# Institute of Water Resources
# Annual Technical Report
# FY 2003

## 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 Resource Management and Engineering, in the College of Agriculture and Natural Resources. The Institute is headed by a Director, Dr. Glenn Warner, and administered by an Associate Director, Dr. Patricia Bresnahan.

Although located at UCONN, the Institute serves the water resource community throughout the state. The foundation for this connection is its Advisory Board, whose compostion reflects the main water resource constituency groups in the state. IWR staff have also recently been participating in the activities of the statewide Water Planning Council, enabling the Institute to establish and maintain good working relationships with agencies, environmental groups, the water industry and water resource academics.

The majority of the Institute's 104 funds go to support research projects selected through a competitive RFP process, with small amounts set aside each year for information transfer projects. Submitted proposals are reviewed for technical merit by outside reviewers as well as by an ad-hoc technical review panel composed of qualified individuals from around the state. In addition, the Advisory Board reviews the proposals with respect to their relevance to state water needs and CT IWR priorities (student support, seed projects, new faculty).

## Research Program

The Connecticut Institute solicits proposals from all academic institutions within the state through its annual RFP. In response to the FY 2003 RFP we received seven proposals: five from UCONN researchers and two from outside institutions. After careful review by outside reviewers, an ad-hoc technical review panel and our Advisory Board, three were selected for funding: two from UCONN and one from Fairfield University. Two projects were funded for one year and one project was funded for two years.

In addition to its 104 activities, the CT IWR continued to administer the Fenton River Aquatic Study for the University of Connecticut, Department of Facilities. The project began November 1, 2002 and is scheduled to end December 32, 2004. The purpose of the study is to determine the potential impacts of withdrawals from the UCONN water supply wells that lie in the floodplain of the Fenton River on the flow and fisheries habitat in the Fenton. There are three components to the study: surface water flow in the Fenton and its tributaries, ground water levels in the alluvial aquifer adjacent to the river, and fisheries habitat and fish use of the Fenton. The study team consists of Fred Ogden (Civil and Environmental Engineering), Glenn Warner (Natural Resources Management and Engineering), Jeff Starn (USGS) Piotr Parasiewicz (UMASS), Ross Bagtzoglou (Civil and Environmental Engineering) and Rick Jacobson (Natural Resource Managment and Engineering & CT DEP). The surface-ground water interactions will be measured and mathematically modeled at different water levels. Fish habitat and fish use will be monitored and used to develop a PHABSIM model. Total study cost is $571,089. A Technical Advisory

Group, consisting of representatives from State and Federal agencies and environmental groups provides technical input to the study.

# Occurrence and Fate of Pharmaceuticals in the Pomperaug River

## Basic Information

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| **Title:** | Occurrence and Fate of Pharmaceuticals in the Pomperaug River |
| **Project Number:** | 2003CT23B |
| **Start Date:** | 3/1/2003 |
| **End Date:** | 12/31/2004 |
| **Funding Source:** | 104B |
| **Congressional District:** | 2nd |
| **Research Category:** | Water Quality |
| **Focus Category:** | Surface Water, Toxic Substances, Waste Water |
| **Descriptors:** | Contaminant transport, Drugs, Pharmaceuticals, Personal-care products, Trace organics, Wastewater, Water quality |
| **Principal Investigators:** | Allison Mackay, Allison Mackay |

## Publication

**Statement of Critical Regional or Water Problem:**

Pharmaceuticals and other compounds of wastewater origin have been observed throughout the US in surface waters impacted by urban activities. The presence of pharmaceuticals in aquatic environments is of concern because, even at ng/L levels, these molecules are biologically active and can affect critical development stages and endocrine systems of aquatic organisms. Current pharmaceutical fate studies have been survey-oriented, only documenting occurrence in a variety of environmental systems. Few data regarding temporal and spatial distributions, or environmental degradation rates of pharmaceuticals in surface waters have been collected. No such studies have been conducted to date in the US.

Environmental occurrence of pharmaceuticals is of particular concern in the Pomperaug River watershed. Here the primary source of pharmaceuticals inputs is a wastewater treatment plant that serves a retirement community of 5000 with an average of 6 medications per person. The treatment plant provides up to 20% of river flow and thus pharmaceutical impacts are expected to be greater in this watershed than the national average.

The objectives of this proposed study are to monitor the temporal and spatial distributions of pharmaceutical compounds introduced to the environment from a well-defined wastewater treatment plant discharge to a river. The specific tasks will include quarterly sample collection from the treatment plant influent and effluent, and at discrete locations downstream in the river channel. Observed concentrations in the river will be compared to predicted concentrations using a conservative transport model to: (1) identify pharmaceutical compounds with potential for ecotoxicological risk in this watershed, and (2) to estimate the magnitude of sink mechanisms for unconserved compounds.

**Methods, Procedures and Facilities:**

<u>Pharmaceutical Compounds</u>

The choice of pharmaceutical compounds to monitor must take into consideration usage and metabolism rates, the potential for toxicological impacts on non-target organisms and availability of analytical methods suitable to environmental samples. Nation-wide, the top 25 most prescribed drugs include lipid regulators, antihypertensives, hormone replacement therapies, beta-blocker and calcium channel blocker medications and anti-inflammatories [19]. All of these medications are typical of those expected to be used in a senior population.

Of the most widely prescribed drugs, the classes that are known, or strongly suspected, to have ecotoxicological risk are serotonin reuptake inhibitors (*e.g.*, fluoxetine) and beta-blockers (*e.g.*, fenfluramine). Direct toxicological evidence for induced spawning behavior in clams and feminization of crabs has been documented for fenfluramine and fluoxetine (Prozac), respectively, at environmentally relevant concentrations [1]. These induced behaviors arise because of common modes of drug action between humans and these non-target organisms [1].

Finally, the combined analytical advances in solid phase extraction techniques and mass spectrometry detection have pushed detection limits of over 125 pharmaceutical compounds below 0.05 μg/L in environmental samples [17, 18].

On the basis of usage, toxicity and our expertise with GC/MS techniques (see Analysis below), we will monitor estrogens, neutral pharmaceuticals (includes common lipid regulators clofibrate and fenofibrate, pschiatric drug diazepam, β-blockers metoprolol and terbutalin), and acidic drugs (includes anti-imflammatoryies naproxen, diclofenac). Additional pharmaceuticals that will also be isolated with the target analytes can be found in methods of Koplin *et al.* [17] and Ternes [18], and are omitted here for brevity. Usage information that is specific to the Southbury community, including Heritage Village, will be obtained from dispensing records from the local pharmacy and used to tune the final list of analytes.

<u>Sampling Locations and Protocol</u>

Quarterly sample collection will be conducted at the Heritage Water Treatment Plant and through the downstream reach of the Pomperaug River. The proposed sample dates are May, August, November 2003 and February 2004 to encompass relevant seasonal variations.

*Heritage Water Treatment Plant:* HWTP operates as a conventional activated sludge plant. Influent is coarsely screened, metered and then flows into one of four extended aeration tanks for removal of organic matter and nitrogen. Aeration is followed by clarification to remove biological solids. The clarified water is next chlorinated to deactivate pathogens. This step signifies the end of engineered treatments. The post-chlorination effluent is directed to one of two man-made ponds for dechlorination. These ponds operate as natural systems with no engineered controls. Finally, flow from these ponds discharges by open channel to the Pomperaug River. Average daily capacity of this plant is 0.4 MGPD.

Three sample points have been identified at the Heritage Water Treatment Plant: (1) influent, (2) post-chlorination, and (3) entry to the Pomperaug River. The intermediate sample location between the chlorination treatment and the dechlorination ponds was included to compare pharmaceutical removals in the engineered system with the natural pond system, and ultimately, with losses in the river system. Oral agreement to sample at this facility has been obtained at the time of this proposal submission (Ray Adamaitis, CT Water Company, personal communication).

*Pomperaug River:* The Pomperaug River is a third-order stream with typical median flows that range from 10 – 30 cfs, as measured at a USGS gauging station 890 m (0.56 mi) downstream of the HWTP discharge. The river reach between HWTP and the Housatonic River is 9700 m (6.1 mi) with only 2 minor brook inputs. Throughout this reach, the river channel is wadeable with a rocky bottom and steep banks, as is characteristic of Connecticut rift geology.

Samples will be collected for pharmaceutical analysis at 5 locations downstream from the HWTP discharge point (Figure 1). One sampling point will be coincident with the USGS gauging station where the most accurate calculations of relative wastewater and channel flow contributions to the Pomperaug River can be made. The other sample points are spaced approximately to a logarithmic scale to improve estimates of environmental degradation rates for the monitored analytes. All of the sample locations are bordered by properties that are town- or land trust-owned, and thus are accessible by the public. Sample locations may be modified to better capture dynamics of pharmaceutical concentrations based upon results of the May 2003 sampling event.

