutants to the lake in 2010. Phase I of this monitoring study is now completed. This paper reports the results of this study. It represents a case study of how a long term goal of reducing nutrient flux to an impaired lake through community monitoring can be employed as a long term educational program through the collaboration with an academic institution. Section II and VI address this latter goal as a presentation of a case study.

A. Statement of the Problem.

As a result of previous funding from the Connecticut Department of Environmental Protection, the City of Danbury's Lake Kenosia Commission sponsored a quantitative evaluation of the general trophic conditions and identification of specific loading sources for Lake Kenosia in western Connecticut. The ***Diagnostic / Feasibility Study***, was conducted in 1999-2000 for the Lake Kenosia Commission by its retained consultant, ENSR. This study assessed the current trophic conditions of the lake, identified the key water quality impacts that were limiting the recreational function of the water body and evaluated an array of management / treatment options to reverse the water quality impairment. The Executive Summary of this study encapsulated the current water quality conditions of the lake:

" ***Phosphorus loading to Lake Kenosia is estimated at 390 kg/year. The Permissible Load, below which water quality problems and use impairment should be rare, is 145 kg/yr.... Resultant in-lake conditions include high inorganic turbidity following storms, algal blooms during periods of prolonged low flows, and dense peripheral submergent, rooted aquatic plant growth throughout the growing season***." (Diagnostic/Feasibility Study, ENSR, 7/2000, page 1)

Following the completion of the Diagnostic study, the Lake Kenosia Commission sponsored a follow-up study to quantify water discharge patterns from the watershed and to identify the sub-watersheds that were contributing the largest load of key stormwater pollutants to the Lake. The study (also conducted by ENSR) was entitled **Evaluation of Drainage Conditions in the Immediate Watershed of Kenosia Lake**. This report, that was executed as a follow-up to the in-lake Diagnostic Study, mapped all of the storm drainage flows from the watershed to input points to the Lake and quantified hydrologic and pollutant loading to the lake. As a result of this study it was determined that a specific location of the watershed (sub watershed 5) discharged on a parcel of land owned by the City of Danbury immediately proximal to Lake Kenosia. This parcel (hereafter referred to as "target treatment zone" - shown on Figure 1, below) provides the setting for the construction and evaluation of a "stormwater treatment train" that will be funded by other sources.

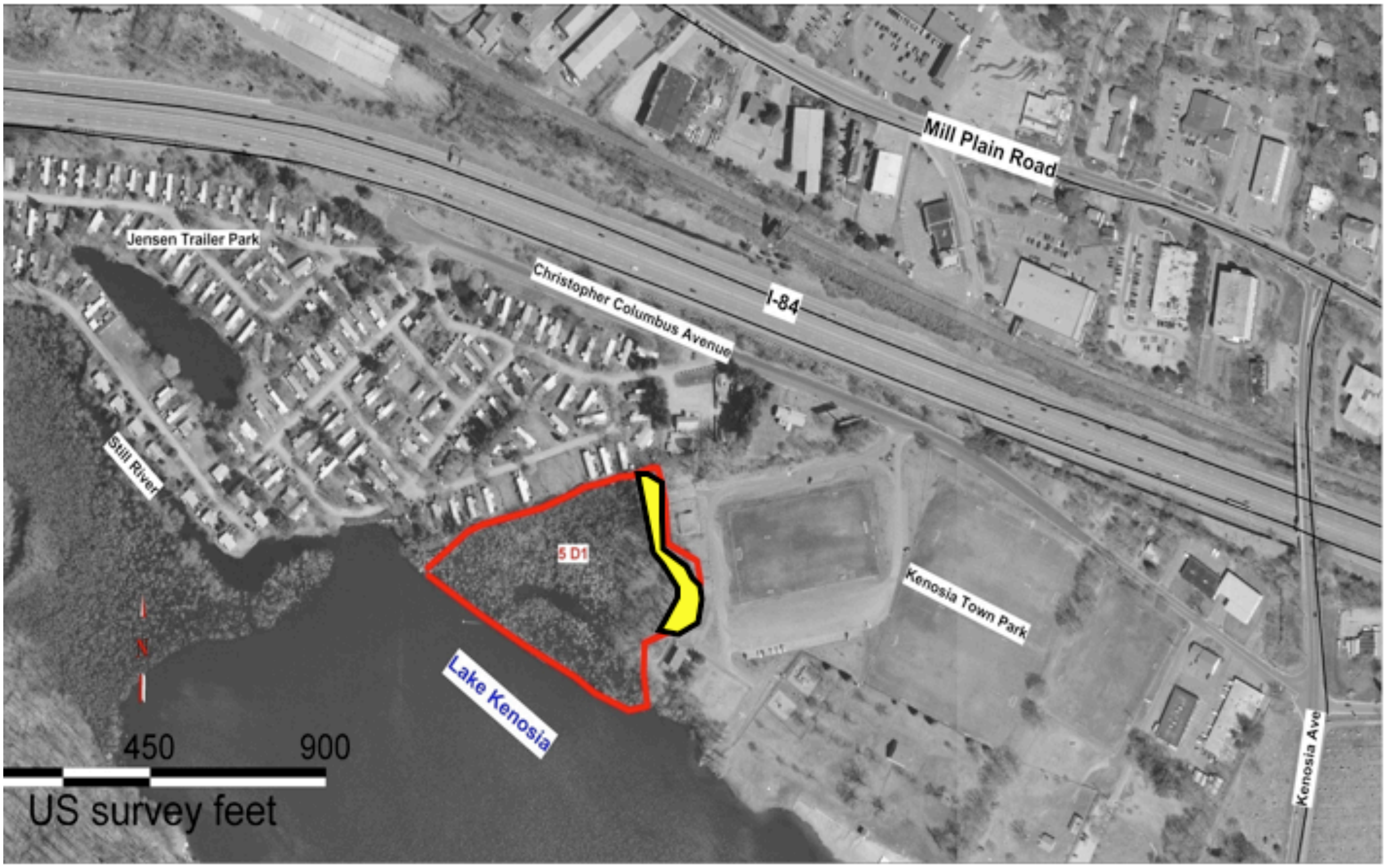


FIGURE 1: Proposed Location of Stormwater Treatment Train on fringe of swamp which receives urbanized drainage from watershed north of site. location for treatment train is illustrated in yellow fringe area northeast edge of swamp

The work for Stage 1 - the definition of the problem - is completed and documented in reports that describe these studies. In 2010, the Connecticut Institute of Water Resources funded stage 2, which subsidized a baseline pollutant loading study that quantified nitrogen and phosphorus loadings to Lake Kenosia from its most urbanized subwatershed. This project has produced a quality Assurance Project Plan (qAPP) that has defined the process for evaluating pollutant loadings during storm events, has obtained one (1) automatic sampler for capturing the runoff from significant storm events, has trained two graduate students in the techniques of stormwater collection, has quantified pollutant loading during base flow at 2 strategic locations in the watershed, and has obtained samples from a major "calibrating storm" that measures pollutant loading at various stages of a major storm event (>0.5 inches) that occurred in the Lake Kenosia watershed on August 22-23, 2010 and from three other storm events (Figures 3&4, Tables1,2,3). The purpose of this baseline study was intended to bridge to an engineering stage of a long term project that will design and construct a staged stormwater treatment structure that will retrofit existing storm drainage and reduce nitrogen and phosphorus loadings at a strategic location (Future grants to Danbury will initiate the design of the stormwater treatment structure). Hence, the 2010 study has quantified the relative loadings of two major loading discharge points in the watershed.

B. Goals of the Study:

1. **Verify the Nitrogen and Phosphorous loadings discharging into Lake Kenosia from the two sub-watersheds northwest of the Lake**.

2. **Document this loading data in a manner that can be used by an environmental engineer in the design of a stormwater treatment train.**

C. Objectives of the Study.

1. Identify strategic locations in the watershed for sampling stormwater.

2. Develop a standardized procedure for:

   (a) Determining which storms to sample and mobilizing the sampling team to capture the storm event at the right time;
   (b) Measuring flow during storm events.
   (c) Obtaining water samples during the storm;
   (d) Analyzing and interpreting the data.

3. Execute the procedures to determine total nitrogen and phosphorous loadings to Lake Kenosia from the sub-watersheds north and west of the Lake.

I. Anatomy of a Study - the Challenges.

The project merged two different sectors, the City of Danbury, who has oversight over Lake Kenosia, with its documented impaired water quality. A second level of the process is the interests of Western Connecticut State University to partner with the City of Danbury in developing a project where students can participate to monitor the level of impairment and its improvement over time. The nexus point of these two institutions is the City's Lake Kenosia Commission, whose science advisor served as the project manager for this study. The University recruited two graduate interns to work with the project manager, who were under the program oversight provided by the University's Principal Investigator of the project. Henceforth, this personnel structure will be referred to as "The Team".

Early on in the study, a series of workshops were held to delineate the process toward executing the study with the dual goals of documenting the nutrient input to lake and to establish a long term process for the University to serve as the objective monitor towards the improvements to the Lake that will occur as the treatment train is designed and built. At the outset, the project team identified the following challenges, as a prelude to the design of the monitoring project.

- Can we identify strategic locations in the study watershed that will accurately portray stormwater loadings and determine the optimum sites for stormwater treatment?

