Connecticut Institute of Water Resources
Annual Technical Report
FY 2005

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. Our seminar series, a long-standing Connecticut IWR tradition, provides a unique 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.

Research Program

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 seek out and facilitate projects funded through other sources.

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 research, the CT IWR this year concluded a three-year, $571,000 study of the Fenton River, funded through the University of Connecticut's department of facilities and administration. This integrated study analyzed the impact of the University of Connecticut water supply wells near the Fenton River on flow in the river and the resulting impacts on the fisheries community. Components of the study included: measurement of discharge in the Fenton River and major tributaries above and below the wells, monitoring of the groundwater levels at various depths and distances from the supply wells, modeling of both ground water and surface water flows, evaluation of stratification in the valley by geophysical techniques, monitoring of fish species in different geomorphological river units, and modeling of changes in fish habitat under various flow regimes. The study was administered through the CT IWR under the direction of Glenn Warner and Fred Ogden, and involved faculty and students from the Departments of Natural Resources Management and Engineering and Civil and Environmental

Engineering and cooperators from the USGS and the University of Massachusetts. The final report is listed on the Institute’s web site (www.ctiwr.uconn.edu), under the "Special Reports" section. Results of this study were also presented in a series of seminars sponsored by our Institute.

With its 104B funds, the Connecticut Institute funded one new project (D. Skelly, Yale), provided second year funding for two previosly funded projects (A. Bagtzoglou, UCONN and D. Post, Yale) and a small amount of funds for some additional sampling for an existing project (G. Robbins, UCONN). Other projects listed in this annual report are included because their project deadlines were extended into the reporting period, but they received no additional funds in FY 2005-2006.

Chaotic Advection Enhanced Remediation

Basic Information

Title:	Chaotic Advection Enhanced Remediation
Project Number:	2004CT31B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2nd
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Treatment, Solute Transport
Descriptors:	
Principal Investigators:	Amvrossios C. Bagtzoglou

Publication

1. Bytautas, D., 2006, Enhanced mixing in groundwater remediation, Senior Thesis, Environmental Engineering Program, University of Connecticut, Storrs, CT, pp. 42.
2. Bagtzoglou, A.C., and P. Oates, 2006, On the Enhanced Groundwater Remediation Potential of Chaotic Advection, ASCE Journal of Materials in Civil Engineering, (in press).
3. Bagtzoglou, A.C., N. Assaf-Anid, and R. Chevray, 2006, Effect of Chaotic Mixing on Enhanced Biological Growth and Implications for Wastewater Treatment: A Test Case with Saccharomyces Cerevisiae, Journal of Hazardous Materials (in press, published online).
4. Bagtzoglou, A.C., 2005, Chaotic Mixing and Enhanced Biological Growth: Implications for Wastewater Treatment, Proceedings of International Material Research Congress, Symposium on Ecomaterials, p. 17/4-5.
5. Bagtzoglou, A.C., P. Oates, and E. Loehmann, 2004, Chaotic Advection Enhanced Remediation, Proceedings of AWRA 2004 Annual Water Resources Conference, Nix, S.J. (Editor), American Water Resources Association, Middleburg, Virginia, TPS-04-3, CD-ROM.

PROJECT TITLE: Chaotic Advection Enhanced Remediation (CAEREM)

STATEMENT OF CRITICAL REGIONAL OR STATE NEED

Water is the most ubiquitous biological compound and is imperative to life. As the world's population continues to grow, the demand for fresh water will continue to increase. Out of the 1% of freshwater available on Earth (excluding brackish water and icecaps/glaciers), 96% is in the form of groundwater. Groundwater accounts for about half of the US population's source of drinking water and this number jumps to 95% when focusing on the rural US. However, quantity is not the only problem; the quality of drinking water is also a concern since this vital resource is vulnerable to contamination. In addition to affecting human health, pollution is also detrimental to natural resources and ecosystems with groundwater contamination threatening our society since industrial, municipal, agricultural, and domestic sources pollute the groundwater that many species ultimately rely on. Studies have linked contaminated groundwater to cancer, fetal abnormalities, birth defects, immunodysfunction, and neurological disorders. In 1994, the National Academy of Sciences estimated that over a trillion dollars, or approximately $4,000 per person in the U.S., would be spent in the next thirty years on clean up of contaminated soil and groundwater. Cost effective and time efficient technologies are, therefore, needed to remediate groundwater.

STATEMENT OF RESULTS AND BENEFITS

Groundwater remediation requires cost effective and time efficient technologies. Recent developments in the field of chaotic advection in low Reynolds number flows have led to the belief that a system of oscillating wells (vis-à-vis injection or withdrawal with time-dependent, randomly constrained flow rates) could cause substantial mixing in an aquifer. This could have profound remedial effects when combined with the advection and dispersion, sorption, and biodegradation aspects of natural attenuation. Chaotic groundwater flow would optimize mixing and allow the processes of natural attenuation to occur much faster.

It is hypothesized that the accelerated mixing provided by chaotic advection will enhance the remedial aspects of natural attenuation. This *in situ* technique treats pollution at its source converting contaminants into carbon dioxide, water, and new cellular mass. Chaotic Advection Enhanced REMediation (CAEREM) could possibly turn decades into years, while reducing both exposure risk and clean up costs. Indigenous microbial nutrients and electron acceptors would spread evenly throughout the contaminant plume to accelerate microbial growth. In addition, wells in the injection phase would allow the engineer to insert specific limiting nutrients, electron acceptors, and even genetically engineered microbes, if so desired (and approved). Removal of limiting factors would allow unhindered microbial growth, and the aquifer would be optimized for biodegradation. It is theorized that there will be temporal and economic advantages in utilizing this technology compared to current remedial approaches. In this research work, we propose to use flow and transport modeling to study the mixing phenomena created in groundwater by oscillating wells. To quantify mixing, an index will be developed using the concept of average inter-particle distances and compared with the dilution index, presented in the literature before. Real world practical design considerations will be examined and laboratory-scale experimentation will provide for model testing and verification.