The HWTP has been identified as the sole point source of pharmaceutical compounds in the Pomperaug River. However, the high use of septic treatment systems throughout the watershed indicate that non-point sources of pharmaceuticals may also be introduced to the Pomperaug River through groundwater flows. Thus, a sixth river water sample will be collected 500 m upstream of the HWTP discharge point to assess background concentrations of pharmaceuticals that are transported into the study area by Pomperaug River flow.

Samples will be collected on a flow-corrected time schedule so that a single ‘packet’ of water is followed from the HWTP discharge. This technique will enable conversion of spatial variations in pharmaceutical concentrations to reaction time equivalents in a batch reactor, and hence meaningful estimates of pharmaceutical attenuation rates will be possible. Standard stream tracer techniques will be employed to delineate the fluid ‘packet’ using fluorescent rhodamine tracer [20]. To further verify channel dilution effects due to infiltration of groundwater, boron and chloride concentrations will be measured at the sample points. Boron is a common tracer of wastewater effluents [21]. Chloride concentrations in wastewater [50 – 90 mg/L, 21] are greater than in freshwater streams [~ 2 mg/L, 22], although other sources (*e.g.*, manure leachate) may contribute chloride to the Pomperaug River.

Samples for pharmaceutical analyses will be collected in clean 1-L polypropylene sample bottles. A total of 4 samples will be collected by immersion at each location. An additional 250 mL sample will be collected for analysis of conserved wastewater tracers in the Pomperaug River. Samples will be stored in a cooler for transport back to Storrs. Samples will be preserved by refrigeration at 4°C and extracted within 72 hours. A unique sample ID number will be assigned to each sample. All treatments will be documented in a bound log-book.

Where possible, river sediment grab samples will also be collected at the sample points during the November 2003 sampling trip. These samples will be extracted to give qualitative verification of whether sediments are important sinks for pharmaceuticals in this watershed. Sediment samples will be collected with a clean metal trowel, transferred to a polypropylene sample bottle and preserved by freezing (-20°C) until analysis.

Analytical

Pharmaceutical analyses in water samples will be conducted using published methods [17, 18]. The four 1-L samples from each location will be compositted and then split to quantify estrogenic pharmaceuticals, neutral pharmaceuticals and acidic pharmaceuticals. Appropriate recovery standards will be added to each sample to account for compound losses in sample analysis methods. Briefly, the method for each of the compound classes entails: (1) pharmaceutical extraction by passage through a solid-phase extraction column; (2) elution with appropriate solvent, and (3) addition of a derivatizing agent to increase pharmaceutical volatility. Slight differences in water pre-treatments, solvent types and derivatization conditions necessitate the use of 3 parallel analyses. Derivatized products will be quantified by gas chromatography (GC) with mass spectrometry (MS) detection (Shimadzu QP5050A GC/MS system available in PI’s lab). If interferences from wastewater constituents limit GC/MS detection for certain key samples, liquid chromatography (LC) with MS detection will be applied for quantification. LC/MS analysis is available from the Chemistry Department at UConn on a fee-per-sample basis.

A number of quality assurance/quality control (QA/QC) checks will be incorporated into the sample design. First, each sample trip will include trip blanks consisting of high purity water that is transferred to a sample container and transported to the sample site. Method blanks consisting of high purity water will be carried through all of the sample preparation and analysis steps. Method spikes will be prepared by adding pharmaceutical compounds to high purity water or samples of wastewater effluent and analyzed to assess compound recoveries. QA/QC checks will account for 10% of sample analyses with a minimum of one trip blank, one method blank and one method spike included in each sampling round. Prior to each sample trip, 2 of the 9 sample locations will be chosen randomly for obtaining duplicate samples.

Boron analyses will be conducted by inductively coupled plasma (ICP) spectrometry (for fee service available from Environmental Research Institute, UConn) and chloride concentrations will be quantified using an ion selective electrode.

Sediment samples will be analyzed using extraction techniques that are currently under development in our lab as part of a USDA-funded investigation of antibiotic fates in agricultural soils. Present sediment extraction techniques (*e.g.* EPA Method 3550) yield inadequate recoveries of polar pharmaceutical compounds; however, competitive displacement, pH and ionic strength adjustments are promising alternate approaches (MacKay, unpublished results).

In all sample analysis techniques, instruments will be calibrated with a 6-point calibration curve. Calibration standards will be run as unknowns every 8 analyses with acceptance criteria of ± 15%, or as determined in method development.

<u>Conceptual Modeling</u>

Ultimately, the results obtained in this study will be used to assess environmental degradation rates of pharmaceutical compounds. First, observed pharmaceutical concentrations in the Pomperaug River will be compared to expected concentrations given dilution effects of inflowing groundwater and minor stream contributions to the river channel. Dilution effects will be calculated from the stream tracer measurements using the added fluorescent tracer (dispersive mixing of sample packet) and the wastewater-derived boron and chloride tracers (fractional contribution of wastewater to total flow) using standard techniques [20]. Insignificant differences on a compound-by-compound basis between observed fluxes and calculated dilution-corrected pharmaceutical fluxes at each downstream sampling point indicate pharmaceutical compounds that undergo no transformations or have no significant loss mechanisms within this ecosystem. On the other hand, observed pharmaceutical fluxes that are lower than obtained solely by dilution will indicate that sinks for these compounds are important within the study reach.

Characteristic environmental degradation rates will be estimated for unconserved pharmaceutical compounds using a simple first-order loss model [20]. This quantitative approach will yield the first reported environmental degradation rate constants for compounds in the pharmaceutical class. However, this approach gives little insight into the exact mechanisms of loss since it quantifies the summative effect of multiple processes (*e.g.*, photodegradation, microbial degradation, sorptive uptake by sediments).

<u>Work Plan and Time Line</u>

PI Dr Allison MacKay will oversee this research project, providing guidance for analytical methods and QA/QC protocols. Sample collection and analysis, including method validation, will be conducted by graduate research assistant Ms. Raquel Figueroa. The following timeline marks milestones in project completion:

March 2003 – Method assessment and validation with genuine standards, preliminary dilution ratio characterization in river channel.

May 2003 – Spring sample collection and data analysis.

August 2003 – Summer sample collection and data analysis.

November 2003 – Fall sample collection and data analysis.

February 2004 – Winter sample collection and data analysis.

March 2004 – Presentation of results to Pomperaug River Watershed Coalition and manuscript preparation.

**Significant Findings and Results:**

We have requested a no-cost extension for CTIWR "Fate of Pharmaceuticals in the Pomperaug River" until Dec. 31, 2004. A no-cost extension is requested because field activities proposed in this grant could not be completed due to the unexpectedly high levels of precipitation in CT during Summer and Fall 2003. We intend to complete these activities in Summer and Fall 2004.

# Handheld Light Meters and Anion Exchange Membranes to Reduce the Threat of Water Pollution from Turfgrass Fertilizers

## Basic Information

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| **Title:** | Handheld Light Meters and Anion Exchange Membranes to Reduce the Threat of Water Pollution from Turfgrass Fertilizers |
| **Project Number:** | 2003CT24B |
| **Start Date:** | 3/1/2003 |
| **End Date:** | 3/1/2005 |
| **Funding Source:** | 104B |
| **Congressional District:** | 2nd |
| **Research Category:** | Water Quality |
| **Focus Category:** | Nitrate Contamination, Non Point Pollution, Nutrients |
| **Descriptors:** | nitrogen, fertilizers, water quality monitoring, water quality management, leaching, solute transport, plant growth, turfgrass management, ion exchange |
| **Principal Investigators:** | Karl Guillard, Karl Guillard |

## Publication


1. Mangiafico, S. S. and K. Guillard, 2004, Desorbed Nitrate from Anion Exchange Membranes as a Predictor of Nitrate Leaching and Turfgrass Color., in Agronomy Abstracts: Proceedings of the National Meeting of the American Society of Agronomy, Madison, WI.