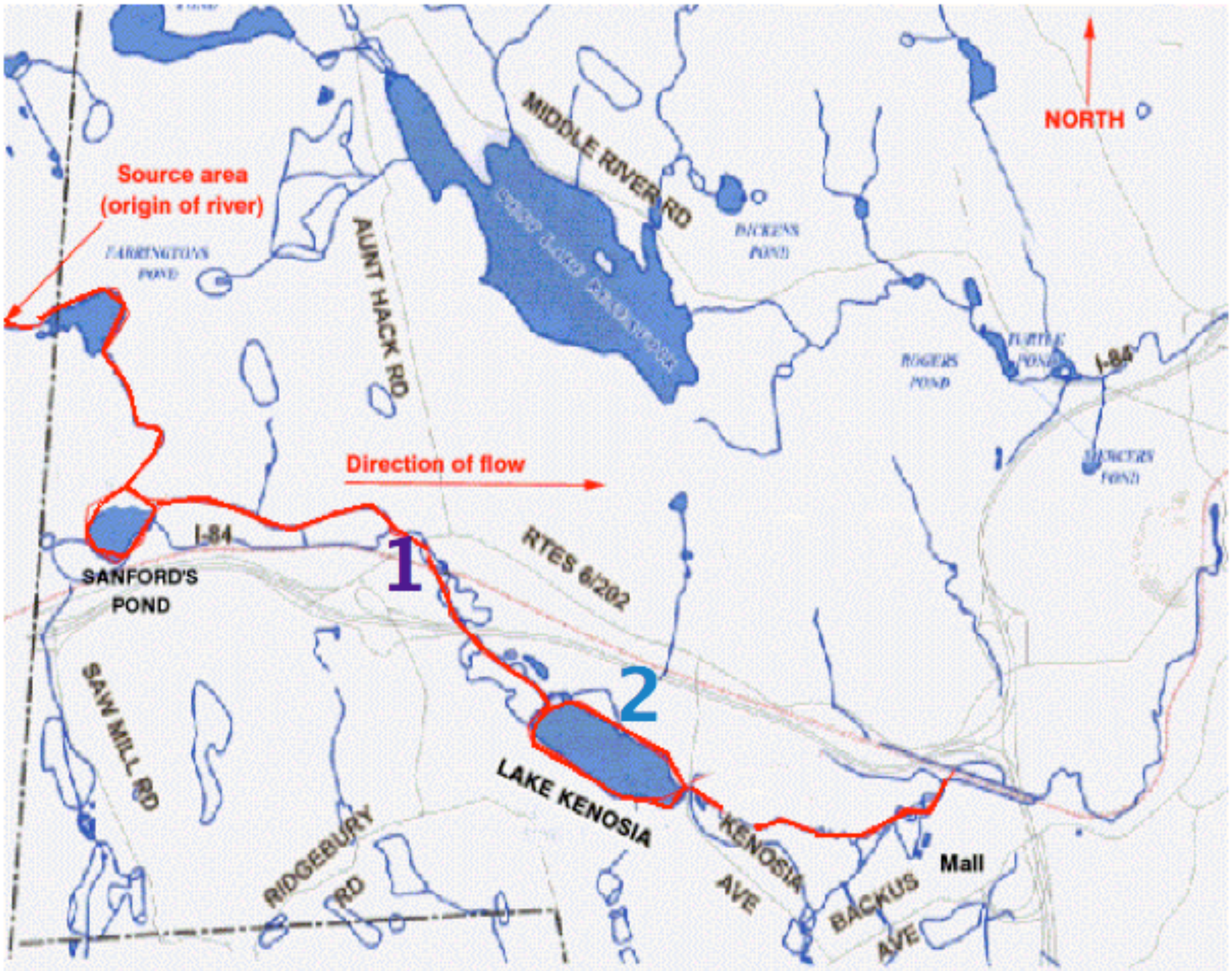
- Can we establish a standardized procedure for capturing storm events, accurately sample storm runoff, analyze the data, and execute these procedures in a manner that can be replicated?

- Can we interpret the data to ascertain nitrogen and phosphorus loadings to the Lake and determine the optimum location for stormwater treatment?

After presenting and interpreting the data from this study, Section VI of this report will evaluate the success of the three process challenges, stated above.

II. Selection of Sampling Stations

Figure 2, below, identifies the storm sampling stations of the Lake Kenosia Watershed that drains to the Lake during storm events. Lake Kenosia is an impoundment of the Still River, whose source is two waterbodies: Farrington's and Sanford's Pond. Sampling Station 1 (Rosy Tomorrow's) portrays the runoff from the upper portion of the watershed that is almost entirely undeveloped. This "top of the watershed" location is directly on the Still River, near its source. Sampling Station 2 is located at the base of the subwatershed that receives the runoff and stormwater loadings from highly urbanized section of the watershed through drainage pipes that ultimately discharge to the watercourse that flows into this station. The urbanized drainage that flows into Sampling Station 2 (Lake Kenosia) has been previously documented with the highest loadings of nitrogen and phosphorous to the Lake.



Segment 1: Source area for The Still River. The river's path is denoted by the red line.

FIGURE 2: SAMPLING STATIONS SELECTED FOR STUDY

III. The Project Design: quality Assurance Project Plan (qAPP) – Appendix I.

A documentation of any scientific study starts with the identification of methods, equipment and supplies that are the blueprint for obtaining accurate data to achieve the objectives of the project. In most cases it is simply identified as "Materials and Methods".

The Environmental Protection Agency (EPA) has established a protocol for creating a "Quality Assurance Project Plan (QAPP) for developing such a foundation document that guides a scientifically defensible study procedure. In addition to standardizing all procedures, equipment and supplies, the QAPP process requires a review and approval process that requires several months to achieve. Due to the time limitation of this project (7 months), it was not possible to secure a fully approved QAPP prior to executing the study. Therefore, the project team developed a project foundation document, which included informal consultation and feedback from the Connecticut Department of Environmental Protection and the U.S. Geologic Service (USGS). However, a formal approval of the plan was not included in this process. Hence, we have identified this document as the quality Assurance Project Plan (qAPP).

The following points summarize the qAPP document developed by the Project Team :

1. **Storm Watch**: The weather requirement specifications for a sampling event was determined as a 0.5 inch storm (or greater), as determined by a rain gauge placed at Station 2 and/or a National Weather Station located at the Danbury Airport, within 1 mile of Station 2. The specified storm must be preceded by 72 hours of dry weather.

   In order to identify the target storms, a daily "weather watch" system was implemented. One of the team members was assigned to checking the short term and long term weather forecast along with several weather models that were provided by the Western Connecticut State University Weather Center (WCSUWC). As a potential target storm event approached the study area, the designated weather watcher consulted with forecasters from the WCSUWC. As the potential storm approached Danbury, the weather watcher placed increasing levels of alert to the samplers. Within 12 hours of the predicted storm the samplers were mobilized by e-mail or phone to meet at the sampling stations at least one hour prior to the predicted onset of the storm.

2. **Sampling stream water** : Samples were collected in 2 ways:

   a. An Auto-sampler at Lake Kenosia was used to collect the samples at this station (see notes in Section VI). This device is programmed to pump 3 liters of water into the reservoir when the rain gauge measured 0.5 inches of rain.

b. Samples were collected at Station 1. The grab sampler was a beaker that was attached to a telescoping pole that was scooped into the stream when 0.5 inches of rain was measured either at the rain gauge or the Weather Station. After collecting the water samples, they were placed in a cooler and transported to a Connecticut Licensed laboratory for analysis of stormwater pollutants.

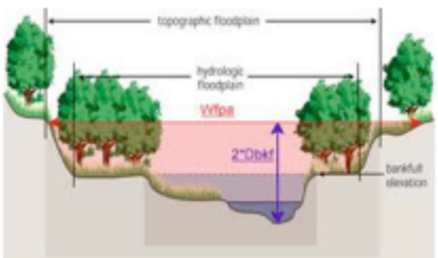
3. Flow measurements. A computer programmed flow meter was established in the qAPP as the method to determine the discharge in liters per minute, and an alternate method, that is described below as the "birdy technique" was also used as a simpler method to be used by monitoring citizens:

   a. LENGTH. A 10 foot length segment was staked at the sampling stations.
   b. WIDTH: The average width of the stream (from multiple locations)at the time of the sampling was measured at each location.
   c. CROSS SECTION = LENGTH x WIDTH
   d. VELOCITY. A badminton birdy was placed in the water at the time of sampling and the time of travel of the birdy along the 10 foot segment was recorded.
   e. DISCHARGE The Flow in the steam was determined according to the following formula: (width in feet) x (depth in feet) x (velocity feet/minute). For the loading calculations, this measurement was later converted to liters / minute.

   It should be noted that this technique is used as a standard monitoring technique by the National Volunteer Storm Runoff Monitoring Program . The simple manual method described here is illustrated in the diagram, below, using an example of a stream that has a cross section 2.5 feet and a velocity of 0.5 feet/second at the time of storm sampling:

DISCHARGE

Cross section (2.5 ft ^{2}) x steam velocity (0.5 ft/minute) = Discharge 1.25 cubic ft/min.



x

=

4. Pollutant Loading Calculation:

   When the sample results were received from the laboratory, stormwater pollutant loading was determined by the following formula:

   LOADING = cross section (feet ^{2}) x velocity (ft/second) x pollutant concentration (mg/liter).

   After conversions into common units of measure, the Loading result was expressed as ***milligrams of pollutant per minute***.

IV. ▪ **The Storm Events**

1. Baseline stream sampling.

   Samples were collected on August 28, 2010 - a dry day preceded by 72 hours of dry weather, - using the methods documented in IV, above. The purpose of this sampling event was to obtain a portrayal of loading from the watershed during non-runoff conditions. Section VI C explains the utility of a “dry weather sampling” event.

2. The “calibrating storm event”

   On August 22-23, 2010, a tropical N’oreaster storm occurred in the study area. The prolonged nature of this event provided the opportunity for sampling a storm at different stages of the weather event, and providing a pollutant loading during the hydrograph of the storm. Samples were collected when 0.5 inches of rain was received at the watershed. The total rainfall during this event was 1.65 inches.

   Some of the data (two) for all of the other storm events was interpreted using the flow vs time and concentration vs. time of this pollutant loading hydrographs from the calibrating storm. For example, if the rainfall during a storm event was 2 inches and the sampler could not obtain direct flow measurements, the flow at that station can be inferred from the calibrating storm. If the Discharge during the calibrating storm was 100 cubic feet / minute, then the discharge at 2” of rain in our example can be extrapolated to 200 cubic feet per meter.

3. The three other storms sampled in this study were as follows:

   - July 14, 2010: 1.21 inches rainfall.
   - September 27, 2010: 0.67 inches rainfall.
   - September 30, 2010: 2.74 inches rainfall.