OBJECTIVES OF PROJECT

This two-year effort addresses the following specific objectives:

- Numerically investigate the applicability of CAEREM for confined and unconfined aquifers
- Develop and compare various indices that will allow us to quantify mixing for conservative tracers
- Numerically investigate the sensitivity of CAEREM to ambient groundwater flows
- Extend the method for 3D flow systems (particular emphasis will be placed on making the active screen depth a design parameter thereby enhancing vertical mixing)
- Design and conduct a medium-scale physical laboratory experiment to demonstrate the practical feasibility of CAEREM and facilitate verification and testing of the method

METHODOLOGY

Numerical models were developed to test the scientific hypothesis that oscillating wells could create substantial mixing in an aquifer. Mathematical tools were developed and applied to quantify both mixing and dilution. It has been suggested that using a system of three oscillating wells could enhance mixing. However, relatively recent theoretical work by Sposito and co-workers at UC Berkeley has questioned whether chaotic streamlines are possible for groundwater flows governed by Darcy's law. Additional, external physical conditions must be invoked in order to induce such chaotic streamlines. To accomplish this, our conceptual model calls for all three wells to be connected by pipes and a manhole (all connections must be below the ground surface for regulatory reasons). This allows such external physical conditions to prevail and mass balance to be conserved so no net water is ultimately removed from or added to the aquifer. To enhance the onset of chaos, the system is made as random as possible. One of the three wells is randomly assigned a random pumping magnitude, within realistic constraints, and a random direction (injection or withdrawal). This magnitude is then randomly partitioned to the other wells, which are assigned the opposite flow direction of the first well. This ensures that mass balance is conserved while maximizing randomness. A conceptual model of this system is depicted in Figure 1.

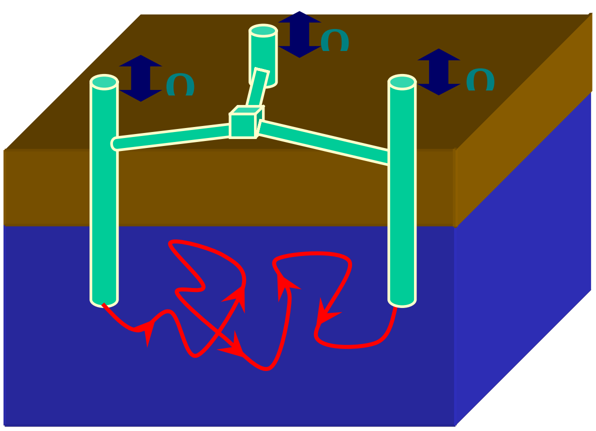

Figure 1. Proposed system

To help quantify the degree of mixing, an index was developed by calculating average inter-particle distances (AIPD). Consider a particular plume (contaminant or nutrients). The average, intra-plume inter-particle distance (*Dg*) for this plume (e.g., nutrients) with particle coordinates *xg* and *yg* is found by calculating the average distance from every particle to every other particle and dividing by the total number of particles. The same analogy can be made for any other plume (e.g., contaminants) with particle coordinates *xr* and *yr*, whose variable will be designated as *Dr*. Since the AIPD of a plume measures the spread of the plume, it is related to the particle cloud variance. It should be noted, however, that the second moment of the particle cloud is not suitable to characterize chaotic advection, since it is insensitive to repeated stretching and folding processes. It is speculated that as these particles mix the AIPD between the contaminant and nutrient plumes (*Dgr*) should decrease. To calculate this value, the contaminant particles look across to the nutrient particles, instead of looking to particles of the same plume.

It is theorized that as the particles become mixed the three AIPDs, *Dg, Dr*, and *Dgr* should converge to the same value. Repeated trials have shown that these values indeed converge as the particles become mixed but there is a great deal of erratic oscillation. When mixing causes the average of *Dg* and *Dr* to approach the value of *Dgr*, it is an indication of small-scale convergence. To help reduce this fluctuation, a variable for AIPD of all the particles (*Dg+r*) is introduced. Here, all particles (contaminant and nutrient), *ngr*, are treated as one plume. The information contained in *Dgr* and *Dg+r* should reveal whether the system is mixed or not. However, there should be less erratic fluctuation because *Dg+r* uses a large-scale, as opposed to small-scale, averaging. First, one has to determine when the system starts mixing. To accomplish this we have developing a concept of mixing based on overlapping circles. When there exists a certain particle overlap between the two plumes, mixing is initiated and calculation of percent mixing as a function of time is based on the ratio of these AIPDs as they evolve in time.

CURRENT EFFORTS

We have built a box (Figure 2) that will allow us to formulate a combination of experimental set-ups in which various flow scenarios will be tested. We have provided for the box to be split in two compartments so there exist three wells in each. We are currently instrumenting the box. This system, in which the sensors will be logged using a data acquisition system (DAS), can be controlled by the LabVIEW software. The experimental set-up consists of a number of different sensors: piezometer probes, ion selective electrodes, a DAS and a control and storage computer. The sensors output an analog signal, which is sampled and measured appropriately with the DAS. It will be controlled through the LabVIEW software, which will be running the pump control system and the sensor triggering system. To demonstrate mixing we intend to use two plumes — *NaCl* and *NaBr* — and measure *Cl* and *Br* ions with the help of selective ion electrodes. The large number of probes requires the use of a corresponding number of analog input channels or a multiplex system. For economical and practical reasons we opted for a multiplexed system. We have also designed and are currently building 2 hele-shaw type of thin boxes (less than a meter by a meter) where we will be able to visualize the complex flow patterns developing in these experiments.

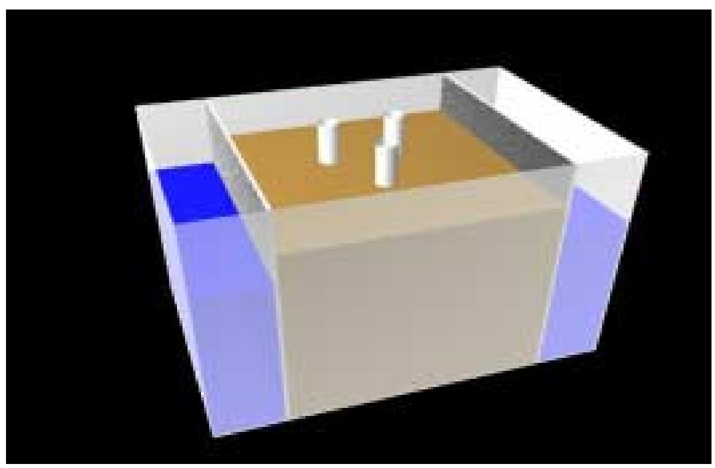

Figure 2. Schematic of experimental facility

FINDINGS TO DATE

Our work to date has culminated to two publications. The first publication – Bagtzoglou, A.C., and P. Oates, 2005, "On the Enhanced Groundwater Remediation Potential of Chaotic Advection", *ASCE Journal of Materials in Civil Engineering* (in press) – can be summarized as follows.