Problem

Traditional agricultural crop production in southern New England has declined rapidly during the last 30 years. As urban and suburban development encroaches into rural landscapes, turf is replacing cropland as the principal managed land cover in the region. Although these areas are not regarded as agricultural cropland, they may receive comparable or greater amounts of fertilizers than are applied to cropland. Because a large land area devoted to fertilized turf (residential and commercial lawns, golf courses, athletic and recreational fields, sod farms) in Connecticut and other Eastern states is located adjacent to pond, lake, river, and coastal shorelines, N losses from turf may contribute significantly to the degradation of sensitive N-limited ecosystems when the total N load over a larger geographical area is considered. This is particularly critical for Connecticut coastal, bay, and estuarine ecosystems which have been documented as experiencing frequent hypoxia events attributed to nonpoint sources of nutrients. Despite concerns with nutrient losses from turf, there has been relatively little research and improvements in traditional fertilization practices of turfgrass in the past 30 years. There are no soil-based N tests currently used to guide N fertilization for turf, and only a few golf course superintendents use tissue N testing on a routine basis. The majority of turf managers and homeowners still rely on decades-old fertilization recommendations where N is applied on a schedule or at set rates based on history rather than being based on criteria of nutrient availability provided by an objective testing method like a soil test. This increases the likelihood of excess N applications that threaten water quality. Preliminary data from my laboratory suggest that handheld meters and anion exchange membranes (AEMs) have great potential in fine-tuning N management for turf. Establishment of a database utilizing tristimulus and reflectance meter readings and desorbed nitrate-N from AEMs will allow for the determination of optimum N fertilization to turf that will decrease the chances of excessive N fertilization that can cause pollution problems.

Research Objectives

- Determine the relationship between tristimulus and reflectance meter readings and turf color quality responses.
- Determine the relationship between soil nitrate-N (desorbed from anion exchange membranes) and turf growth and quality responses.
- Determine the relationship between tristimulus and reflectance meter readings and soil nitrate-N (desorbed from anion exchange membranes).
- Determine the relationship between soil nitrate-N (desorbed from anion exchange membranes) and nitrate leaching from turf.

Methodology

Field experiments were conducted at the University of Connecticut's Plant Science Research and Teaching Facility using established plots of Kentucky bluegrass managed as home lawns. Treatments consisted of nine N fertilization rates: 0, 5, 10, 20, 30, 40, 50, 75, and 100 kg N per hectare per month. Anion exchange membranes were inserted into each of the plots and replaced on two-week intervals to monitor soil nitrate dynamics *in situ*. A Minolta CR-200 tristimulus chroma meter and a Spectrum CM-1000 chlorophyll meter were used to determine hue angle (color), lightness (brightness of color), chroma (saturation of color), and relative chlorophyll content of the turf. Measurements of the turf included shoot growth (clipping yields), shoot density, color (hue, lightness, chroma), chlorophyll concentration, and total N concentration. These variables were correlated to meter readings and nitrate-N desorbed from AEMs. Plateau models were used to analyze the response curves resulting from these analyses to determine critical values for soil nitrate-N or meter readings needed for optimum responses (plateau values) of the dependent variables.

A soil monolith lysimeter experiment was conducted in a greenhouse and consisted of 64 undisturbed soil columns that were collected from a sod farm in Wethersfield, CT. The columns were seeded to a Kentucky bluegrass blend and fertilized with 16 rates of N: 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, and 100 kg N per hectare per month. Anion exchange membranes were inserted into each column and replaced on two-week intervals. A Minolta CR-200 tristimulus chroma meter and a Spectrum CM-1000 chlorophyll meter were used to determine turf color quality. The columns were irrigated weekly at a precipitation rate equal to the 30-yr normal weekly mean. The upper 2.5 cm of turf sod in the columns was removed after the natural growing season ended in November and irrigation was continued. This was done to prevent continual uptake of fertilizer N and allow for N to leach from the columns during a period of minimal turf growth, which would occur naturally during the winter and before regrowth in the spring. Percolate samples were collected weekly and analyzed for concentrations of $NO_3$-N. Nitrate leaching losses and meter readings were correlated to nitrate-N desorbed from AEMs. Plateau models were used to analyze the response curves resulting from these analyses.

<u>Principle Findings and Significance</u>

Results from the field study suggest that AEM desorbed $NO_3$-N can be used to predict a critical level needed for maximizing turf color quality characteristics (Fig 1). Greenness of the turf (CIE hue angle) and relative chlorophyll content (Spectrum units) were maximized at critical AEM desorbed $NO_3$-N value of approximately 3.5 $\mu$g/cm$^2$/day. Any further increase in available soil N did not increase turf greenness, but only increased the chance of N losses.

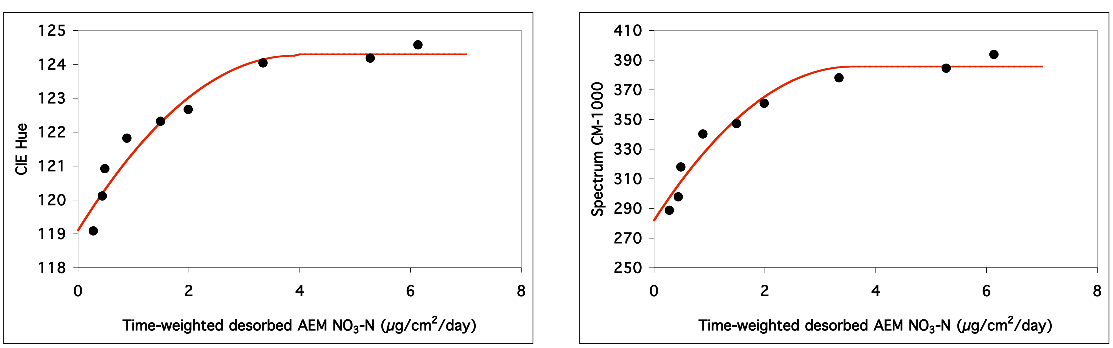


Fig 1. Relationship between soil nitrate-N desorbed from anion exchange membranes (AEMs) and CIE hue angle (greenness) and relative chlorophyll (Spectrum units) collected from a Kentucky bluegrass-perennial ryegrass-creeping red fescue lawn. Each data point represents the mean of four replications.

Preliminary results from the soil column study indicate that desorbed soil nitrate-N from AEMs has potential to accurately predict percolate nitrate-N concentrations and mass losses from turf (Fig. 2). The data indicate that percolate nitrate-N concentrations and mass losses will increase at an exponential rate with increasing N availability in the soil. The color quality of the turf canopy (as measured with a chlorophyll meter), however, did not increase past a critical level of nitrate desorbed from the AEMs (Fig. 3). The chlorophyll meter was useful as well in predicting N leaching losses in this study (Fig. 3). These data suggests that more N applied to turf only increases the probability of N loss, and does little to improve the color once a sufficient level of soil nitrate availability is reached.

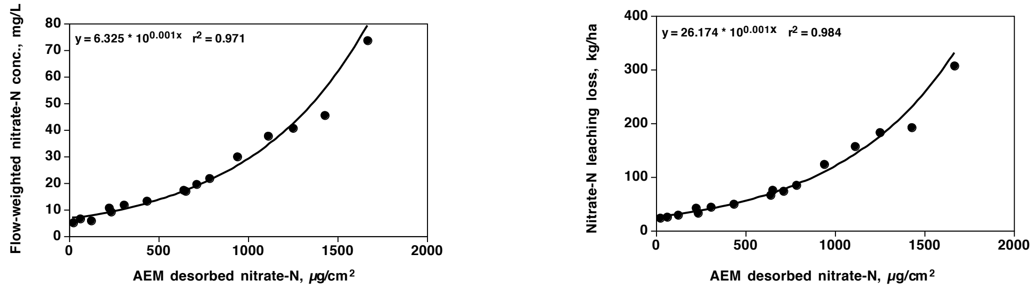


Fig 2. Relationship between soil nitrate-N desorbed from anion exchange membranes (AEMs) and flow-weighted nitrate-N concentrations and leaching losses of percolate collected from Kentucky bluegrass grown in soil columns. Each data point represents the mean of four replications.

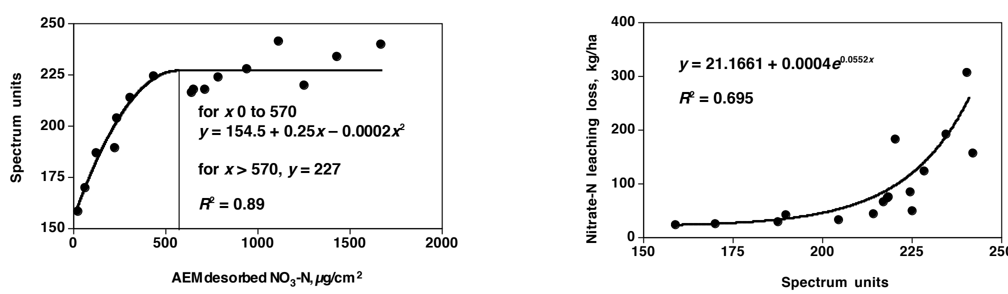


Fig 3. Relationship between soil nitrate-N desorbed from anion exchange membranes (AEMs) and turf chlorophyll content and nitrate leaching losses averaged across the experimental period in Kentucky bluegrass as measured with a Spectrum chlorophyll meter. The vertical line to the *x*-axis indicates the critical AEM value at which no statistical change in chlorophyll content is observed. Each data point represents the mean of four replications.