V. **The Data.**

The pollutant concentration and loading data for the four storm events is presented in Tables 1 - 3 and Figures 3-4:

1. The up-gradient station near the top of the watershed is identified in these illustrations as “Rosy T’s”.
2. The down-gradient station near Lake Kenosia at the base of the watershed is labeled “Kenosia”.
3. Figure 3 represents the loadings from individual samplings taken at various stages of the storm. Baseline” represents dry flow - sampled on a different dry day (8/28) - and is added to the hydrograph as a basis of comparison. “Post storm was at the end of the 8/22 storm (rain had tapered to a light drizzle) and was collected after 1.6” had fallen.

4. Figure 4 is the loading data from all four storm events. Note that the loading data from the 8/22 storm event averaged the loadings from each stage of the storm.
5. Table 1 averages all 4 loadings from the storm events for Lake Kenosia and Rosy T's for nitrogen and phosphorous.
6. Tables 2 and 3 used the average loading from Table 1 to broadly estimate the storm loading per year for the period November 1, 2009 - November 1, 2010. Data was obtained from the Western Connecticut State University Weather Center to total the hours during this year when rainfall exceeded 0.5 inches (314 hours). This was used in the redbox calculation in Tables 2 and 3 to estimate the total loadings of nitrogen and phosphorous per year when rainfall exceeded 0.5 inches per event. The blue box calculation on these tables was calculated by using the balance of hours during the year when there was 0.5 inches of rain or less to provide the dry weather pollutant loading estimate.

Figure 3: The Calibrating Storm

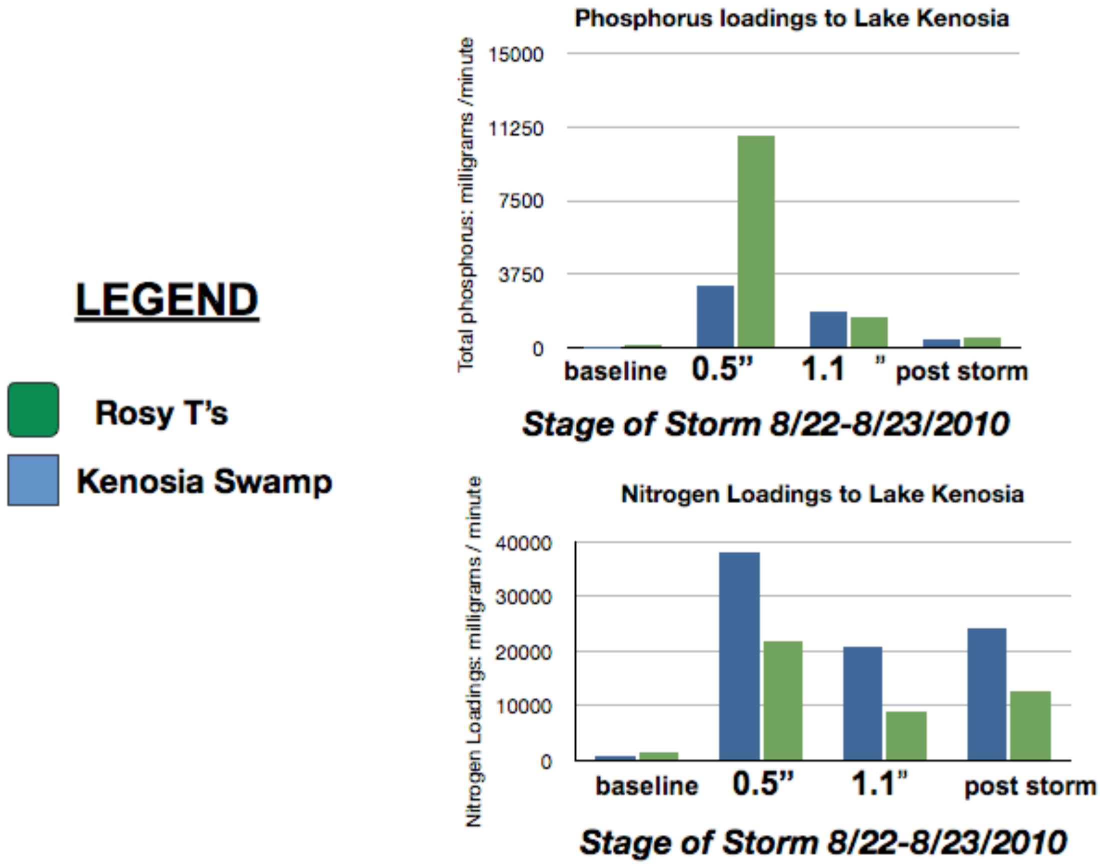
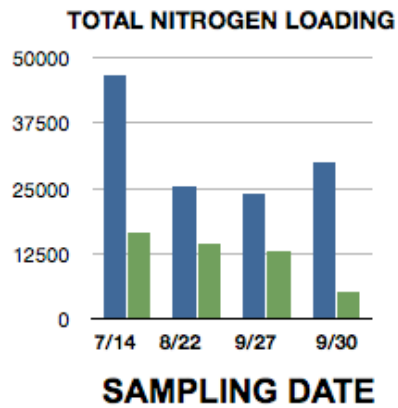


FIGURE 4: Total Loadings during all storms:

LEGEND

■ = KENOSIA

■ = ROSY T's



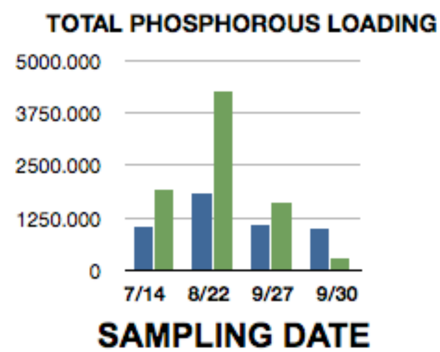


TABLE 1

- The Total Data Set:

TOTAL PHOSPHORUS LOADINGS

	KENOSIA	ROSY T'S
Jul 14, 2010	951	1901
Aug 22, 2010	1811	4284
Sep 27, 2010	1057	1603
Sep 30, 2010	972.1	274.5

AVERAGE KENOSIA: **1198 mg / minute**
Phosphorous

AVERAGE ROSY T's: **2015 mg / minute**
Phosphorous

TOTAL NITROGEN LOADINGS

DATE	KENOSIA	ROSY T'S
Jul 14, 2010	46538	16683
Aug 22, 2010	27696	14451
Sep 27, 2010	23251	13089
Sep 30, 2010	29989	5280

AVERAGE KENOSIA **31,869 mg / minute**
Nitrogen

AVERAGE ROSY T's : **12,376 mg / minute**
Nitrogen

TABLE 2: Estimate of Mass Balance Estimate of Phosphorous Discharge to Lake Kenosia

Data from West Conn Weather Center:

# of hours / year with 0.5 inch storm event : 314
# of hours during year with baseline discharge: 8374

	BASELINE	STORMS
Annual Phosphorous Loading of NW subwatershed:	6 mg/ minute KENOSIA + 97 mg/minute ROSY's 103 mg/minute TOTAL	1198 mg/ minute KENOSIA + 2015 mg/minute ROSY's 3213 mg/minute TOTAL
	.000103 kg/min. 60 min/hr x 8374 hours = 51.75 killigrams/year during dry weather	.00323 kg./min x 60 min/hr x 315 days = 61.047 kilograms / year

TOTAL ANNUAL LOADING: (51.75) + (61.05) = **112.8** kilograms/year (75% of watershed)

ENSR Estimate of Phosphorus Loading: 294 kilograms / year

DEP TOTAL MAXIMUM DAILY LOAD : = 248 kg/yr (entire watershed) **186** kilograms/yr (NW study area)

TABLE 3: Estimate of Mass Balance Estimate of Nitrogen Discharge to Lake Kenosia

Data from West Conn Weather Center:

# of hours / year with 0.5 inch storm event : 314
# of hours during year with baseline discharge: 8374

	BASELINE	STORMS
Annual NITROGEN Loading of NW subwatershed:	674 mg/ minute KENOSIA +1448 mg/minute ROSY's 2122 mg/minute TOTAL	31,869mg/ minute KENOSIA +12,376 mg/minute ROSY's 44,245 mg/minute TOTAL
	.00212 kg/min. 60 min/hr x 8374 hours = 1065 killigrams/year during dry weather	.04425 kg./min x 60 min/hr x 315 days = 836 kilograms / year during storms

TOTAL ANNUAL LOADING: (1065) + (836) = **1901** kilograms/year (75% of watershed)

ENSR Estimate of Phosphorus Loading: 6730 kilograms / year

DEP TOTAL MAXIMUM DAILY LOAD: = 4790 kg/yr (entire watershed) **3592** kilograms/yr (NW study area)

VI. DATA INTERPRETATION: Summary of Project Findings.

1. The Nitrogen and Phosphorous Loadings to Lake Kenosia is substantially higher during storm events than during dry weather. This phenomenon is well established for stormwater loadings to water bodies throughout the nation. Nevertheless, Figures 3 and 4 verifies this finding for the study area.

2. Stormwater loadings during the calibrating storm (Figure 3) indicates that these pollutant discharges peak out at 0.5 inches and begin to tail off after 1 inch of rain.

3. For all storms, nitrogen loading is higher at the base of the watershed (Kenosia - see Figure 4). The more urbanized land use in the catchment area that drains to the Kenosia sampling station explains this finding. However, total phosphorous loading is higher in Rosy T Station (top of watershed) for three out of four storm events. This would contradict the fact that the undeveloped portion of the watershed that drains into Rosy T's should predicate a lower loading. Higher flow at Rosy T is a partial explanation for this observation. More data is needed to verify and explain this finding.

4. If the higher phosphorous loading found in observation 3 is verified in future monitoring, this would call into question the premise of the ideal location for a stromwater treatment train system being designed and constructed at the site illustrated in Figure 1. It may be that two or more stormwater treatment systems should be installed in the Lake Kenosia watershed, including the area immediately upgradient of the Rosy T sampling station.