Numerical experiments performed, verified that three randomly oscillating wells, connected through a re-circulation system, can produce substantial mixing. The mixing index developed proved a useful tool when combined with the preexisting dilution index to evaluate this novel technology when tested for realistic remediation parameters. Even though pump and treat has been the remediation method of choice for the past several decades, recent studies have shown many common contaminants become trapped in the subsurface making necessary pumping of extremely large volumes of water over long time periods. It is speculated that CAEREM could take a few years when compared to the several decades of pump and treat. CAEREM could have economic advantages as well; a rough estimate developed with the help of a practicing remediation company suggests that CAEREM could cost around half of pump and treat. Factors contributing to cost reduction include reduced time for site monitoring, reporting, and management, as well as reduced need for maintenance, labor, and supplies. However, it needs to be made clear that this technology is not a "silver bullet" that would be the best choice for every situation. In many cases, the optimal choice may be to combine CAEREM with other technologies.

The second publication – Bagtzoglou, A.C., N. Assaf-Anid, and R. Chevray, 2005, "Effect of Chaotic Mixing on Enhanced Biological Growth and Implications for Wastewater Treatment: A Test Case with *Saccharomyces Cerevisiae*", *Journal of Hazardous Materials* (accepted) – can be summarized as follows.

Mixing patterns and modes have a great influence on the efficiency of biological treatment systems. A series of laboratory experiments was conducted with a controlled, small-scale analog of a pilot wastewater aeration tank, consisting of two eccentrically placed cylinders. By controlling the rotation direction and speed of the two cylinders it has been possible to develop chaotic flow fields in the space between the walls of the cylinders. Our experiments utilized *Saccharomyces Cerevisiae* as the biological oxidation organism and air bubbles as the mixing agent supplied by a large fine pore diffuser to the cells in their exponential growth phase. The effect of various mixing patterns on cell growth was studied at different cylinder eccentricities, rotation directions and speeds. It was found that chaotic advection flow patterns a) enhanced growth, and b) sped up the onset of maximal growth of the organism by 15-18% and 14-20%, respectively.

The dual influences of Alewife, Alosa pseudoharengus, on inland water quality: nutrient fluxes and food web effects

Basic Information

Title:	The dual influences of Alewife, Alosa pseudoharengus, on inland water quality: nutrient fluxes and food web effects
Project Number:	2004CT38B
Start Date:	4/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	Third
Research Category:	Biological Sciences
Focus Category:	Water Quality, Nutrients, Ecology
Descriptors:	None
Principal Investigators:	David M Post

Publication

CT INSTITUTE OF WATER RESOURCES: Annual Report 2005-2006 Project Summary

BASIC PROJECT INFORMATION

YearInitiated	2004	**UCONNFRS**	528333
ProjectID	Post2004_104B_R	**FundSource**	USGS104B
NIIWRProposalNu	2004CT38B	**CongressionalDistrict**	3rd
ProjectlType	Research	**IWR_Role**	Admin
FundingStatus	Funded	**FinalReport**	Not Submitted

Title **The dual influence of Alewife, Alosa pseudoharengus, on water quality**

ResearchCategory

FocusCategories water quality, nutrients, ecology

Keywords river herring, alewife, nutrients, food webs, zooplankton, anadromous, landlocked,

PROPOSALS AND AWARD

	Proposal ID	Start	End Date	Federal	NonFed
2	Post2005_104B_R	3/1/2005	2/28/2006	$24,959	$56,698
1	Post2004_104B_R	4/1/2004	3/30/2005	$25,296	$41,484

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Walters	Annika	PHD	EEB
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PUBLICATIONS

Journal Article — Palkovacs, E.P., and D. M. Post. In prep. Anadromy, landlocking, and the evolution of feeding morphology and prey selectivity in the alewife. To be submitted to Ecology

Journal Article — Post, D.M., E. P. Palkovacs, and S. A. Dodson. In prep. Size selective predation by alewives: a classic ecological system revisited. To be submitted to Ecology

Journal Article — Post, D.M., A. Walters, and S Gephart. In prep. Nutrient loading by anadromous alewives: contemporary patterns and implications for restoration efforts. To be submitted to Canadian Journal of Fisheries and Aquatic Sciences

Journal Article — Post, D.M., E. P. Palkovacs. In prep. The in and out of nutrient loading by anadromous fishes. To be submitted to Ecology.

Journal Article — Walters, A. and D. M. Post. In prep. Influence of nutrient loading by alewives on a coastal Connecticut stream.

Journal Article — Dalton, C.M., D. M. Post, D. Ellis. In prep. Extent and impact of Double-crested Cormorant predation on anadromous alewives in Bride Lake, Connecticut

NOTABLE ACHIEVEMENTS, AWARDS, RECOGNITION

Project Status Report:
The dual influence of Alewife, Alosa pseudoharengus, on water quality

A) Problem and Research Objective

Problem statement – Zooplanktivorous fishes, such as the alewife, *Alosa pseudoharengus*, can have profound impacts on lake water quality, both because they strongly affect the biomass and size structure of zooplankton communities and because they transport, store, and recycle large quantities of nutrients. High densities of zooplanktivorous fishes can seriously exacerbate the symptoms of eutrophication by extirpating populations of large bodied zooplankton, such as *Daphnia* spp., which could otherwise hold phytoplankton biomass to levels well below those established by phosphorus limitation alone. Water quality can be further degraded by zooplanktivorous fishes as they redistribute nutrients within a lake, for example by moving nutrients from benthic to pelagic regions of the lake where the nutrients can promote algal growth or, in the case of anadromous fishes such as alewife, shad, and salmon, import large quantities of new nutrients into lakes, further increasing rates of eutrophication.