These preliminary results suggest that N management of turf can become less subjective and more reliable with the use of handheld reflectance meters and AEMs. This is a significant improvement over the current methods (visual or scheduled application rates) used for turf and marks an important step forward in turf nutrient management. In the absence of a quantitative method to indicate excess N availability for certain turf growth and quality measures, the likelihood of over-application of N increases. As more of the landscape in the Northeast and elsewhere is converted from farmland to suburban and urban use, nutrient management of turf will come more important because of water quality concerns.

# Effects of Variation in Nitrogen and Phosphorus Ratios and Concentrations on Phytoplankton Communities of the Housatonic River

## Basic Information

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| **Title:** | Effects of Variation in Nitrogen and Phosphorus Ratios and Concentrations on Phytoplankton Communities of the Housatonic River |
| **Project Number:** | 2003CT25B |
| **Start Date:** | 3/1/2003 |
| **End Date:** | 12/31/2004 |
| **Funding Source:** | 104B |
| **Congressional District:** | 4th |
| **Research Category:** | Water Quality |
| **Focus Category:** | Ecology, Nutrients, Water Quality |
| **Descriptors:** | algae, eutrophication, impoundments, nitrogen, nutrients, phosphorus, rivers, saline-freshwater interfaces, water chemistry, water quality |
| **Principal Investigators:** | Jennifer Klug, Jennifer Klug |

## Publication

## Problem and Research Objectives

One of the most serious threats to freshwater and marine ecosystems is an overabundance of nutrients, particularly nitrogen and phosphorus. These nutrients fuel high algal growth (blooms), leading to numerous other changes in aquatic systems. Surface blooms reduce light and nutrient availability to other algal species leading to lower algal diversity. When algae die, they provide an organic carbon source for bacteria. Bacterial decomposition consumes oxygen and in temperature or salinity stratified systems, bottom waters are depleted of oxygen. In addition, algal blooms impair recreation and may cause taste and odor problems in drinking water systems. The series of symptoms including high nutrient levels, high algal growth, and low oxygen concentration is called eutrophication.

Many freshwater and estuarine systems in Connecticut are highly eutrophic. The leading cause of eutrophication in estuarine systems is excess nitrogen, whereas the nutrient contributing to algal blooms in freshwater systems is typically phosphorus. Nitrogen and phosphorus enter freshwater and estuarine systems in many different chemical forms (dissolved vs. particulate and biologically available vs. biologically unavailable). Sewage treatment plants, runoff from urban and agricultural lands, storm sewer overflow, and atmospheric deposition are the main sources of nutrients in Connecticut. In order to comply with the Clean Water Act, Connecticut and New York, in collaboration with the Environmental Protection Agency, have implemented the Long Island Sound Study, which aims to improve the water quality of Long Island Sound by reducing nitrogen input. Under that plan, phosphorus is not targeted for reduction and many of the methods used to reduce nitrogen will not alter phosphorus concentration. Because nutrients enter Long Island Sound *via* rivers and streams, these freshwater systems are targets for reduction. A model has been constructed to predict how dissolved oxygen levels in Long Island Sound will change with particular reductions in nitrogen loading; however, it is not clear how the proposed management will affect algal growth in freshwater systems. This study addresses the impacts on freshwaters by assessing the effects of changing nitrogen and phosphorus ratios and concentrations on algal growth in the Housatonic River.

To begin to identify how nutrient concentration and N:P ratios impact the phytoplankton on the lower Housatonic River, I 1) Identified seasonality of phytoplankton and nutrient concentrations in the lower Housatonic River, 2) Identified areas of nitrogen vs. phosphorus limitation from upstream to the mouth of the Housatonic River, and 3) explored how changes in the nitrogen to phosphorus ratio (N:P ratio) in the Housatonic affect short-term phytoplankton growth.

## Methodology

The three objectives listed above were accomplished using two approaches. To identify seasonality in phytoplankton abundance, species composition, and nutrient concentration, I continued the monitoring program I began during Summer 2002. Phytoplankton biomass, species composition, concentrations of nitrate, ammonia, phosphate, total nitrogen, total phosphorus, secchi depth, temperature, salinity, conductivity, and oxygen were sampled monthly from May - September. Phytoplankton biomass was estimated using chlorophyll *a* concentration. Chlorophyll *a* concentration was quantified using the non-acidification fluorometric method of Welschmeyer 1994. Species composition was determined through microscopic examination of samples preserved in 1% gluteraldehyde. Nutrient concentrations were analyzed at the University of Connecticut Environmental Research Institute (protocols available upon request). Temperature, salinity, conductivity, and oxygen were measured in the field using a YSI meter.

To assess the degree of nitrogen vs. phosphorus limitation, standard nutrient bioassays were conducted at 5 sites starting at Lake Lillinonah and ending at the mouth of the Housatonic River. These sites included 1 freshwater impoundment, 1 site in the freshwater tidal portion of the Housatonic River, 2 sites at which salinity varies from ~5 ppt to 20 ppt, and a site in Long Island Sound. Bioassays were be performed early June, mid-July, and mid-late September to assess seasonal changes in nutrient limitation. Water and phytoplankton collected at each site were incubated in 4-liter plastic mesocosms at either ambient nutrient concentration, elevated phosphorus, elevated nitrogen, or elevated phosphorus and nitrogen concentrations. Because differences in herbivory between sites may bias the results, zooplankton were excluded from the experiments. Phytoplankton growth in each treatment was assessed by looking at changes in chlorophyll *a* concentration over 3 days.

To identify how changes in N:P ratio affect short-term phytoplankton growth and species composition, I conducted an experiment in Lake Lillinonah using 120 liter plastic limnocorrals. In this experiment, changes in dissolved nutrient concentration and phytoplankton species composition were monitored over the course of 13 days in treatments with different N:P ratios.

**Principal Findings and Significance**

Although the research supported by this grant is still ongoing, the results have been summarized in one invited research seminar and two poster presentations. Results from objectives 1 and 2 were presented in February 2004 at a seminar at the National Marine Fisheries Laboratory in Milford, CT and will also be presented as a poster at the Ecological Society of America Annual Meeting in August 2004. These results show that diatoms were one of the dominant taxa at all sites throughout the year. Other important taxa included cryptophytes (spring and fall in river sites) and euglenoids (summer in LIS). Phytoplankton in Long Island Sound were always strongly N limited and were co-limited by P in spring. In spring, phytoplankton in the upper river were P-limited. During low flow (summer), phytoplankton in the lower river were N limited. Phytoplankton in the middle reaches showed no evidence of N or P limitation. In general, periods of N or P limitation correlated with lower concentrations of nitrate or phosphate but not with changes in N:P ratio. These results suggest that decreases in N concentration should increase the prevalence of N limitation in the upper river which could alter species composition and nutrient export to LIS.

In April 2004, Sean Boyle and Cristina Worth (undergraduate biology majors supported off the grant) presented a poster entitled "Do Lake Lillinonah nuisance algal blooms fit the conceptual model?" at the Fairfield University Chapter of Sigma Xi's 3$^{rd}$ annual poster session. Lake Lillinonah phytoplankton are phosphorus limited all year and undergo a shift in species composition from a spring community dominated by diatoms and cryptophytes to a summer community dominated by dinoflagellates and cyanobacteria. Sean and Cristina's main conclusions were that Lake Lillinonah has less thermal stability, higher N:P ratios, and more Daphnia than many other lakes prone to cyanobacteria blooms and that reduction in nitrogen may increase the intensity of cyanobacteria blooms in Lake Lillinonah by reducing N:P. To avoid favoring the conditions of the cyanobacteria blooms, they suggest that both nitrogen and phosphorus should be reduced.

I am still analyzing the samples collected during the limnocorral experiment but preliminary results suggest that reducing the N:P ratio by reducing nitrogen loading to Lake

Lillinonah may increase the frequency of algal nitrogen limitation and favor dominance by nitrogen-fixing cyanobacteria.