5. The mass loading estimate for nitrogen and phosphorous, presented in Tables 2 and 3 show a surprisingly low estimate of loading of both nitrogen and phosphorous to the Lake. The loadings were approximately 50% and 75% lower than the ENSR loading estimates that were made in 2000 that are based upon land use loading models. Indeed, if the lower loadings estimated from these tables are verified and correct, it can be argued that the pollutant loadings from the watershed to the Lake may be close to meeting the Total Daily Maximum Load established by the Connecticut Department of Environmental Protection (DEP) and that Lake Kenosia is not an impaired Lake. This preliminary empirical findings can be explained:

   (a) The process for estimating the pollutant loads exhibited in Tables 3 and 4 is flawed. In particular, the assumption that runoff loading "starts" at 0.5 inches of rainfall may be underestimating loadings during events from 0.1 - 0.5 inches of rain.
   (b) Alternatively, the land use model used by ENSR overestimates pollutant loading during storm events.

(c) Finally, the drought conditions of 2010 produced less storms, less total runoff and less pollutant loadings than would occur during an average year of rain events.

More data is needed to verify.

VI. **Conclusion** : What we learned: the performance of the "Process" of the Study and prospects for future phases.

We conclude this case study with a documentation of how this study was performed in addressing the challenges listed in Section III of this report:

- ✦ Can we identify strategic locations in the study watershed that will accurately portray stormwater loadings and determine the optimum sites for stormwater treatment?

  YES. The station at the base of the watershed identified as KENOSIA clearly is an accurate representation of the total pollutant runoff discharging from the urbanized area of the watershed directly north of Lake Kenosia. The station near the top of the Watershed (ROSY T) hydrologically was a good representation of the undeveloped catchment area that drains into it. However, the unexpected result of observing higher phosphorus loadings at this location begs for additional data. In the next stage of monitoring a station should be located closer (i.e., more upstream) to the source of the Still River at the top of the watershed.

- ✦ Can we establish a standardized procedure for capturing storm events, accurately sample storm runoff, analyze the data, and execute these procedures in a manner that can be replicated?

  YES. The process for establishing the qAPP was dynamic and the document was flexible enough to modify during unexpected findings. In fact, the qAPP from the 2010 monitoring study can be used as the foundation document for the qAPP in the next stage of baseline monitoring. The only improvement that could be made to this process would be to elevate the qAPP to a QAPP. However, the duration of the study for this to occur must be much greater than 9 months due to the approvals of the QAPP that would be needed prior to the initiation of sampling.

- Can we interpret the data to ascertain nitrogen and phosphorus loadings to the Lake and determine the optimum location for stormwater treatment?

  YES, our study demonstrated that Nitrogen and Phosphorous loadings to Lake Kenosia can be measured and documented, **BUT**

  NO, the data from this years monitoring cannot definitively verify a single optimum location for a stormwater treatment structure in the watershed. More data is needed.

ACKNOWLEDGEMENT: The authors acknowledge the contribution of the Western Connecticut Weather Center in providing support for the Storm Watch System. In particular, the consultation of Mr. Gary Lessor in advising us of storm tracks was critical to the success of capturing the 4 storm events. We also thank the City of Danbury and the Lake Kenosia Commission for their cooperation.

APPENDIX I – qAPP

A Baseline Study of phosphorus and nitrogen loadings to Lake Kenosia

quality Assurance Project Plan (qAPP)

Theodora Pinou, PI, Western Connecticut State University

Jack Kozuchowski, Project Manager

Abstract: “A qAPP for Baseline Study of Phosphorous and Nitrogen loadings to Lake Kenosia”

The Environmental Protection Agency (EPA) has long identified the challenge of controlling and remediating non-point sources of water pollution stemming from stormwater runoff from watersheds to water bodies. Mid and large sized municipalities are required to have prepared a stormwater management plan aimed at controlling these sources of pollution. However, the challenges of taking steps to control stormwater pollution that are needed to remediate water bodies that are classified as “impaired” can be overwhelming, particularly in a difficult budget climate.

The City of Danbury, Connecticut is proposing an innovative water quality research project that will serve to demonstrate the following technological objectives:

1. Design a staged and expandable series of water treatment structures that will capture, divert and treat stormwater that would otherwise enter into an impaired water body, untreated.
2. Construct the first stages of water diversion and treatment system for this retrofitted drainage.
3. Conduct a baseline water quality analysis of the runoff that discharges to the lake untreated.
4. As the stormwater treatment system is installed, conduct an environmental performance monitoring of raw runoff (upstream) and treated runoff (downstream) of the treatment train.
5. Based upon the stormwater monitoring, determine the loading reduction from these treatment structures and the level of significance in bringing the lake into conformance with the Total Daily Maximum Load that has been assigned for the lake by EPA. The magnitude of further reductions that may be needed can be determined from this pilot study.
6. Provide collaboration with students of varying levels of by providing access to teachers to the treatment structures and sampling ports, along with opportunities for simple water testing for any grade level.
7. Develop a model for water quality treatment from a designed stormwater treatment structure that can be used to evaluate mitigation measures for future development projects that add impervious surface to the watershed.

Danbury provides an ideal setting for this pilot project with an impaired water body - Lake Kenosia - an opportunity for installing these treatment structures on City owned land and the ability to expand the treatment train (if needed) as further funding opportunities become available. This qAPP is aimed exclusively for implementing the foundation step for this 7 step program: The baseline Study (objective 3, above). This qAPP was developed, reviewed and approved by the Project Team prior to field sampling. In addition to providing a step by step procedure for executing the baseline study, it identifies the quality control process that will assure the scientific integrity of this project.

A1. Approval Sheet

_____ ______________________________________ ______________________

Jack Kozuchowski Date:
Western Connecticut State University
Title Project Manager

______ _____________________________________ ______________________

Aaron Ferraro
Western Connecticut State University Date
Title: Quality Assurance Officer

____ ______________________

Nicole Stiteler Date
Western Connecticut State University
Title: Data Management Officer

A2. Table of Contents

List of Tables

List of Figures

A3. Distribution List

Each person listed on the approval sheet and each person listed under Project/Task Organization will receive a copy of this Quality Assurance Project Plan (QAPP). Individuals taking part in the project may request additional copies of the QAPP from personnel listed under Section A4. This document has been prepared according to the United States Environmental Protection Agency publication EPA Requirements for Quality Assurance Project Plans dated March 2001 (QA/R-5).

A4. Project/Task Organization

Personnel involved in project implementation are listed in Table 1.

Table 1: Project Implementation Personnel

Individual	**Role in Project**	**Organizational Affiliation**
Jack Kozuchowski	Project Manager	WCSU Project Manager
Aaron Ferraro	QA Officer	WCSU graduate student intern
Nicole Stiteler	Data Manager	WCSU graduate student intern
Dr. Theodora Pinou	Project Investigator	WCSU Faculty

The **Project Manager** will be responsible for the following activities:

Train graduate student interns
- Direct development of qAPP. Maintain official, approved qAPP. Make amendments when needed.
- Oversee sampling, data management, interpret data
- Prepare final project report
- Present initial findings at Conservation Biology Course at WCSU, and to partners (January 25, 2011).

The Data Manager will execute the following tasks:

- Receive data results from laboratory and maintain hard copies of analytical data;
- Enter pollutant concentrations for each storm event to database.
- Calculate pollutant loadings and enter into database as per loading formula.
- For the calibration storm event, enter laboratory results in table.

The QA Officer will:

- Create a quality control checklist and monitor each storm sampling to assure that each item is maintained;
- Double check all data entries made by the Data Manager and maintain a separate digital file on a computer independent of the WCSU Website database;
- Assist in the interpretation of the data.
- Retain all updated versions of the qAPP and be responsible for its distribution.

Project Organizational Chart

There is no figure inserted here. This is a simple study with a Project manager and 2 graduate interns serving the roles of “Data Manager” and QA Officer.

A5. Problem Definition/Background

As a result of previous funding from the Connecticut Department of Environmental Protection, the City of Danbury's Lake Kenosia Commission sponsored a quantitative evaluation of the general trophic conditions and identification of specific loading sources for Lake Kenosia in western Connecticut. The Diagnostic / Feasibility Study, was conducted in 1999-2000 for the Lake Kenosia Commission by its retained consultant, ENSR. This study assessed the current trophic conditions of the lake, identified the key water quality impacts that were limiting the recreational function of the impoundment and evaluated an array of management / treatment options to reverse the water quality impairment. The Executive Summary of this study encapsulated the current water quality conditions of the lake:

"Phosphorus loading to Lake Kenosia is estimated at 390 kg/year. The Permissible Load, below which water quality problems and use impairment should be rare, is 145 kg/yr.... Resultant in-lake conditions include high inorganic turbidity following storms, algal blooms during periods of prolonged low flows, and dense peripheral submergent, rooted aquatic plant growth throughout the growing season." (Diagnostic/Feasibility Study, ENSR, 7/2000, page 1)

Following the completion of the Diagnostic study, the Lake Kenosia Commission sponsored a follow-up study to quantify water discharge patterns from the watershed and to identify the sub-watersheds that were contributing the largest load of key stormwater pollutants to the Lake. The study (also conducted by ENSR) was entitled Evaluation of Drainage Conditions in the Immediate Watershed of Kenosia Lake. This report, that was executed as a follow-up to the in-lake Diagnostic Study, mapped all of the storm drainage flows from catch basins to input points to the Lake and quantified hydrologic and pollutant loading inputs to the lake. As a result of this study it was determined that a specific location of the watershed (sub watershed 5) discharged on a parcel of land owned by the City of Danbury immediately proximal to Lake Kenosia. This parcel (hereafter referred to as "target treatment zone") provides the setting for the construction and evaluation of a "stormwater treatment train" that will be funded by other sources.