River restoration efforts in CT (and throughout New England) aimed at removing dams or adding fish ladders to existing dams will once again provide access for river herring to lakes and ponds along the Atlantic coast. There is considerable concern by local lake associations, landowners, and resource managers that the recovery of anadromous river herring, in particular alewives, will cause water quality problems in coastal lakes. At the same time, EPA restrictions on total daily loads of nutrient pollutants are increasing pressure to limit non-point source nutrient pollution. The addition of river herring to this mix causes lake managers to cringe when they consider the potential new nutrient vector, and lake residents become resistant to restoration efforts when they see images of algal blooms and fish die-offs that occur in lakes with landlocked alewives (alewives that spend their entire life in freshwater). Some stake holders also worry that restored anadromous alewife populations will become landlocked (although most just think they are ecologically the same).

Alewives were a natural part of these ecosystems for thousands of years, and are an important prey for fish, birds and mammals. Furthermore, it is not clear that anadromous herring have the same impacts upon water quality as landlocked populations. Young-of-the-year anadromous alewives are resident in lakes for just a few months, and adults on spawning runs probably do not feed (although this is not well documented). These factors could reduce the impact of anadromous alewives on food web structure as compared to landlocked alewives, which feed year round in lakes and ponds and have caused water quality problems in the Great Lakes, which they invaded in the past century. Likewise, the life history shift from an anadromous to an entirely freshwater lifestyle represents a significant ecological shift, with important implications for body size, abundance, and foraging efficiency (e.g., landlocked alewives typically grow to just half the maximum body size of and mature one to two years earlier than anadromous alewives). Such changes in life history traits could diminish or exacerbate the influence of alewife populations on food web structure and lake water quality, but, to date, there has been very little research on this topic.

Objectives – My objectives were to test the ecological role and evolutionary history of river herring within the context of river restoration efforts. I have:

1) Addressed the effects of anadromous and landlocked alewives in their first summer of life on water quality in Linsley Pond, where access for alewives was restored in the spring of 2006, and Rogers Lakes, where restoration of river access is planned for the spring of 2008.
2) Addressed the magnitude of nutrient loading by anadromous alewives in lakes with existing anadromous alewife populations and provided a nutrient-loading model to estimate nutrient loading by anadromous alewives during population growth after river restoration. This model will allow managers to minimize nutrient loading within the context of population recovery through adaptive management of adult alewife passage through planned fishways.
3) Evaluated the population genetics of landlocked and anadromous alewives in Connecticut as a first step towards understanding the evolutionary origin of landlocked populations.
4) Started monitoring Linsley Pond, Rogers Lake and four reference lakes to gather pre-manipulation data before fish ladders are installed and anadromous alewives recover into these lakes. Anadromous alewives entered Linsley Pond in the spring of 2006 for the first time in over 100 years.

B) Methodology

Objective 1 **–** I addressed the effects of anadromous and landlocked alewives in their first summer of life on water quality using a set of mesocosm experiment in Rogers Lake (summer of 2004) and Linsley Pond (summer of 2005). These lakes were chosen because they were, at the time, sites of planned river herring restoration efforts and represent the two types of lakes that are subject to river herring restoration efforts: lakes with landlocked alewives (Rogers Lake) and lakes without any alewives (Linsley Pond). Linsley Pond has since been restored and anadromous alewives entered the lake in the spring of 2006.

In Rogers Lake, I compared the food web effects of landlocked alewives to the food web effects of anadromous alewives at a fish density similar to that observed naturally in Rogers Lake. I compared landlocked to anadromous alewives in Rogers Lake because planned restoration efforts would slow anadromous alewives to "invade" this lake that already contains a health population of landlocked alewives. In the summer of 2004, I raised twelve experimental mesocosms (2 m diameter, 6 m deep; Figure 1) through the water column of Rogers Lake to fill them with natural lake water. In these mesocosms, I stocked four replicates with 15 (4.8 m^{-2}) young-of-the-year (YOY) anadromous alewives (mean length = 41 mm), four with 15 YOY landlocked alewives (mean length = 40 mm), and retained four as a no fish treatment. Fish were stocked on 24 June and the experiment was ended in late August. In each mesocosm I monitored temperature, dissolved oxygen, total nitrogen and total phosphorous concentrations, water transparency (secchi depth), zooplankton community structure, and phytoplankton biomass. This experiment asks the question: "what effect would

Figure 1. Experimental mesocosms in Rogers Lake in 2004.

replacing landlocked alewives with anadromous alewives have on summer food web and water quality?"

In Linsley Pond, I stocked two replicate experimental mesocosms at 7 different densities of anadromous alewives (0, 0.32, 0.64, 1.27, 2.55, 5.1 and 10.19 alewives m^{-2}) to simulate the food web effects of anadromous alewives at different densities on a lake that currently contains no alewives. Fish were stocked in mid June. Again, in each mesocosm I monitored temperature, dissolved oxygen, total nitrogen and total phosphorous concentrations, water transparency (secchi depth), zooplankton community structure, and phytoplankton biomass. This experiment asks the question: "which densities of YOY anadromous alewives will cause noticeable changes in summer food web structure and water quality?" This experiment had the secondary benefits of providing me with data on the form of density dependent growth and mortality in YOY anadromous alewives, which is important for developing nutrient loading models.

Objective 2 **–** Direct nutrient loading is one of the multiple concerns for the reintroduction of anadromous alewives. I addressed the magnitude of nutrient loading by anadromous alewives in Bride Lake and developed a generalized alewife nutrient loading model estimate nutrient loading by anadromous alewives during population growth after river restoration. This model will help us understand *when* in the restoration process and under which environmental conditions alewives might serve as net sources or sinks for nutrients, and provide an adaptive management framework for managers to minimize nutrient loading within the context of population recovery.