# Development of Regionally Calibrated Land Cover Impervious Surface Coefficients

## Basic Information

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|---|---|
| **Title:** | Development of Regionally Calibrated Land Cover Impervious Surface Coefficients |
| **Project Number:** | 2002CT3B |
| **Start Date:** | 3/1/2002 |
| **End Date:** | 6/30/2003 |
| **Funding Source:** | 104B |
| **Congressional District:** | 2nd |
| **Research Category:** | Water Quality |
| **Focus Category:** | Methods, Models, Non Point Pollution |
| **Descriptors:** | Impervious Surfaces, Land Use, Nonpoint Source Pollution, Water Quality Modeling, Watershed Management |
| **Principal Investigators:** | Michael Prisloe, Michael Prisloe |

## Publication


1. Chabaeva, A., D. L. Civco and S. Prisloe, 2004, Development of a Population Density and Land Use Based Regression Model to Calculate the Amount of Imperviousness, in Proceedings of the 2004 ASPRS Annual Convention, Denver, CO, 9.
2. Chabaeva, A, Development of a Population Density and Land Use Based Regression Model to Calculate the Amount of Imperviousness, Masters Dissertation, Natural Resource Management and Engineering, University of Connecticut, Storrs, CT.

**Title:** Development of Regionally Calibrated Land Cover Impervious Surface Coefficients

**Principal Investigators**: Michael (Sandy) Prisloe and Daniel Civco, University of Connecticut

**Research Problem:** Nonpoint source pollution (NPS) has been cited as the nation's number one water quality problem and, in coastal areas, urban runoff is the pollutant of greatest concern (U. S. EPA, 1994). A number of researchers have found that the amount of urban runoff and its impacts on stream conditions and water quality are linked to the percent area of impervious surfaces within a watershed (Schueler, 1994; Arnold and Gibbons, 1996; Schueler, 2002). Research also indicates that the percent imperviousness threshold, above which impacts on stream health are noticeable, is quite low, being around 10 percent or less (Schueler, 1994).

Limiting the amount of impervious surface in a watershed is an important component of overall watershed management. Water resource and land use managers need to be able to determine the existing percent imperviousness in order to develop appropriate watershed management and/or NPS mitigation plans. While much research has focused on determining the relationship between watershed impervious surface coverage and water resource impacts, little work has been done to develop methods to measure impervious surfaces at the watershed scale (Cappiella and Brown, 2001). Past efforts to determine watershed imperviousness have been hampered by inconsistent methods and outdated or unavailable data. There is a need for easy to use tools to calculate watershed imperviousness that use well-documented methods and that achieve an acceptable level of accuracy.

**Methods and Procedures**: The study design originally specified that coefficients would be developed using data from a number of regions throughout the country; however, acquiring adequate numbers of high quality datasets turned out to not be possible. Therefore, the PIs used calibration and validation data for municipalities in Connecticut, Massachusetts and New York: Groton, Marlborough, Milford, Stonington, Stamford, Suffield, Waterford, West Hartford and Woodbridge in Connecticut, Amherst in Massachusetts, and North Castle and Mount Vernon in New York. The municipalities vary from rural to highly urbanized and represent a good cross section of development patterns within the study area.

Data required for the development of the model included: planimetric impervious feature data for calibration and validation, land use and land cover data, and population (density) data. Further, initial analyses were bounded by US Census Bureau Tracts, and subsequently were extended to watershed units. Census tract boundaries, which include many positional inaccuracies, were edited as described below.

The digital planimetric data generally were circa 1995; however some municipal datasets were a year or two older and several were more recent. These data represent the footprint of impervious surface features within the study area.

There are two major groups of features that can be labeled as impervious: rooftops and the various components of the transportation system. Structures such as buildings, pools and patios fall within the rooftop component of imperviousness. Roads, sidewalks, driveways and parking lots are included in the transportation system. Features such as rock outcrops and barren lands that are not anthropogenic, but still can be considered as impervious surface, were not included in the analysis.

National Land Cover Data (NLCD) were obtained from the United States Geologic Survey (USGS), and were chosen because of their nationwide availability, thereby enabling the geographic extension of the model under development to parts of the country other than the Northeast. Once processed, this data set had a resolution of 100 by 100 feet. NLCD contains 22 land cover categories, 17 of which were present in the area of study.

Digital 1990 Census tract boundaries for Connecticut, Massachusetts and New York and Population data for the 1990 census tracts in each state were obtained from the U.S. Census Bureau web site. The municipal boundary data for Connecticut were downloaded from the Map and Geographic Information Center (MAGIC) at University of Connecticut. Watershed data were acquired from the Connecticut Department of Environmental Protection.

Where necessary, the boundary for each municipality was edited to exclude significant areas of water. This applied especially to those municipalities bordering Long Island Sound and to those that had a large river within or bounding the municipality.

Considerable editing was done to the Census tracts. Tract boundaries were adjusted to match road centerlines, municipal boundaries and waterbody shorelines as depicted on the municipal planimetric data and the edited municipal boundaries datasets. These edits were necessary to insure that tracts could be overlaid accurately with planimetric and other digital datasets.

The NLCD data were downloaded in a *grid* format from the USGS, and were subsequently converted into an ESRI shapefile with ArcView version 3.2 and the Spatial Analyst Extension using a simple Avenue script. (Note: the script used a "no weed" option that preserved grid edges.) NLCD shapefiles were then clipped to the boundary of each municipality. Each polygon contained information on the area of NLCD classes present.

All planimetric feature datasets were in ESRI shapefile format and contained polygons assigned to a single impervious class regardless of the original impervious feature class (*e.g.* building, driveway, parking lot, etc.). All the impervious feature shapefiles were clipped with the appropriate town boundary.

Population density in people per square mile was calculated from the Census Bureau 1990 population tables using the edited area of each tract within the study municipalities.

A watershed dataset was created to eliminate large out-of-state watersheds that had only a small area within Connecticut. Only watersheds, which had their center within the boundary of the state, were selected from the Connecticut watershed dataset.

Land use specific impervious surface coefficients were derived using a method developed at the University of Connecticut. NLCD shapefiles for each tract were combined with the planimetric data using ArcView's Geoprocessing *Union* operation. This resulted in a new shapefile where each polygon had two values: NLCD class and a binary value to indicate if the polygon was impervious or not. For each tract, two frequency tables were created using XTOOLS, an ArcView Extension developed by the Oregon Department of Forestry[1]: (1) the sum of the area of each land cover class, and (2) the sum of the impervious surface area for each land cover class. The tables were exported to Excel and impervious surface coefficients, which are the percent area of each land cover class that is covered with impervious features, were calculated using the following formula:

$$LULCcoefficient = \frac{LULC_{ISarea}}{LULC_{Area}} \cdot 100\%,$$

where $LULC_{ISarea}$ is the total area of impervious surface for the NLCD class, and $LULC_{Area}$ is the total area for the same NLCD class.

This procedure was repeated for each of the 108 tracts within the study area, resulting in a database containing the total area of the tract, the percent impervious surface area of the tract, the area of each land cover category within each tract and its calculated impervious surface coefficient. The Census tract 1990 population density data were added to the database. The percent impervious surface for each tract was plotted with the population density data (Figure 1). The strong positive relationship between percent IS cover and population density is well illustrated, especially for lower densities and levels of imperviousness. The inclusion of a land cover variable will serve to strengthen this relationship.

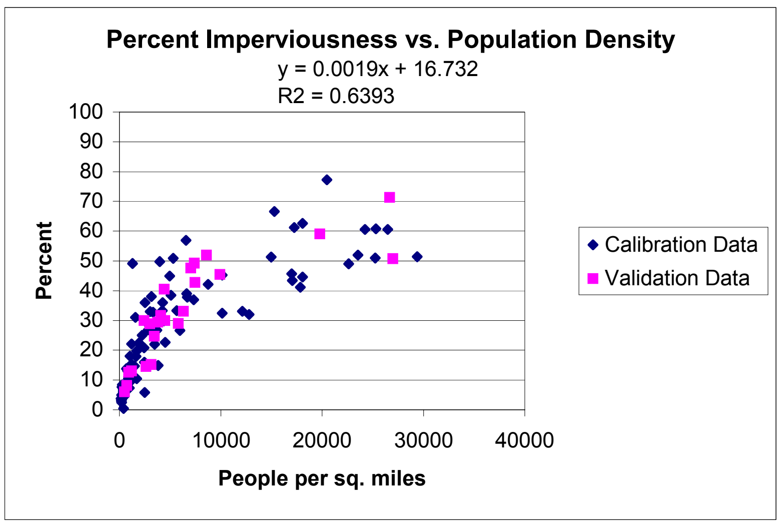


**Figure 1.** Population Density vs. Percent Imperviousness

[1] http://www.odf.state.or.us/DIVISIONS/management/state_forests/XTools.asp

The JMP Statistical Discover Software[2] was used to create a regression model for calculating the amount of imperviousness. There were 17 variables used for the *Fit Model* application of JMP: population density and the percentage of each land use land cover class per tract. Due to the non-linear nature of the data, land use percentages were transformed with the square root of this value and population density was transformed to its $Base_{10}$ logarithm. Eighty percent of the tracts were randomly selected from the sample, upon which multivariate statistical analysis was applied and a regression equation derived. The remaining tracts were used for the testing and validation.