Rationale for initiating the project

Subsequent to the issuance of the ENSR report, described above, the Environmental Protection Agency established a "Total Maximum Daily Load for phosphorous (248 kg / year) and nitrogen (4790 kg / year). Although the City of Danbury is not under orders or regulatory pressure to achieve the TMDL, the Lake Kenosia Commission is committed to establish a process for the City to reduce the nitrogen and phosphorus loadings to the Lake to enhance the recreational character of the lake. Hence, the priority mission of the project is to retrofit existing stormwater discharges from the most polluted sub-watershed of the Lake as a significant first step towards reducing loading from all other areas of the watershed.

The specific goal of this project is to verify baseline loadings of nitrogen and phosphorous from this sub-watershed. The data generated in this project will be used in the next phase of the overall project mission in the preliminary design of the stormwater treatment train for retrofitted drainage to sub-watershed to the Lake.

In summary, this one year project is a stormwater study of "snapshot" baseline nitrogen and phosphorous loadings to Lake Kenosia, aimed as a start-up for a larger project that will be funded by other sources. The larger project will involve the design of a staged stormwater treatment train system in the "target treatment zone" at the base of the most polluted sub-watershed, described above.

Objectives of the project

The scientific objectives of this project, listed below, are targeted as a simple baseline study that will be completed in the spring/ summer/ fall stormwater season of 2010:

1. Identify specific sampling locations for stormwater events in the target treatment zone and at a control location near the top of the subwatershed.
2. Select and secure sampling equipment (including automatic field sampling and area-flow velocity instruments) for the one-year study.
3. Prepare a "quality Assurance Project Plan" (qAPP) for the study and train two graduate students selected as interns for the field sampling procedures that are quantified in the qAPP.
4. Collect samples from the field sampling devices at the target treatment zone and the control station for 5 distinct storm events in 2010 and deliver these samples to a licensed laboratory for analysis of the key pollutants.
5. Compile all data in a simple database and interpret the findings in a project report.

Regulatory information, applicable criteria and action limits:

The Total Daily Maximum Load of nitrogen and phosphorous discharge established for Lake Kenosia is currently only a guideline. The City is under no regulatory obligation to achieve this water quality goal.

A6. Project/Task Description

Project overview

This project is atypical of QAPPs that are prepared and reviewed by State and/or federal agencies. In general, a QAPP is prepared by a regulated industry that is striving to achieve compliance with an environmental standard for a specific discharge limit.

In the case of "The Baseline Study of Phosphorous and Nitrogen Loadings to Lake Kenosia", Western Connecticut State University is conducting a scientific study that is intended to assist the City of Danbury in the design of a stormwater treatment system that is aimed at voluntarily reducing historical discharges of nutrient levels in runoff from historical drainage systems to the Lake. Hence this document is entitled as a qAPP, to reflect the fact that it is unofficial, not subject to state review and approval and will only be promulgated internally by the Project Team.

Nevertheless, Western Connecticut State University is employing the innovative process of the EPA QAPP template to align this study with scientific integrity.

Project summary and work schedule

This project's major tasks and timeline are outlined in the table below.

Table 2: Schedule of Major Project Tasks

Task Name	Task Description	Start Date	End Date
Outreach	Outreach to internal and external stakeholders (including targeted facilities) about the project	October 2010	December 2010
Goals identification	Finalize the goals of this project, upon which metrics will be based	May 2010	June 2010
Data input & management	Excel database format will be used. Data entry will be checked and verified by QA Officer	June - December 2010	December, 2010
QAPP finalization	Finalize QAPP based upon results of the measures	May 2010	June 18,

& approval	identification, statistical methodology, and data management tasks. Primary data collection will not occur before relevant parts of the qAPP are finalized and approved by Project Team		2010
Sample Collection	Collect storm samples as per procedures in experimental design, described below	July, 2010	November, 2010
Data analysis	Analysis of baseline, self-certification, and post-certification data to understand change in facility performance and overall outcomes of interest. Assessment of project efficiency	November 2010	December 2010

Geographic focus

Maps of the Study area are presented in Figures 1a-1c, below, with subtitles identifying the specific locations.

Figure 1a: Overall location map illustrating the locations of the two sampling stations (green & yellow squares)

(SEE FINAL REPORT)

Figure 1b: Top of the Watershed location for sample collection at top of watershed (blue dot)

(SEE FINAL REPORT)

Figure 1c: Bottom of the Watershed location for sample collection at base of watershed (yellow dot)
(SEE FINAL REPORT)

Resource and time constraints

This project is severely limited by a very short time period and a limited budget. It is also a preliminary gear up for a project (impending dependent upon grant award) that will be initiated in 2011 that will extend this baseline study into a statistical comparison of the top of the watershed vs. base of the watershed loadings of nitrogen and phosphorous loadings to the Lake, that will be employed in the design of a stormwater treatment system.

Hence, this study will provide a snapshot approximation of loadings to the Lake that will be further refined and substantiated by continued sampling in 2011 which will provide a statistically significant loading comparison. This limitation has particular significance to the hydrographic data that will be collected in this study,

A7. Quality Objectives and Criteria

Detailed performance measures:
The performance of this project will be evaluated on the basis of the task identified in the following table

TABLE 3

Task	Performance Goal	Achievement of measure
Develop qAPP	Development of qAPP was integrated into the training of	The qAPP is adopted and approved by the project team before

	graduate students and the considered input of all parties including one review from an outside party (USGS).	sampling commences
Collection of water samples during "calibrating storm" event	Samples collected in accordance with procedure of experimental design, for an intense storm event that meets specifications of the weather conditions specified in the plan	Samples collected, delivered to laboratory and data recorded into database as the first storm events by early summer 2010
Collection of water samples for 4 subsequent storm events	Samples collected in accordance with procedure of experimental design for four storm events that meet the weather specifications of the experimental design.	Samples collected, delivered to laboratory and data recorded into database as the four subsequent events by November, 2010
Data Analysis	Analysis and tabulation of all sample results and presentation of data into final project report	Report submitted to WCSU Project Investigator by December 2010
Report Presentation	Present data at WCSU Science at Night program	Prepare power point presentation and present to WCSU forum by December 2010

Quality objectives

This qAPP is intended to be a uniform standard procedure for all work to be conducted in the baseline study. However, it is also intended to be a flexible document and the Quality Assurance Officer may periodically update the document with revisions (see Table 7 page 21).

The amendment to the QAPP will ensure that the quality objectives for these performance measures are appropriate for the regulatory and non-regulatory decisions to be made based upon those measures. This determination will take into account both the best practices for similar projects and the resources available for this project. In part, the Project Manager will rely upon EPA's Generic Guide to Statistical Aspects of Developing an Environmental Results Program (2003) for advice in making decisions related to the optimizing the following aspects of data quality for this project:

- Precision
- Bias
- Representativeness
- Completeness
- Comparability
- Sensitivity (if applicable)

A8. Special Training/Certification

Western Connecticut State University, through its contracted Project Manager, conducted four in-service training sessions for the graduate interns who are employed as sampling / analytical technicians for this project. There were three (3) main objectives for these four (4) sessions:

1. Provide an overview of the project, its intended mission, its specific objectives and the methodology that will be employed to achieve the project goals;
2. Identify QA/QC measures that will be integrated into the project;

3. Prepare this qAPP, (through the lead of the Project Manager) to provide insight into how a QAPP is developed and to convey the key elements of quality control that are developed in this project.

At the conclusion of these training sessions, the project team promulgated this document. Hence, this qAPP provides the Project Manager with documentation that the procedures used in sample collection, data management and interpretation of results are conducted with integrity and uniformity.

A9. Documents and Records

Report format/information

The format for all data reporting packages will be consistent with the requirements and procedures used for data validation and data assessment described in this QAPP.

Document/record control

The recording media for the project will be both paper and electronic. The project will implement proper document control procedures for both. For instance, hand-recorded data records will be taken with indelible ink, and changes to such data records will be made by drawing a single line through the error with an initial by the responsible person. The Project Manager will have ultimate responsibility for any and all changes to records and documents. Similar controls will be put in place for electronic records.

The project's assigned Quality Assurance Officer shall retain all updated versions of the QAPP and be responsible for distribution of the current version of the QAPP.

Other records/documents

Project final report (to include discussion of QA issues encountered, and how they were resolved)

Storage of project information

The data for this project will be maintained by the PI, Western Connecticut State University. It will remain there throughout the term of this project and into the future for use as a platform for phase II of the project. Duplicate files will be stored on separate computers.

Backup of electronic files

The Projects assigned Data Manager will back up files on a separate database associated with the Western Connecticut State University Department of Biology and Environmental Science. The data will also be backed up on a portable thumb drive.

B DATA GENERATION AND ACQUISITION

B1. Sampling Process Design (Experimental Design)

B1.a. Selection of sampling stations.

The project is designed to document nitrogen and phosphorous loadings at the base of the most polluted sub watershed that is illustrated on Figure 1a, above. There are 2 distinct sampling locations that will be utilized. The "upstream" station occurs near the top of the watershed where there is minimum urbanization from the catchment area that drains to it. The "pollutant loading" station is located at the base of the watershed (see yellow dot on figure 2).

B1.b. Sampling objectives. To achieve the objective of determining the loadings of nitrogen and phosphorous from significant storms that discharge runoff to Lake Kenosia, the sampling team will collect stormwater samples at the generally established "first flush" guideline that will be calibrated for the "pollutant loading" station. For five separate storm events will be targeted for sampling during the summer and fall 2010.

B1.c.1. The Storm Watch System

This project is aiming to collect samples from 5 storm events that meet the following conditions:

1. The storm is precede by 72 hours of dry weather;
2. The storm must be at least 0.5 inches of precipitation;
3. The first 0.5 inches must occur in the first 12 hours of the event.

For a six month period, this will be a challenge. Additionally, the storm sampler must be checked prior to the onset of the storm. Hence, "readiness" is an important element of quality control to assure that the correct storm event is sampled and the correct period of time. The following storm watch procedure is adopted.