The nutrient loading model (for simplicity I present only the phosphorous model here) is described in the most general terms as:

$$\text{Net P loading} = (P_{adults} + P_{eggs} + P_{excretion}) - P_{juv} \qquad (1)$$

Where P_{adults} is the mass of phosphorus loaded into the lake by adult mortality, P_{eggs} in the mass of phosphorus loaded into the lake by inputs of eggs, and $P_{excretion}$ is the mass of phosphorus loaded into the lake through direct excretion of phosphorus by adults during their residence in the freshwater ecosystem. P_{juv} is export of phosphorus by juvenile fish as they emigrate from the ecosystem.

The mass of phosphorus loaded by adults (P_{adults}) is modeled as:

$$P_{adults} = n_a \bullet \mu_a \bullet mass_a \bullet p_a \qquad (2)$$

where n_a is the number of adults, μ_a is the adult mortality rate, $mass_a$ is the average mass of the adults (wet weight) entering the lake (and therefore includes the mass of egg), and p_a is the concentration of phosphorus in adults (g P / g wet weight). The number of adults (n_a) was either estimated directly for estimates of net nutrient loading into Bride Lake, was used as a dynamic variable to look at patterns of net nutrient loading across a range of adult densities, or determined by the demographic model used to predict patterns of population growth during restoration. The in lake adult mortality rate (μ_a) was estimated from data on adult immigration and emigration taken at the Bride Lake fish counter. Adult mass ($mass_a$) was estimated directly from fish entering Bride Lake or as an output of the demographic model. Adult phosphorus content (p_a) as measured directly for Bride Lake anadromous alewives (see below).

The mass of phosphorus loaded by eggs (P_{eggs}) is modeled as:

$$P_{eggs} = (1-\mu_a) \bullet n_a \bullet m_a \bullet mass_e \bullet p_e, \qquad (3)$$

where m_a is the fecundity of each adult (female fecundity divided by 2; assumes a 1:1 sex ratio), $mass_e$ is the mass of each egg, and p_e is the concentration of phosphorus in each egg (g P / g wet weight). Egg mass ($mass_e$) and p_e were measured in 10 anadromous alewives taken at the entrance of Bride Lake in early May of 2004 and April of 2005. Fecundity (m_a) was estimated as a function of fish mass ($mass_a$) based on the relationship $m_a = 1321 \cdot mass_a - 31628$ (n=24, t=3.91, $r^2 = 0.41$, $p < 0.01$) derived from data in (Kissil 1969) and from fish sampled in 2004 and 2005. The $1-\mu_a$ term was included because we assume that all of the P contained in a fish remains in the lake when that fish dies ($mass_a$ is the mass of fish entering the lake). Thus, P_{adult} includes P_{eggs} for each adult that dies and the $1-\mu_a$ term was included to avoid double counting P_{eggs} from adults that die.

The mass of phosphorus loaded through direct excretion ($P_{excretion}$) is modeled as:

$$P_{excretion} = (1-\mu_a) \cdot n_a \cdot mass_a \cdot E_a \cdot t_a, \qquad (4)$$

where E_a was the excretion rate of adults (g P / g wet weight / day) and t_a was the time spend in freshwater by spawning adults. Again, the $1-\mu_a$ term was included because we assume that fish that die contribute all of their P to the lake. Excretion is only important for fish that survive spawning and leave the system. Rates of excretion were estimated experimentally at Bride Brook in the spring of 2004 and 2005.

The mass of phosphorus exported by YOY or juvenile alewives was modeled as:

$$P_{yoy} = n_{yoy} \cdot mass_{yoy} \cdot p_{yoy}, \qquad (5)$$

where n_{yoy} and $mass_{yoy}$ are density dependent functions and p_{yoy} is the concentration of phosphorus in each YOY (g P / g wet weight). Here, the number of YOY (n_{yoy}) was modeled as: $m_a \cdot n_a \cdot (1- \mu_b - \mu_d \cdot m_a \cdot n_a)$ where μ_b is a density independent mortality rate and μ_d is the density dependent mortality rate that depends upon the initial number of eggs spawned ($m_a \cdot n_a$). The mass of YOY leaving the lake ($mass_{yoy}$) was modeled as: $b_0 + b_1 \cdot \exp(-b_2 \cdot m_a \cdot n_a)$ where b_0, b_1, and b_2 are parameters of a negative exponential growth curve such that growth depends upon the initial number of eggs spawned ($m_a \cdot n_a$). The form of n_{yoy} and $mass_{yoy}$ were estimated from mesocosm experiments performed in Linsley Pond in the summer of 2005 (see figures below). These two density dependent can also be combine to produce a relationship between P_{yoy} and $m_a \cdot n_a$ (the total number of eggs spawned) that approximates the Beverton-Holt stock recruit model used by Moore and Schindler (2004) and Post et al. (in prep) to model net nutrient loading. p_{yoy} was measured in YOY alewives caught in Bride Lake in the falls of 2004 and 2005.

Table 1 presents the major variables and parameters. There are a few variables that are still under study but for which values are expected by August of 2006.

Table 1: Parameters and sources for the alewife nutrient-loading model.

Trait	Value	Notes
Egg mass ($mass_e$)	0.00012 g	1,2
Egg P content (p_e)	Still to be measured	1
Adult fecundity (m_a)	1321 • $mass_a$ – 31628	1,2
Adult numbers (n_a)	Variable	1
Adult mass ($mass_a$)	160 g	1,4
Adult P content (p_a)	0.42%	3
Adult mortality rates (μ_a)	50-60%	1,2
Adult excretion rates (E_a)	2.3 $\mu g\ g^{-1}\ hr^{-1}$	1
Adult time in system (t_a)	~2-4 weeks	1,2
YOY mass ($mass_{yoy}$)	$f(m_a, n_a, t_{yoy})$	1
YOY P content (p_{yoy})	0.43%	1
YOY numbers (n_{yoy})	$f(m_a, n_a, t_{yoy}) \cdot m_a \cdot n_a$	1

[1] This study
[2] Kissil 1974
[3] Durban et al. 1979
[4] Average wet mass of adult alewives returning to spawn in 2004 and

Objective 3 **–** One of the concern expressed by lake associations and lake property owners is that the restoration of anadromous herring population will provide a mechanism for the establishment of new local landlocked populations of alewives. This concern derives from the strong effects of landlocked alewives on zooplankton community structure and water quality in lakes across North America. Because the origin of landlocked alewives is not clear, I am conducting a molecular genetics study of alewives across Connecticut and New England. This analysis will be based on mitochondrial DNA (mtDNA) and microsatellite. Sample analysis is underway and will be completed in the fall of 2006.