**Significant Results**: The regression analysis resulted in a set of coefficients that predicts, at the tract level, percent imperviousness as a function of population density and percent coverage of the NLCD land use types (Table 1). The Fit Model automatically omitted from the regression formula several of the NLCD classes due to their statistical insignificance. Of the 17 NLCD land cover classes found in the study areas, 10 were observed to be significant contributors. They are listed in Table 1.

| **Variable Description** | **Variable** | **Coefficient** |
|---|---|---|
| Intercept | $b_1$ | 1.61051845 |
| Population Density | PopDen | 0.93584385 |
| High Intensity Residential | $A_{22}$ | 0.20444150 |
| Commercial/Industrial/Transportation | $A_{23}$ | 0.28746228 |
| Bare Rock/Sand/Clay | $A_{31}$ | -0.20257370 |
| Deciduous Forest | $A_{41}$ | -0.26362550 |
| Evergreen Forest | $A_{42}$ | -0.20714210 |
| Shrubland | $A_{51}$ | 1.18131149 |
| Orchards/Vineyards/Other | $A_{61}$ | 1.87563299 |
| Pasture/Hay | $A_{81}$ | 0.17330553 |
| Row Crops | $A_{82}$ | -0.47697190 |
| Emergent Herbaceous Wetlands | $A_{92}$ | -0.22767610 |

**Table 1.** Regression model coefficients.

These coefficients can be used in a regression model that was created based on the classical linear regression and can be described by the following equation:

$$\text{Percent of Imperviousness} = b_1 + b_2 \cdot \lg PopDen + b_3 \cdot \sqrt{\%A_{22}} + b_4 \cdot \sqrt{\%A_{23}} + \ldots + b_{19} \cdot \sqrt{\%A_{92}}$$

where $b_1$, $b_2$, $b_3$, … $b_{19}$ are the regression coefficients, *PopDen* is the Population density and $\%A_{22}$, $\%A_{23}$, $\%A_{31}$,…$\%A_{92}$ are the percent of the NLCD category area within the tract. This regression equation was tested on the remaining 20 percent of the tracts. The comparison of the regression model results with the actual impervious surface area measured from planimetric data for each tract yielded an $R^2$ of 0.95 and an RMSE of less

[2] http://www.jmp.com/

than 6%, when applied to validation data. The model then was applied to all the tracts and the actual and predicted values of imperviousness were compared. This resulted in an overall RMSE of 4.

To test further the impervious prediction model, a procedure was developed to apply it at the watershed-level, a common and meaningful resource management unit. For Connecticut, there are 6,711 watersheds ranging in size from 0.4 to 13481 acres, with an average size of 474 acres. To apply the regression model, we required the area of each NLCD class within each watershed and a population density value. Calculating NLCD class areas was done in the same manner as was done for the Census tracts, as previously described. However, it was necessary to develop a methodology to approximate population density for each watershed. Census block and population data for 2000 were used to calculate the population density at the block level. The Census block boundaries then were converted to a grid format having the same origin, grid cell size and extent as the NLCD data and the population density values were saved as grid cell values. The ArcView Spatial Analyst Extension was used with the gridded Census block population density data summarized over the zones defined by the areal extent of each watershed. Watersheds that fell completely within study municipalities for which we had planimetric impervious feature data were selected and the actual percent impervious surface area within these watersheds was calculated.

The Census tract based regression model was applied to all the watersheds and the percent impervious surface area for each watershed was calculated and plotted (Figure 2).

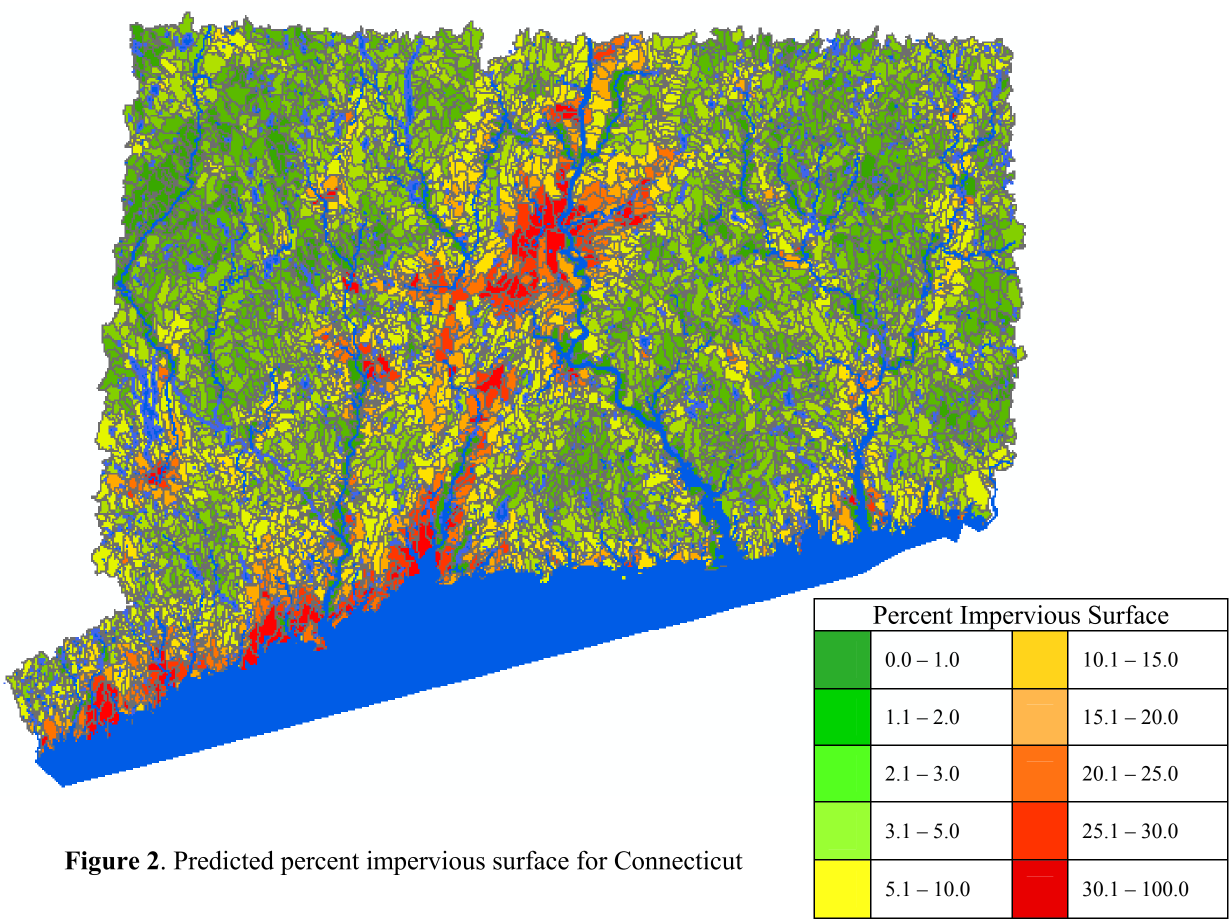


**Figure 2**. Predicted percent impervious surface for Connecticut

The results of the regression model were compared to the actual percent impervious surface area for the 236 watersheds for which we had complete coverage with planimetric data (Figure 3). The RMSE was less than 4% and many watersheds were within 1% to 2% of the actual value.