Each week, one of the team members will be assigned as the weather watcher. The other team members must indicate their availability each day of the week to prepare the automatic sampler (before the event), and collect the samples for delivery to the laboratory after the event. The weather watcher will be responsible for:

Monitoring the on-line long term (2 week) weather forecasting services:

- http://wxweb.meteostar.com/sample/sample.shtml?text=KDXR

Keeping other team members informed of the impending event(s), as per 2 and 3, below.

The assigned weather watcher will check these databases every 3 days. When a storm is predicted in the 2 week period that has the potential of yielding 0.5 inches of rain, the storm watcher will "red flag" the event on a table or database that has the following characteristics listed in the table below and immediately e-mail the other members of the project team of the potential event.

If prediction is condensed within a few blocks of time (as per 1a), it is a good candidate storm.

TABLE 4: Storm Watch Prediction

RED FLAG STORM EVENT: Predicted Date and time of onset	# of hours of dry weather preceding predicted storm	Amount of rain predicted	Sample team members available for sampling

If a storm on the database is predicted within 36 hours, the weather watcher will monitor the predictions on a more frequent basis and contact the team for "readiness" when the storm is within 12 hours of occurrence. A sampling team of 2 individuals must be available to prepare the sampler before the event and to collect and deliver the sample after the event in order for the storm to be considered viable for sampling. Within 24 hours of the onset of the red flag storm, the weather watcher will monitor the predicted event more frequently, possibly hourly within a few hours of the storm.

Between 2 and 12 hours prior to the onset of the storm, the weather watcher will "confirm" the event and deploy the sampling team for either the "calibrating storm" event or the four other routine events.

After the storm event has passed, the weather watcher should verify the actual amount of rainfall that was recorded at the Danbury Airport, along with the recorded time of collection of the first 0.5 inches of rain at the sampler and record this data in the sample collection database.

B1.c.2. Sample Collection

B1. c.2a "The Calibrating Storm" SEE APPENDIX "A" & "B" FOR REVISIONS TO THIS SECTION

One of the first storm events for sampling stormwater is the "getting our feet wet" storm. As the name implies, it is the one storm that will be used where the collectors will be present at the sampling stations at the onset of the storm. The sampling steps for the calibrating storm are as follows:

1. Prior to the first storm event, a rain gauge will be installed at each of the two sampling stations.

2. Samplers will assemble at the Rosy Tomorrows Bridge Station and await the approach of the first 0.5 inches of rain. When 0.5 inches has accumulated in the rain gauge, the team will collect a water sample and obtain a stream flow measurement.

3. Immediately prior to the accumulation of 0.5 inches in the rain gauge, one of the samplers will descend the embankment to the River. He(she) will prepare the area-velocity meter for a measurement. The depth of the river will be measured. The sensor of the area-velocity meter will be lowered to a depth 2/3 to the bottom in the center of the channel and the steam velocity will be measured. The reading will be announced to the sampler at the top of the embankment, who will then repeat the recorded velocity for verification. The velocity will be recorded, first on a sample log, then on a database on a laptop computer. The sampler at the top of the embankment will then lower the telescoping pole with the sample bottle attached to it down toward the sampler at the River who will guide the collecting bottle to collect the sample at the same location (at 2/3 depth, center of channel) in the channel. The sample will then be brought to the surface and immediately placed in a cooler packed with ice.

4. Immediately following the collection of the sample at the Rosy Tomorrow's station, the team will then move to the Lake Kenosia Station, note the rain gauge and conduct a stream flow measurement in the same manner as described in 1, above.

5. Following the collection of each water sample, sign off on the "Chain of Custody" form, shown on Exhibit 1.

6. Two (2) hours after the collection of the sample at the Rosy Tomorrow's Bridge, repeat steps 1-2 to collect a second set of stream flow measurements and flow samples.

7. If necessary, place the samples in the refrigerator until laboratory opens. As soon as possible (i.e., when the laboratory is next open for business) deliver the samples to the laboratory. Have the laboratory sign off on the Chain of Custody. Make a photocopy of the form and leave one with them so that they can sign off when the sample analysis is completed.

8. The laboratory will analyze the samples received for the following constituents:

- pH
- Total dissolved solids
- Total suspended solids
- Ammonia
- TKN
- organic nitrogen
- nitrates
- nitrites
- Total nitrogen
- Total phosphorus
- dissolved phosphorous

9. When the data from the calibrating storm is completed, a table of stormwater pollutant concentrations and loading estimations for the two sampling locations will be prepared as a project deliverable The loading will be determined by the following formula:

Loading = Concentration (mg/liter) x flow (meters/second)
It should be noted that this data will portray an estimate of the loadings at one instant of time - the first flush of the storm at 0.5 inches of rainfall in the storm event. This will be represented as a "snapshot" of loadings at this uniform collection time for each storm event.
The results will be immediately tabulated into the baseline study database. It should also be noted that this loading comparison is qualitative, limited by the absence of detailed hydrographic information (noted in # 11, below).

The data will be logged into the table below, for each storm event: **TABLE 5**

Constituent	Concentration/ flow at top of watershed	Concentration/ flow base of watershed	Snapshot loading at top of watershed	Snapshot loading at base of watershed
total suspended solids	**D. Storm 1:** **E. Storm 2:** **F. Storm 3:** **G. Storm 4:** **H. Storm 5:** **MEAN:**	**D. Storm 1:** **E. Storm 2:** **F. Storm 3:** **G. Storm 4:** **H. Storm 5:** **MEAN:**	**D. Storm 1:** **E. Storm 2:** **F. Storm 3:** **G. Storm 4:** **H. Storm 5:** **MEAN:**	**II. Storm 1:** **III. Storm 2:** **IV. Storm 3:** **V. Storm 4:** **VI. Storm 5:** **MEAN:**
total phosphorous	✦ **Storm 1:** ✦ **Storm 2:** ✦ **Storm 3:** ✦ **Storm 4:** ✦ **Storm 5:** **MEAN:**	**IV. Storm 1:** **V. Storm 2:** **VI. Storm 3:** **VII.Storm 4:** **VIII. Storm 5:** **MEAN:**	**4. Storm 1:** **5. Storm 2:** **6. Storm 3:** **7. Storm 4:** **8. Storm 5:** **MEAN:**	**4. Storm 1:** **5. Storm 2:** **6. Storm 3:** **7. Storm 4:** **8. Storm 5:** **MEAN:**
dissolved phosphorous	**V. Storm 1:** **VI. Storm 2:** **VII.Storm 3:** **VIII. Storm 4:** **IX. Storm 5:** **MEAN:**	**V. Storm 1:** **VI. Storm 2:** **VII.Storm 3:** **VIII. Storm 4:** **IX. Storm 5:** **MEAN:**	**VI. Storm 1:** **VII.Storm 2:** **VIII. Storm 3:** **IX. Storm 4:** **X. Storm 5:** **MEAN:**	**VII.Storm 1:** **VIII. Storm 2:** **IX. Storm 3:** **X. Storm 4:** **XI. Storm 5:** **MEAN:**

Constituent	Concentration/ flow at top of watershed	Concentration/ flow base of watershed	Snapshot loading at top of watershed	Snapshot loading at base of watershed
total nitrogen	**Storm 1:** **Storm 2:** **Storm 3:** **Storm 4:** **Storm 5:** **MEAN:**	**Storm 1:** **Storm 2:** **Storm 3:** **Storm 4:** **Storm 5:** **MEAN:**	**6. Storm 1:** **7. Storm 2:** **8. Storm 3:** **9. Storm 4:** **10. Storm 5:** **MEAN:**	**6. Storm 1:** **7. Storm 2:** **8. Storm 3:** **9. Storm 4:** **10. Storm 5:** **MEAN:**
nitrate nitrogen	**VII.Storm 1:** **VIII.Storm 2:** **IX. Storm 3:** **X. Storm 4:** **XI. Storm 5:** **MEAN:**	✦ **Storm 1:** ✦ **Storm 2:** ✦ **Storm 3:** ✦ **Storm 4:** ✦ **Storm 5:** **MEAN:**	**1. Storm 1:** **2. Storm 2:** **3. Storm 3:** **4. Storm 4:** **5. Storm 5:** **MEAN:**	**1. Storm 1:** **2. Storm 2:** **3. Storm 3:** **4. Storm 4:** **5. Storm 5:** **MEAN:**
organic nitrogen	**1. Storm 1:** **2. Storm 2:** **3. Storm 3:** **4. Storm 4:** **5. Storm 5:** **MEAN:**	**2. Storm 1:** **3. Storm 2:** **4. Storm 3:** **5. Storm 4:** **6. Storm 5:** **MEAN:**	**2. Storm 1:** **3. Storm 2:** **4. Storm 3:** **5. Storm 4:** **6. Storm 5:** **MEAN:**	• **Storm 1:** • **Storm 2:** • **Storm 3:** • **Storm 4:** • **Storm 5:** **MEAN:**

10. Additionally, a time profile of concentration change during a storm will be established from the concentration difference at the beginning of the storm , at sample collection time + 2 hours during the event and sample collection time + 12 hours after the event. This will be done for a single storm event ("the calibrating storm", as described below) and will be used to adjust the concentrations that are determined at the "top of the watershed" sampling station for each of the subsequent storm events. The concentration at the base of the watershed location will not need to be adjusted for concentration change in the storm profile, since it will be based upon real time collection at the first flush moment (0.5 inches of rainfall) that is determined by the automatic sampler.

The results should be immediately tabulated into the baseline study database in the following format:

TABLE 6

Constituent	Concentration at top of watershed, first flush	Concentration at top of watershed, first flush + 2 hrs	Concentration at top of watershed, first flush + 12 hrs	Concentration at base of watershed, first flush	Concentration at base of watershed, first flush + 2 hrs	Concentration at base of watershed, first flush + 12 hrs
total suspended solids						
total phosphorous						
dissolved phosphorous						
total nitrogen						
nitrate nitrogen						
organic						

nitrogen							

11. Hydrographic Data

A true representation of quantitative annual loadings of nitrogen and phosphorus to the Lake would require the construction of a detailed hydrograph. This project will not provide such a hydrograph.