Objective 4 – In 2004, I started monitoring Linsley Pond, Rogers Lake and four regional reference lakes to gather pre-manipulation data before fish ladders are installed and anadromous alewives recover into these lakes. Anadromous alewives entered Linsley Pond in the spring of 2006 for the first time in over 100 years. A fish way is planned for Rogers Lake in the fall of 2007. In all of these lakes I monitored temperature, dissolved oxygen, total nitrogen and total phosphorous concentrations, water transparency (secchi depth), zooplankton community structure, and phytoplankton biomass.

3) Principal Findings and Significance

Objective 1 **–** Data from the 2004 mesocosm experiment in Rogers Lake have been analyzed. Data from the 2005 Linsley Pond mesocosm experiment have not been fully analyzed. In the Rogers Lake mesocosm experiment, there was some tendency for greater water clarity (Figure 2) and algal biomass (data not shown) in the no fish treatments early in the experiment, there were no significant differences among the treatments across July and August in both phytoplankton biomass and Secchi depth (Figure 2). There were some differences in zooplankton community structure among all three treatments, but these differences were subtle and did not cascade to an effect on algal biomass and water quality measures. These results indicate that YOY anadromous alewives have similar effects on food web structure as landlocked alewives when found at the same densities. In lakes such as Rogers Lake where landlocked alewives already reside, these results suggest that the replacement of landlocked alewives with anadromous alewives will not worsen water quality through food web effects. The second result, that there was no increase in water clarity in the no fish treatments, may appear paradoxical, but is expected given the current structure of the Rogers Lake zooplankton community. There are no large zooplankton in Rogers Lake because of the intense predation in zooplankton by landlocked alewives. By filling the mesocosms with Rogers Lake water, and therefore the Rogers Lake zooplankton community, there was little scope for large zooplankton (particularly large bodied *Daphnia*) to invade the bags, increase grazing pressure, and increase water clarity. Mean cladoceran length in our bags was 0.4 mm (s.d. = 0.1 mm) on 22 June. By the end of August the mean cladoceran length had declined to 0.3 mm (0.12) and 0.24 mm (0.05) in the landlocked and anadromous treatments, respectively, while mean cladoceran length had increased to only 0.54 mm (0.18) in the no fish treatment. The largest zooplankton found in the no fish treatments were *Cerodaphnia*, which are not as efficient a grazer as the much larger *Daphnia* spp. The limited impact of fish exclusion on water quality, in this case, is a short term effect – over a few to several years a lake without alewives would be invaded by *Daphnia* and water clarity would increase, as I have observed in other of my study lakes that do not contain any alewives.

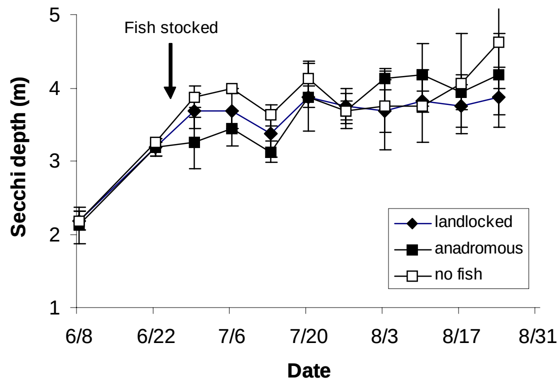

Figure 2. Secchi depth (a measure of light penetration) in the experimental mesocosms. Plotted are the mean +/- 1 standard deviation for each treatment.

Objective 2 **–** I now have a fully functional nutrient loading model. Key results revolve around how net nutrient loading changes as adult abundance and resulting YOY densities influence nutrient export by YOY alewives. Furthermore, estimates of loading are quite sensitive to adult mortality rates. The experiments performed in Linsley Pond in 2005 showed that YOY growth and mortality are density dependent (Figure 3). My results indicate that 1) at very high levels of adult returns (levels seen only in well-established runs) alewives load very large quantities of nutrients 2) at low levels of adult returns (1000s to 10000s) net nutrient loading is relatively low and there can even be a net export of nutrients when adult returns are low and YOY growth is high.

Nutrient excretion experiments performed in the spring of 2004 and 2005 provide, for the first time, an estimate of nutrient loading through direct excretion by an anadromous fish (Table 1). Estimates of the mass specific excretion rate were similar in both years.

Adult mortality rates are a key parameter for the nutrient-loading model. In collaboration with the CT DEP we estimated the adult mortality rate for anadromous alewives spawning in Bride Lake in the spring of 2005. Our estimate of mortality, around 60%, was similar to the estimate of around 50% found in Bride Lake by Kissel (1974).

Objective 3 – My work on the evolutionary origins of landlocked alewives is ongoing and results are expected by the fall of 2006.

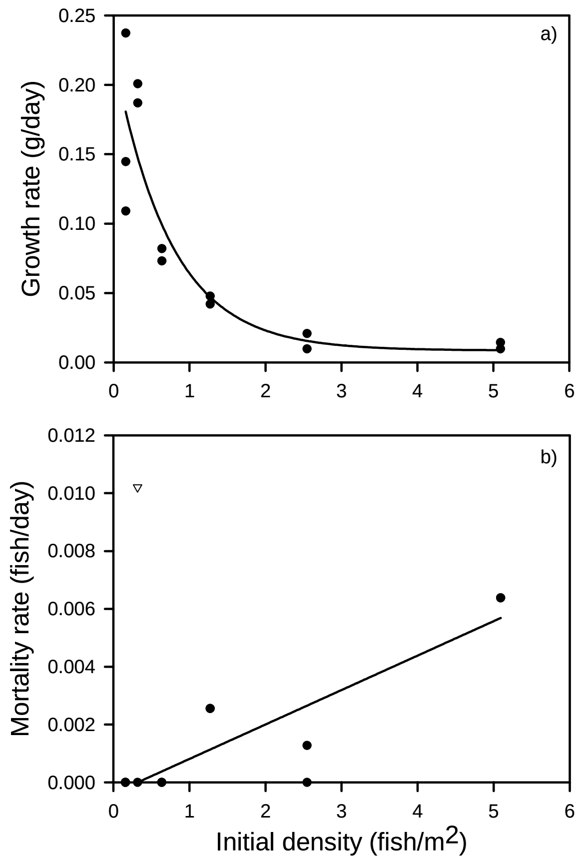

Figure 3. Patterns of density dependent growth (a) and mortality (b) from the Linsley Pond mesocosm experiment.