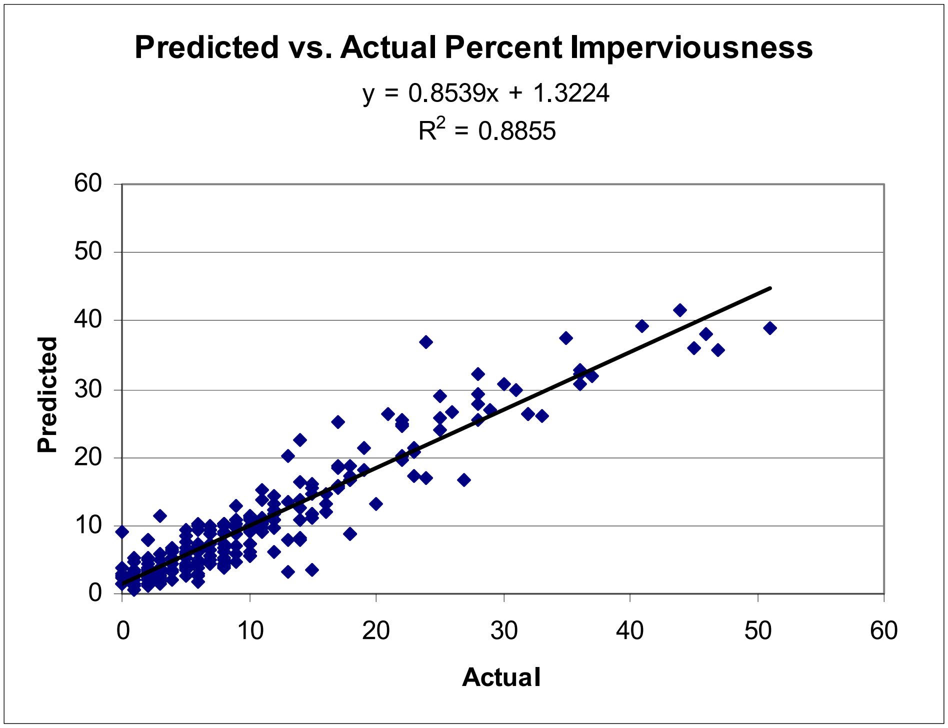


**Figure 3.** Predicted vs. actual percent imperviousness for Connecticut watersheds.

**Project Status:** The project has been completed.

# Information Transfer Program

The Connecticut Institute information transfer program consists of five main components: 1) funded IT projects, 2) seminar series, 3) web site, 4) publications and 5) conferences and workshops. In FY 2003-2004, the main emphasis was on web development, the Digital Archives project, and a special report on historical rainfall patterns in the state. These activites were conducted under our Water Resources Technology Transfer Initiative project, described below.

In addition to our 104B supported activities, Pat Bresnahan has been awarded a contract to work with the statewide Aquatic Nuisance Species Workgroup on developing a management plan for the State of Connecticut. Her role is to synthesize and manage the material contributed by workgroup members, and prepare the final document for review. Once the plan is approved by the State and the Federal ANS Taskforce, Connecticut will become eligible for federal funds for ANS research, education, prevention and management projects.

# Water Resources Technology Transfer Initiative

## Basic Information

| | |
|---|---|
| **Title:** | Water Resources Technology Transfer Initiative |
| **Project Number:** | 2002CT5B |
| **Start Date:** | 3/1/2002 |
| **End Date:** | 2/28/2005 |
| **Funding Source:** | 104B |
| **Congressional District:** | 2nd |
| **Research Category:** | Not Applicable |
| **Focus Category:** | Water Quality, Water Supply, Water Use |
| **Descriptors:** | |
| **Principal Investigators:** | Glenn Warner, Pat Bresnahan |

## Publication


1. Advisory Committee on Potential Best Management Practices for Golf Course Water, 2001, Report of the Advisory Committee on Potential Best Management Practices for Golf Course Water, CT Institute of Water Resources, Storrs, CT, 75p.
2. Miller, D. R., G. S. Warner, F. L. Ogden and A. T. DeGaetano, 2003, Precipitation in Connecticut, CT Institute of Water Resources, Storrs, CT, 66p.

## Purpose

The WRTTI is an “umbrella” project that encompasses the information transfer activities conducted by the Institute, beyond those supported through individual PI 104B projects.

## FY 2003-2004 Activities

### 1. Seminar Series.

Two seminars were held in FY 2003-2004:

“The Connecticut Drought Management Plan,” presented by Sid Albertsen, Planning Specialist, Policy Development and Planning Division, Office of Policy and Management.

“Public Water Systems: The Effect of Rates on Demand,” presented by Dr. Julie Hewitt, Economist, National Center for Environmental Economics, U.S. Environmental Protection Agency.

### 2. Report: Precipitation in Connecticut

This report was initiated at the request of the CT DEP, and was developed by a team of UCONN and other researchers. It presents descriptions of the occurrence and distribution of precipitation in Connecticut determined from analyses of long-term records at weather stations, using 100 years of data.

### 3. Digital Archives Project.

The Connecticut Institute partnered with the UCONN library in having our Special Reports series professionally scanned, archived, and installed on the UCONN library web server. This not only preserves the information for future generations, but also makes the content more widely and easily disseminated. Links to each report are available both on the CTIWR web site (http://www.ctiwr.uconn.edu) and the through the library. Appropriate metadata has been developed for each report, enabling the series to be catalogued and accessible through standard online, searchable databases. The library has expressed an interest in working with other NIWR Institutes in our region on similar projects.

### 4. Web site development.

The importance of the CT IWR web site to the mission of our Institute continues to grow as our expertise evolves and our collection of information in electronic format expands. In the process of collecting information in electronic format for the NIWR web, we have started to develop our own internal ACCESS database. We will gradually be adding historical project and other institute information to the database, and making it available through our web. In FY 2003, the web site was maintained by a graduate student supported through the WRTTI project.

# Student Support

| Student Support | | | | | |
|---|---|---|---|---|---|
| **Category** | **Section 104 Base Grant** | **Section 104 RCGP Award** | **NIWR-USGS Internship** | **Supplemental Awards** | **Total** |
| **Undergraduate** | 3 | 0 | 0 | 0 | 3 |
| **Masters** | 3 | 0 | 0 | 0 | 3 |
| **Ph.D.** | 1 | 0 | 0 | 0 | 1 |
| **Post-Doc.** | 0 | 0 | 0 | 0 | 0 |
| **Total** | 7 | 0 | 0 | 0 | 7 |

# Notable Awards and Achievements

# Publications from Prior Projects

1. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Bean, J., B. Branco and T. Torgersen, 2002, Energy Budgets and Pond Stratification Controls: An Undergraduate Study, in Spring Meeting, AGU, Washington, DC.
2. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Branco, B. and T. Torgersen, 2000, Detention Pond Multi-Scale Chemo-Dynamics, in Fall Meeting of the AGU, San Francisco, CA.
3. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Branco, B., T. Torgersen and J. Bean, 2002, Real-Time in Situ Monitoring of Coupled Dynamics in Ponds, in Spring Meeting, AGU, Washington, DC.
4. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Torgersen, T. and B. M. Kennedy, 2000, Noble Gas Processes and Components in Hydrocarbon Fluids (Invited)., in Fall Meeting, AGU, San Francisco, CA.
5. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Torgersen, T., B. Branco and J. Bean, 2002, Assessing Chemical Retention Process Controls in Ponds: Real-Time in Situ Monitoring of Coupled Dynamics in Ponds., in Spring Meeting, AGU, Washington, DC.
6. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Torgersen, T., J. Bean, B. Branco and S. Auer, 2003, Bloom Coupling with the Biological, Chemical and Physical Dynamics of a Small Pond Observed with an in Situ Profiler, in ASLO Meeting, Salt Lake City, UT.
7. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Young, M., M. Wlodarczyk and T. Torgersen, 2002, An Ecological Psychology Framework for Customizing Anchored Instruction with Real-Time Authentic Data, in AERA Annual Meeting, New Orleans, LA.
8. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Conference Proceedings - Young, M., M. Wlodarczyk and T. Torgersen, 2002, Gee-Wis Anchored Problem Solving Using Real-Time Authentic Water Quality Data, in Spring Meeting, AGU.
9. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Articles in Refereed Scientific Journals -

Torgersen, T., B. Branco and J. Bean, (In Press), Chemical Retention Processes in Ponds, Environmental Engineering Science.

10. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Articles in Refereed Scientific Journals - Torgersen, T., B. Branco and J. Bean, (Submitted), Environmental Process Analysis, Journal of Geoscience Education.
11. 2000CT2B ("Internal Phosphorous Loading in Ponds") - Articles in Refereed Scientific Journals - Torgersen, T., B. Branco, J. Bean and R. Sytsma, (Submitted), Environmental Process Analysis, 1: Residence Time and First Order Processes, Journal of Geoscience Education.
12. 2000CT5B ("A Study of Vernal Pool Ecosystems in Southern New England") - Conference Proceedings - Jokinen, E. J., 1998, Invertebrate Community Structure in Vernal Pools, in Our Hidden Wetlands, The Proceedings of a Symposium on Vernal Pools in Connecticut., Center for Coastal and Watershed Systems of the Yale University School of Forestry and Environmental Studies and the Wetland Management Section of the CT DEP, New Haven, CT, 6-8.
13. 2000CT5B ("A Study of Vernal Pool Ecosystems in Southern New England") - Conference Proceedings - Pyle, C., 1998, Vernal Pool Ecosystems; Similarities and Differences at What Scale?, in Our Hidden Wetlands, The Proceedings of a Symposium on Vernal Pools in Connecticut, Center for Coastal and Watershed Systems of the Yale University School of Forestry and Environmental Studies and the Wetland Management Section of the CT DEP., New Haven, CT, 9-11.
14. 2000CT5B ("A Study of Vernal Pool Ecosystems in Southern New England") - Other Publications - Jokinen, E. J., J. Morrison and E. Kosnicki, 1998, Animal Community Structure and Succession in Ten Vernal Pools in Southern New England, (In Preparation).
15. 2000CT5B ("A Study of Vernal Pool Ecosystems in Southern New England") - Dissertations - Kosnicki, E., 2001, Aspects of the Life History of the Mayfly Siphlonurus Typicus (Ephemeroptera: Siphlonuridae) Occurring in Two Connecticut Temporary Ponds, Masters Dissertation, Natural Resource Management and Engineering, University of Connecticut, Storrs, CT, 65.
16. 2000CT6G ("An Assessment of the Transferability of Habitat Suitability Criteria for Brown Trout in Southern New England Streams") - Conference Proceedings - Strakosh, T. and R. M. Neumann, 2000, Development and Assessment of Habitat Suitability Criteria for Brown Trout in a Southern New England River., in Southern New England Chapter, American Fisheries Society, Winter Meeting.
17. 2000CT6G ("An Assessment of the Transferability of Habitat Suitability Criteria for Brown Trout in Southern New England Streams") - Articles in Refereed Scientific Journals - Strakosh, T., R. M. Neumann and R. A. Jacobson, 2001, Development of Habitat Suitability Criteria for Adult Brown Trout in a Southern New England River Asn Assessments of Transferability, in Annual Meeting, Kansas Chapter, American Fisheries Society, Pittsburg, Kansas.
18. 2000CT6G ("An Assessment of the Transferability of Habitat Suitability Criteria for Brown Trout in Southern New England Streams") - Articles in Refereed Scientific Journals - Strakosh, T., R. M. Neumann and R. A. Jacobson, 2003, Development and Assessment of Habitat Suitability Criteria for Adult Brown Trout in Southern New England Rivers, Ecology of Freshwater Fish, 12, 266-274.
19. 2000CT6G ("An Assessment of the Transferability of Habitat Suitability Criteria for Brown Trout in Southern New England Streams") - Water Resources Research Institute Reports - Strakosh, T. and R. M. Neumann, 2001, Final Report: Development of Habitat Suitability Criteria (Hsc) for Adult Brown Trout and Assessment of Hsc Transferability between Southern New England Rivers., CT Institute of Water Resources, Storrs, CT.
20. 2000CT6G ("An Assessment of the Transferability of Habitat Suitability Criteria for Brown Trout in Southern New England Streams") - Other Publications - Strakosh, T., R. M. Neumann and R. A. Jacobson, 2001, Development of Habitat Suitability Criteria (Hsc) for Adult Brown Trout and Assessment of Hsc

Transferability between Southern New England Rivers., CT Department of Environmental Protection, Fisheries Division, Hartford, CT.

21. 2000CT6G ("An Assessment of the Transferability of Habitat Suitability Criteria for Brown Trout in Southern New England Streams") - Dissertations - Strakosh, T., 2000, Development and Assessment of Habitat Suitability Criteria for Adult Brown Trout in Southern New England Streams, Masters Dissertation, Natural Resource Management and Engineering, University of Connecticut, Storrs, CT, 51.
22. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Conference Proceedings - Chandran, K. and B. F. Smets, 2004, Biokinetic Characterization of the Acceleration Phase in Autotrophic Ammonia Oxidation., in WEFTEC 2004, 77th Annual Conference & Exposition, New Orleans, LA.
23. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Conference Proceedings - Chandran, K., Z. Hu and B. F. Smets, 2001, Optimal Experimental Design for Estimating Ammonia and Nitrite Oxidation Biokinetics from Batch Respirograms, in 74th Annual Water Environment Federation Conference, Atlanta, GA.
24. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Conference Proceedings - Chandran, K., Z. Hu and B. F. Smets, 2004, Applicability of an Extant Batch Respirometry Assay in Describing Dynamics of Ammonia and Nitrite Oxidation in a Nitrifying Bioreactor., in WEFTEC 2004, 77th Annual Conference and Exposition, New Orleans, LA.
25. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Conference Proceedings - Hu, Z., K. Chandran, B. F. Smets and D. Grasso, 2001, Evaluation of Nitrification Inhibition by Heavy Metals Nickel and Zinc, in 74th Annual Water Environment Federation Conference, Atlanta, GA.
26. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Conference Proceedings - Hu, Z., K. Chandran, D. Grasso and B. F. Smets, 2002, A Comparative Study of Nitrification Inhibition by Heavy Metals: The Influence of Metal Exposure Time on Biological Effect, in 8th Annual Industrial Waste Technical and Regulatory Conference, Atlantic City, NJ.
27. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Articles in Refereed Scientific Journals - Hu, Z., K. Chandran, D. Grasso and B. F. Smets, (Accepted for Publication), Comparison of Nitrifiaction Inhibition by Metals in Batch and Continuous Flow Reactors, Water Research.
28. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Articles in Refereed Scientific Journals - Hu, Z., K. Chandran, D. Grasso and B. F. Smets, 2002, Effect of Nickel and Cadmium Speciation on Nitrification Inhibition, Environmental Science and technology., 36, 3074-3078.
29. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Articles in Refereed Scientific Journals - Hu, Z., K. Chandran, D. Grasso and B. F. Smets, 2003, Impact of Metal Sorption and Internalization on Nitrification Inhibition, Environmental Science and technology., 37, 728-734.
30. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Articles in Refereed Scientific Journals - Hu, Z., K. Chandran, D. Grasso and B. F. Smets, 2003, Nitrification Inhibition by Ethylenediamine-Based Chelating Agents., Environmental Engineering Science, 20, 219-227.
31. 2001CT621B ("Development of Predictive Tools to Infer Inhibition of Biological Nitrogen Removal

at POTWs vi Long Term Bench-Scale and Full-Scale Monitoring") - Dissertations - Hu, Z., 2002, Nitrification Inhibition by Heavy Metals and Chelating Agents., Ph.D. Dissertation, Environmental Engineering, University of Connecticut., Storrs, CT.

32. 2001CT721B ("A Characterization of the Discontinuous Nature of Kriging Digital Terrain Models") - Conference Proceedings - Meyer, T. H., 2003, The Discontinuous Nature of Kriging Interpolation for Digital Terrain Modeling, in Proceedings of the ACSM Annual Conference, Phoenix, AZ.
33. 2001CT721B ("A Characterization of the Discontinuous Nature of Kriging Digital Terrain Models") - Articles in Refereed Scientific Journals - Meyer, T. H., (In Review), The Discontinuous Nature of Kriging Interpolation for Digital Terrain Modeling, Journal of Cartography and Information Science.
34. 2001CT741B ("A Tracer Dilution Method for Deriving Fracture Properties in Crystalline Bedrock Wells") - Conference Proceedings - Brainerd, R. and G. A. Robbins, 2002, A Stepwise Discharge Tracer Dilution Method for Deriving Fracture Properties in Crystalline Bedrock Wells, in Geological Society of America, Northeastern Section Meeting, Springfield, MA.
35. 2001CT741B ("A Tracer Dilution Method for Deriving Fracture Properties in Crystalline Bedrock Wells") - Articles in Refereed Scientific Journals - Brainerd, R. and G. A. Robbins, (In Press), A Tracer Dilution Method for Fracture Characterization in Bedrock Wells, Ground Water.
36. 2001CT741B ("A Tracer Dilution Method for Deriving Fracture Properties in Crystalline Bedrock Wells") - Dissertations - Brainerd, R., 2002, A Stepwise Discharge Tracer Dilution Method for Deriving Fracture Properties in Crystalline Bedrock Wells, Masters Dissertation, Dept. Geology and Geophysics, University of Connecticut, Storrs, CT, 162.
37. 2002CT2B ("Water Quality Assessment in Connecticut: Evaluation of Current Protocols and Development of Improved Methods") - Dissertations - Threadgill, M., 2003, Monte Carlo Analysis of High-Resolution Bacterial Water Sampling Data, Masters Dissertation, Yale School of Forestry and Environmental Studies, Yale University, New Haven, CT.
38. 2002CT2B ("Water Quality Assessment in Connecticut: Evaluation of Current Protocols and Development of Improved Methods") - Dissertations - Van Duzer, G., 2003, Temporal Variability in Bacterial Indicators and Water Quality in the Quinnipiac River, Ct, Masters Dissertation, Yale School of Forestry and Environmental Studies, Yale University, New Haven, CT.