Nevertheless, the area-velocity meter that will be deployed for the calibrating storm event will measure base flow before the storm event, flow at first flush (o.5 inches of rain at the sampling location), first flush + 2 hours and first flush + 12 hours. This data will be logged in the project database and will be used in the next phase (pending funding for 2011) that will construct a storm hydrograph for this section of the watercourse

12. Sample Collection for subsequent storm events

The sample collecting during the four storm events that occur outside of the calibrating storm follows a much simpler procedure. When the "storm watcher" for the week confirms the onset of the storm (as per Section III), the deployment of the sampling team will follow four simple actions:

a) Within 24 hours of the onset of a red flag storm event, the samplers should assure that sample bottles are intact in the cooler and a clean funnel is placed in the cooler.

b) Within 2 hours of the storm, the automatic sampler should be checked, emptied of any water (in the collection bottle) from a previous event and packed with gel ice or ice cubes.

c) Within 12 hours after the storm delivers the first 0.5 inches (this time should be monitored by the weather watcher), the grab samples should be collected from Rosy Tomorrows and the sample should be collected from the automatic sampler:

- The sample from the top of the watershed location (Rosy Tomorrows) will be collected at the designated location on the River. Extend the telescoping pole to 2/3 of to the bottom of the channel and scoop the sample from this depth. Pour the water from the container, using a funnel if necessary.
- The samples from the automatic sampler at the base of the watershed (Lake Kenosia Swamp) should be carefully poured into the sample bottles using a funnel.
- The samples from both Rosy Tomorrows and the Lake Kenosia swamp should be immediately placed in the cooler packed with ice.
- A field blank should be placed in the cooler for each storm event.
- All samples should be immediately delivered to the laboratory, after collection. If the laboratory is closed for business after the time of collection, they should be delivered to Western Connecticut State University and placed in a refrigerator. As soon as the laboratory is open, the samples should be delivered to the laboratory. Have the laboratory sign off on the Chain of Custody. Make a photocopy of the form and leave one with them so that they can sign off when the sample analysis is completed.

13. After the results are received, the data should be logged into the sampling database and the loading should be calculated (as per Section V, step 8 above).

B2. Sampling Methods

As described above, the primary data collected and used by this ERP will come from a survey data collection process. This section of the QAPP will be amended upon completion of the project-specific statistical methodology, which will detail the statistical sampling methods to be used. As mentioned elsewhere, that methodology will be prepared consistent with the principles identified in the EPA's Generic Guide to Statistical Aspects of Developing an Environmental Results Program (2003).

Preparation of data collection instruments

The operation of the stormwater sampler and the Streamflow area-velocity meter for the project is critical to its success. The following step by step process will be used.

- Select the appropriate Automatic Sampler and area-velocity steam flow meter that will accomplish the sampling objectives of the baseline study.
- Review and analyze the technical specifications of the automatic sampler and the area-velocity flow meter. Make all tech support calls to vendors of instruments, consult various experts on its operations and (if necessary) arrange for half day orientation.
- Prepare checklist for calibrating and readying instruments for storm event.
- When automatic sampler arrives install it at the Lake Kenosia sampling station, secured to tree.
- Make test run of automatic sampler before first major storm event (i.e., try unit during minor storm event or trip sampling unit by pouring water into the rain gauge).
- When leased area-velocity flow meter arrives, conduct a baseline “dry weather” flow monitoring at various stations to test it out.

B3. Sample Handling and Custody

Upon completion of the QA Officer’s paper checklist, samplers will sign the checklists.

Data entry QA procedures

Procedures for entering hand-written data into the database will follow standard quality assurance procedures (e.g., verification using QA Officer’s verification of data entry). This data check will be conducted independently of data manager’s data logging and reconciled when a discrepancy is noted.

B4. Analytical Methods

The analytical procedures and quality management program for the analysis of samples will be the responsibility of the licensed laboratory retained by this project for analysis. Their analytical procedures for each of the constituents identified for analysis is documented in the Appendix.

There will be no statistical analysis of data for this project.

B5. Quality Control

This project will undertake the following specific steps to measure/estimate the effect of data errors.

B5a. Crosschecking data

The Data Management officer is responsible for tabulating the data from analytical reports. The Quality Control Officer of the Project will independently check the correct input of the laboratory data into the project database.

B5b. Data anomalies

This will be a qualitative comparison of top of the watershed vs. base of the watershed stormwater loadings. The QA Officer will flag potential anomalies in the data obtained from the project. The Project Team will discuss such anomalies and determine if they should remain in the report with a footnoted explanation or whether it should be eliminated from the data set with justifications noted in the project report. There is an insufficient amount of data to consider outliers.

Quality control statistics

No statistical analysis is anticipated; hence quality control statistics are not applicable.

B6. Instrument/Equipment Testing, Inspection and Maintenance

Equipment testing will occur prior to each sample collection as described in the Experimental Design.

B7. Instrument/Equipment Calibration and Frequency

Not Applicable. No calibration of equipment is required.

B8. Inspection/Acceptance for Supplies and Consumables

This section is not relevant to this project. The project will not involve such supplies and consumables.

B9. Non-Direct Measurements (I.e., Secondary Data)

Not applicable.

Key resources/support facilities needed

Western Connecticut State University will require access to the data sources mentioned above, and this information will be managed within the database created/utilized for the overall project. Western Connecticut State University does not anticipate any obstacles to this approach.

Determining limits to validity and operating conditions

NOT APPLICABLE.

[Add more information about this topic if using different kinds of secondary data]

B10. Data Management

The data management officer will be responsible for

*entry of data into the database;,
*sending each laboratory report to the Quality Control Officer for a check of accuracy of transcription;
*entering the database on to a designated website for the project;

*making electronic back-ups of the database.

C. ASSESSMENT/OVERSIGHT

C1. Assessment and Response Actions

NOT APPLICABLE.

C2. Reports to Management

NOT APPLICABLE.

D. DATA REVIEW AND EVALUATION

D1. Data Review, Verification and Validation

This QAPP shall govern the operation of the project at all times. Each responsible party listed in Section A4 shall adhere to the procedural requirements of the QAPP and ensure that subordinate personnel do likewise.

This QAPP shall be reviewed at least annually to ensure that the project will achieve all intended purposes. All the responsible persons listed in Section A4 shall participate in the review of the QAPP. The Project Manager and the Quality Assurance Officer are responsible for determining that data are of adequate quality to support this project. The project will be modified as directed by the Project Manager. The Project Manager shall be responsible for the implementation of changes to the project and shall document the effective date of all changes made.

It is expected that from time to time ongoing and perhaps unexpected changes will need to be made to the project. The Project Manager shall authorize all changes or deviations in the operation of the project. Any significant changes will be noted in the next report to EPA, and shall be considered an amendment to the QAPP. All verification and validation methods will be noted in the analysis provided in the final project report.

D2. Verification and Validation Methods

To confirm that QA/QC steps have been handled in accordance with the QAPP, a readiness review will be conducted before key data collection/analysis steps.

D3. Evaluating Data in Terms of User Needs

NOT APPLICABLE

TABLE 7: REVISIONS RECORD FOR qAPP

Date	Section and page # of revision	Reason and substantive content of revision
8/11/10	B1.c.2. Sample Collection	Rev. to reflect field conditions – Appendix A
8/28/10	B1.c.2. Sample Collection	Rev. to reflect field conditions – Appendix B
8/30/10	Appendix C	Include field checklists for information only

APPENDIX "A" - PROCEDURE MODIFICATION, 8/11/2010

B1.c.2a"The Calibrating Storm":

The sampling steps for the calibrating storm are modified as follows:

I. Prior to the predicted storm event, the rain gauge that is connected to the automatic sampler will be set up in the open - in the open marsh immediately across from the automatic sampler.

J. Samplers will assemble at Lake Kenosia Swamp and await the approach of the first 0.1 inches of rain. When 0.1 inches has accumulated in the rain gauge, the team will collect a water sample and obtain a single stream flow measurement with the area-velocity meter at the center of the channel. In addition to having the velocity and depth measured directly into the meters database, the reader of the laptop computer will announce the depth and flow to a second sampler, who will manually record the depth/ velocity in the channel into a notebook. The sample will be collected by activating the by-pass button on the automatic sampler to fill the plastic jug in the sampler, which will then be poured off into the laboratory's sample bottles.

K. Immediately following the collection of the sample at Kenosia, the samplers will move on to the Rosy Tomorrows station. One of the samplers will descend the embankment to the River. He(she) will prepare the area-velocity meter for a measurement.. The sensor of the area-velocity meter will be lowered to the bottom in the center of the channel and the steam velocity and depth will be measured and read by a second sampler at the top of the bank off of the programmed laptop computer. The area-velocity will be measured at 2 other locations in the channel. In addition to having the velocity and depth measured directly into the meters database, the reader of the laptop computer will announce the depth to another sampler, who will manually record the velocity at the three locations in the channel into a notebook.

The sampler at the top of the embankment will then lower the telescoping pole with the sample bottle attached to it down toward the sampler at the River who will guide the collecting bottle to collect the sample at the center of the channel. The sample will then be brought to the surface and immediately placed in a cooler packed with ice.

L. The samplers will then return to the Lake Kenosia swamp and repeat the sample collection and area-velocity measurement as described in Step (2) above when the rain gauge records between 0.3 and 0.5 inches of rainfall.

M. Immediately after the second water sample is collected from the Kenosia swamp, the samplers will return to the Rosy Tomorrows station to collect a second set of water samples at this location, repeating the procedure of step 3, above.

N. Six to eight hours after collecting the second set of samples, samplers will return to the Kenosia Swamp and Rosy Tomorrows and collect the third set of samples, repeating the procedures of 2 and 3 above. The samplers will record the precise amount of hours that have lapsed between the second and third set of samples.

Following the collection of each sample set, the sampling team will employ the same refrigeration and laboratory delivery procedure specified in the original qAPP.