Objective 4 – The long-term goal is of this research is to evaluate the influence of recovering anadromous alewife populations on ecosystem function at the whole lake scale. Most of the work outlined in this proposal represents intermediate steps towards understanding the mechanisms through which effects of alewives could be manifest. In Rogers Lake and Linsley Pond, CT we have the opportunity to directly observe the effects of recovering alewives as fish ladders are put into those watersheds during the next year or two. Of particular interest are the contrasting current conditions of Rogers Lake and Linsley Pond: Rogers Lake has a resident population of landlocked alewives while Linsley Pond appears to have no current alewife population (although alewives were resident in the lake as recently as the 1960; Brooks and Dodson 1965). Effects of these restoration efforts will emerge over the next decade or more, but pre-manipulation data is essential to understand changes manifest at the whole lakes scale.

I am now in the third year of monitoring Linsley Pond, Rogers Lake, and four other regional reference lakes. The fish way installed below Linsley Pond will allow me to test the effects of anadromous alewives on ecological interactions in a lake that contained no alewives before the reintroduction. In the spring of 2006, over 3000 alewives passed the Branford Supply Ponds fish way and over 600 entered Linsley Pond. I expect to see effects on Linsley Pond this summer or next.

Project Extension and Supplemental Funding for Investigating the Influence of Purging on Long-Term Remediation Compliance Monitoring

Basic Information

Title:	Project Extension and Supplemental Funding for Investigating the Influence of Purging on Long-Term Remediation Compliance Monitoring
Project Number:	2004CT45B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	second
Research Category:	Not Applicable
Focus Category:	Groundwater, Water Quality, Toxic Substances
Descriptors:	None
Principal Investigators:	Gary a Robbins

Publication

1. Robbins, G.A., Metcalf, M. and Budaj, 2005, Observations of Spurious MTBE Fluctuations, presented at API Soil and Groundwater Technical Task Force Meet., June 15, Storrs, CT.
2. Robbins, G.A., Metcalf, M., 2006, Evaluating the Effectiveness of Connecticut's MTBE Ban, presented at the USEPA, National UST Conference, Memphis, TN, March 20-22.
3. Robbins, G.A., 2006, 17 Years of Groundwater Sampling at a UST Site: So what have we learned? EPA Region 3 Technical Conference, May 5, Roanoke, VA.
4. Robbins, G.A., 2006 To Purge or Not to Purge that is the question, but is it the right one?, presented at Environmental Professional Organization of Connecticut, June 6, Rocky Hill, CT.
5. Metcalf, M., and Robbins, G.A. 2005, Dissipation of MTBE Ground Water Contamination Following the Connecticut 2004 MTBE Ban, Ground Water Monitoring and Remediation,
6. Metcalf, M., and Robbins, G.A. 2005, Comparison of Water Quality Profiles from Shallow Monitoring Wells and Adjacent Multilevel Samplers submitted to Ground Water Monitoring and Remediation, In Review.

PROGRESS REPORT
2005 - 2006

Investigating the Influence of Purging on Long-Term Remediation Compliance Monitoring

Principal Investigator

Gary A. Robbins
Department of Geology and Geophysics
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Storrs, CT

Problem and Research Objectives

Monitoring wells are commonly used for remediation compliance monitoring across the Country. The objective of this study is to determine if monitoring wells should be purged when conducting groundwater monitoring. The study will provide information to regulatory agencies and the environmental consulting industry that can be used to develop sound sampling guidance and improve compliance monitoring at ground water contamination sites.

Methodology

The research site is the Motor Pool at the University of Connecticut in Storrs, Connecticut. The Motor Pool is the refueling station for the University, and the location of previous gasoline and diesel fuel spills. A near field monitoring well was sampled three different ways, during nine sampling rounds to develop data for conducting a statistical comparison on water quality parameters. We also profiled the water quality in the well before and after sampling. Water quality data was also compared to that derived from an adjacent multilevel sampling cluster. This permitted examining how the water quality derived from wells compares with formation water quality and to model concentration averaging in the well.

Principal Findings and Significance

The research has been completed and papers on the work have been submitted and are being developed. Our major findings are as follows:

- The undisturbed concentration distribution in the well bore does not mimic the formation vertical concentration distribution. This implies that the characterization of the vertical concentration distribution of a formation by taking grab or passive (e.g., diffusion bag samplers) samples in a shallow monitoring well will be highly inaccurate.

- Statistical analysis indicated the three sampling methods tested provide similar results for inorganic constituents and MTBE.
- The curtailment of MTBE in gasoline can eliminate the contamination of ground water by gasoline vapor releases. MTBE levels were monitored during this study shortly after it was banned in Connecticut gasoline. Levels continually declined throughout the monitoring period from over 1000 ppb to near non-detections. As of 2006, the site was free of MTBE.
- Our past models predicted that constituent concentrations from no purge samples should differ from those taken after purging because of flow weighted averaging. But this was not observed. Well mixed contaminant concentration conditions occur in the well bore owing perhaps to thermal mixing, turbulence when water enters the screen section or by divergent flow caused by the screen section low porosity. The well mixed water forms a shadow zone downgradient of the well that reenters the well during purging and mutes out predicted affects of flow weighted averaging. It is our conclusion that typical ground water monitoring wells screened across the water table do not have to be purged before sampling.