APPENDIX "B" - PROCEDURE MODIFICATION, 8/28/2010

B1. c.2a Sample Collection

B1. C.2b "The Dry Weather Storm":

The sampling procedure, below, was added to provide an additional dimension to the baseline study and will substitute for one stormwater sampling event, reducing the total storms sampled from five to four. It is added for the following reasons:

C. The second storm event, collected on 8/22/2010 measured streamflow by a manual method that timed the flow of an object (badminton birdy) down a 10 foot segment of the stream channel whose depth and width dimensions were measured and recorded. This manual method was used as a substitute for the more accurate area-velocity (A-V) meter, due to the failure of the A-V meter to function on that day. On August 23, 2010, when the A-V meter was back on line, a side by side comparison of the measurement of the a-v meter vs the manual flow method described above was conducted at the Kenosia Swamp and the Rosy Tomorrows station. On Saturday, August 28, 2010, a second side by side comparison of flow will be conducted during a dry weather period using the A-V meter and the manual method .

D. Adding a storm flow will provide a complete hydrograph for Sundays storm event. The base flow on Saturday August 29, 2010 (following 72 hours of dry weather) will be the same as the base flow that was occurring just before the storm event on Sunday August 22, 2010, which will produce a hydrograph that starts at Time 0 (before rain), at 0.5 inches (8/22 sample at 4:45), 1.1 inches (8/22 at 6:45) and T + 20 hours after the storm ended (sample collected 8/23 at noon). This will be a very elegant capture of a fast flush after 2 major storm cells on 8/22/10 and the recovery period 12 hours after the storm. Adding the base flow with the 8/28 sampling will complete the picture.

E. It will add the dimension of a base low flow pollutant loading during a dry weather period.

The sampling procedure that will be employed during the dry weather sampling event will be as follows:

1) Collect base low flow sample after 72 hours of weather with no significant precipitation;
2) Measure flow at Kenosia Swamp and Rosy Tomorrows using the manual method as follows:
   (a) Measure and mark a 10 feet length of stream at a constricted point of the channel near the Kenosia Swamp sampling station and at the culvert of Rosy Tomorrow station.

(b) Measure and record the width of channel at 3 separate locations at Kenosia Swamp location; use 11 foot culvert width for Rosy Tomorrows.

(c) Measure and record the depth across channel at multiple locations (at the 3 intervals identified in b, above) at both stations and average the width.

(d) Measure the time of travel of a birdy placed in the stream (in seconds) from the upstream to the downstream points of the steam channel

(e) Quantify the flow by the following formula: (10 feet length) x average width in feet) / (travel time in seconds) / (1 minute/60 seconds)

(f) Measure and record replicate measurements of flow using A-V meter at replicate locations

(g) After sampling period, a decision will be made whether to use the manual **OR** the A-V meter measurement of flow for the sampling stations. If the A-V meter produces reasonably precise measurements, these data will be used and the 8/22 sampling data will be normalized using a ratio of the automated vs. manual measurements obtained on 8/23 and 8/29 for the 8/22 manual flow data.

3) Following streamflow measurements collect grab samples from both sampling stations and deliver to laboratory for analysis.

APPENDIX "C"

Field Work Summary (refer to qAPP for complete procedures).

Pre-Storm Set Up (triggered by weather watcher within 24hrs of event)

1. Items you should have when you leave WCSU:

Clear Sampling Hose w/ strainer and "big staple"
Charged Battery
Ice Packs
Field Journal
Key to Sampler Locks
Auto Sampler Quick Guide with GSS-GLS conversion codes inside
Automatic Rain Gauge (if not prev. deployed)

General Procedure:

2. Go to Rosy Tomorrows site and empty manual Rain Gauge

3. Go to Kenosia Swamp site and empty manual Rain Gauge

4. Install auto rain gauge

5. Install sampling hose to sampler and "staple" strainer end to stream bed

6. Install new battery in Sampler and bring old one back for charging

7. Verify program settings (GSS, Program, 0.5", one sample), run program

8. Empty sampler bottle.

9. Install Ice packs

10. Re-secure sampler.

11. Update Chain of Custody Form throughout process & Note in journal time/date/conditions when set up completed.

12. Put battery on charger in Lab.

Field Work Summary (refer to qAPP for complete procedures).

Sample Collection Event

1. Items you should have when you leave WCSU:

Grab Sampler Pole & Container
Sample Jars with system for labeling jars
Cooler with additional ice packs
Field Journal
Key to Sampler Locks
Custody Sheet
Funnel

General Procedure:

2. Go to Rosy Tomorrows within 12 hours after ½" of rain is estimated to have fallen. Lead sampler that week should coordinate with other team members when s/he will be at Rosy Tomorrows so one other team member can try to attend for safety/quality control (especially first few events).

3. Verify rain amount in manual rain gauge > ½" and record amount in field journal.

4. Grab samples at approximately 60% depth of stream.

5. Fill sample jars, label (RT##-*dd/mm/yy/time)*, and place in cooler.

6. Go to Kenosia Swamp and record rain gauge amount in journal.

7. Fill sample jars from sampler (use funnel) and label (KS##-dd/mm/yy/time) and place in cooler.

8. Remove sample tube, auto rain gauge, and icepacks. Power off sampler and secure.

9. Deliver samples to Lab or temporary refrigerator if needed. Prepare blank sample and label and deliver.

10. Update Chain of Custody Form throughout process & Note in journal time/date/conditions when sample completed.

11. Return equipment to lab and clean.

Water Education for Local Decisionmakers

Basic Information

Title:	Water Education for Local Decisionmakers
Project Number:	2010CT220B
Start Date:	3/1/2010
End Date:	2/28/2011
Funding Source:	104B
Congressional District:	2
Research Category:	Not Applicable
Focus Category:	Surface Water, Groundwater, Education
Descriptors:	None
Principal Investigators:	Glenn Warner, Patricia Bresnahan

Publications

There are no publications.

Project Scope and Objectives

In CT, water resources are increasingly being impacted by the results of decisions made at the local scale. Most local decision makers do not have a good understanding of basic hydrologic processes such as infiltration and ground water There is a need to educate local decision-makers about how their decisions affect water resources, e.g. the role of land use in controlling infiltration and therefore the amount of runoff.

In a recent unpublished study conducted by at the University of Connecticut in conjunction with the Connecticut Institute of Water Resources, a survey instrument was designed to assess local decision-maker's perceptions of the following topics: effects on water quality and quantity from municipal land use decisions, municipal land use decision maker's responsibility for types of land use decisions and what information is used in the municipal decision making process ("Perceptions of Effects of Land Use Decisions on Water Quality and Supply: A Survey of Municipal Decision Makers", Holly Drinkuth, May 11, 2009). The results of this study showed that "… participants believe the decisions they make or are involved in making have significant effects on water quality and supply in their communities, but there appears to be a disconnect between how they can implicitly exercise legal or advisory authority associated with their positions to positively affect or maintain water quality and water supply. This survey indicates that opportunities exist to assist municipal land use decision makers in better understanding their role in local and regional water quality and water supply. "

The purpose of this project is to define the key requirements of an education program that teaches local decision-makers in the state of Connecticut basic hydrologic principles and how land use decisions may change the hydrology, and to develop the core curriculum for that program. It is hoped that the planning information gained from this project will be used to assist stakeholders and potential implementers with formulating a strategy for developing a basic hydrology education program for local decision-makers and to advocate for funding of that program.

Key Tasks and Progress

The five major tasks of this project are listed below, and progress to-date is described. One Master's student in the Department of Natural Resources and the Environment, Marissa Theve, participated in developing the core curriculum, evaluating existing educational efforts, and exploring delivery methods and developing draft storyboards. In spring of 2010 a steering committee was formed consisting of interested representatives of agencies, the water industry, environmental groups and local decision-makers. The committee made many initial recommendations, and we will be following up with them as the project concludes.

To organize and share the curriculum and draft media, a "wiki" web site was developed. Although the original intent was to allow members of the steering committee to contribute actively if desired, in practice it has mainly been updated by CTIWR staff and the results shared with others as needed. The material currently on the wiki is still "work in progress, " but it can be accessed at: http://watereducation.wikispaces.com/message/list/space.menu

- **Target audience will be defined and described.** At the Spring 2010 steering committee, it was decided that the target audience for this program would be local planning and zoning officials, but that the content should also be appropriate for other types of local decision makers.

- **The major elements of the core curriculum will be developed**. Currently, there are four main content areas being developed on the wiki, however it is anticipated that these will eventually be broken into 6-10 teaching segments. The content areas are:
    - The Hydrologic Cycle. An overview of surface and groundwater, Connections in Connecticut, Landscapes, Precipitation, Evapotranspiration, Runoff, Infiltration and Percolation, Hydrologic balancing, and management implications
    - Watersheds. Topographics maps, delineating watersheds, watershed scale, watershed attributes (topography, size, land cover, percent water, boundaries), management implications
    - Surface Water. Streams and Rivers, base flow, stream order, flood plains, wetlands, surface water / ground water connectivity, management implications.
    - Ground Water. Groundwater in Connecticut, soil water, aquifers, wells, ground water / surface water connectivity, contamination, management implications
- **Existing water education efforts and curricula will be assessed.** An overview and discussion of other efforts that were evaluated are provided on the project wiki.
- **Recommended program delivery methods will be developed.** Several members of UCONN's Cooperative Extension group were consulted to get an understanding of the various current outreach efforts related to water education, and how this new effort might be developed to complement and not duplicate existing efforts. Topic discussed included:
    - Agencies and organizations
    - Personnel requirements
    - Distribution format
    - Educational materials

  A number of different distribution formats were discussed, including the development of online or downloadable content that might be used on a stand-alone basis by students working independently, or used in conjunction with a more formal lecture setting. It was felt that a number of key concepts might best be conveyed through the use of animations, and the potential use of FLASH animations was investigated.

- **Financial analysis.** This portion of the project has not yet been completed. Potential costs will be estimated for one or more recommended delivery methods. Funding sources and alternatives will be identified.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	0	1
Masters	4	0	0	0	4
Ph.D.	1	0	0	0	1
Post-Doc.	0	0	0	0	0
Total	6	0	0	0	6

Notable Awards and Achievements

Publications from Prior Years