Gonadal Deformities in Connecticut Amphibians

Basic Information

Title:	Gonadal Deformities in Connecticut Amphibians
Project Number:	2005CT76B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	3rd
Research Category:	Biological Sciences
Focus Category:	Ecology, Toxic Substances, Surface Water
Descriptors:	None
Principal Investigators:	David Skelly

Publication

CT INSTITUTE OF WATER RESOURCE PROJECT STATUS REPORT

Gonadal Deformities in Connecticut Amphibians (Project # 2005CT76B)
PI: David Skelly, Yale University

Problem and Research Objectives: Freshwater wetlands are the recipients of an enormous diversity of compounds created or modified by humans. Fates and effects of most are poorly known and difficult to forecast. The practical impossibility of screening all contaminants for multiple potential impacts means that scientists must rely on a variety of means to identify threats to environmental health.

The use of wildlife sentinels as indicators of environmental condition is rapidly gaining currency. Effectiveness of this approach relies on careful selection of species that are likely to be exposed to potential contaminants and that are readily sampled.

Recently, amphibians resident in freshwater wetlands have been identified as sentinel candidates. A number of studies show that amphibian development can be impacted by chemical contaminants at relevant doses or exposures.

These laboratory results have been complemented by a recent field study (Hayes et al. 2002) showing that natural populations of amphibians in the Midwestern United States exhibit rates of gonadal abnormalities of up to 92%. The presence of vertebrate populations with high rates of developmental abnormalities including hermaphroditism has generated widespread attention. These findings are particularly alarming as the amphibian populations in question were often living in freshwater environments that form public drinking water supplies. These patterns generated enough concern that the U.S. Environmental Protection Agency convened a Science Advisory Panel in 2003 to consider their implications (USEPA 2003). The EPA noted that it was critical for more field studies to be conducted to determine the scope of the problem.

The status of populations in the northeastern United States remains unknown.

Connecticut is a particularly appropriate location for further field study. The state has a diverse set of landscapes including extensive tracts of undeveloped forest, intensive agriculture, residential areas and large urbanized zones. This variation in land cover within a relatively small area is ideal for discovering whether developmental abnormalities are present and whether land use is associated with these patterns.

Project Objectives:

1. Determine whether gonadal abnormalities are present in amphibians in Connecticut.

2. Characterize observed deformities.

3. Estimate the association between deformity rate and landscape composition.

Methodology: We conducted a sampling survey of amphibians living in wetlands across Connecticut stratified across 4 land use types: urban, suburban, agricultural, and undeveloped. GIS coverage for the state of Connecticut was used to designate each wetland in one of the four categories based on the dominant cover type surrounding the wetland perimeter. Wetlands for examination were selected at random using the National Wetlands Inventory conducted by the U.S. Geological Survey. In identifying wetlands for study, we employed the

Connecticut Land Use Land Cover Data Layer (LULC). The LULC is based on LANDSAT Thematic Mapper Satellite Imagery data with 23 categories of land use and land cover We visited 138 wetlands. During initial visits we ground truthed land cover designations and assessed the presence of green frogs (*Rana clamitans*). In the end we found 23 wetlands which had ground truthed land cover designations that matched remotely sensed data and for which we could successfully recover adequate amphibian specimens.

There are few published studies documenting patterns of gonadal abnormalities in wild Ranid frog populations (Hayes et al. 2002). We based our analysis of gonadal abnormalities on recommendations produced as a part of a recent EPA Science Advisory Panel Report (U.S. EPA 2003). Frogs are being scored for the presence of secondary sexual characters (e.g., thumb pads, vocal sacs) and sexed by gonadal examination under a dissecting microscope. Gonads will be removed and fixed with Bouin's preservative. Fixed gonads are embedded in paraffin, sectioned at 5 µ, and stained with hematoxylin and eosin (Qin et al. 2003). Gonadal structure is examined under a compound microscope. A wide variety of amphibian gonadal abnormalities have been described ranging from abnormal pigmentation to hermaphroditism. Specimens will be scored for all varieties of abnormalities.

Principal research Findings: We collected a total of 369 green frogs from 23 different wetlands. To date we have completed dissections (removal of a gonad and preparation for sectioning) on 354 individuals; the remaining individuals were gravid females or were otherwise unable to be prepped for histological analysis. Of these, histological preparations have been completed on 72 individuals.

In response to our first research objective, we can report that gonadal abnormalities are present in wild Connecticut amphibians. Of the 72 individuals completed so far, we have found serious abnormalities in 8 individuals; a gonadal abnormality rate of 11%.

The deformities uncovered have all been of a single type: ovarian follicular tissue within a testis. This deformity has been reported in wild collected amphibians in the western U.S. as well as laboratory reared individuals exposed to pesticides.

Recognizing that we are only part way through our histological examinations, we can report preliminary evidence for an association between deformities and land cover type. All but one of the deformities reported so far have been recovered from suburban contexts. The remaining individual was recovered from an agriculture associated wetland. None have been found in urban or undeveloped land cover types.

References:

Hayes, T., K. Haston, M. Tsui, A. Hoang, C. Haeffele, & A. Vonk. 2002. Feminization of male frogs in the wild: waterborne herbicide threatens amphibians in parts of the United States. Nature 419:895-896.

U.S. Environmental Protection Agency. 2003. FIFRA Scientific Advisory Panel Report. SAF Report No. 2003-01.

Qin, P., R. Cimildoro, D. M. Kochhar, K. J. Soprano, & D. R. Soprano. 2002. PBX, MEIS, and IGF-I are potential mediators of retinoic acid-induced proximodistal limb reduction effects. Teratology 66:224-234.

Occurrence and Fate of Pharmaceuticals in the Pomperaug River

Basic Information

Title:	Occurrence and Fate of Pharmaceuticals in the Pomperaug River
Project Number:	2003CT23B
Start Date:	1/1/2003
End Date:	12/31/2005
Funding Source:	104B
Congressional District:	2nd
Research Category:	Water Quality
Focus Category:	Surface Water, Toxic Substances, Waste Water
Descriptors:	
Principal Investigators:	Allison Mackay, Allison Mackay

Publication

PROJECT TITLE: OCCURRENCE AND FATE OF PHARMACEUTICALS IN THE POMPERAUG RIVER

PRINCIPAL INVESTIGATORS: Dr. Allison MacKay, University of Connecticut

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. 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. Few data regarding temporal and spatial distributions, or environmental degradation rates of pharmaceuticals in surface waters have been collected that would enable ecological exposure risks of these bioactive compounds to be calculated.

OBJECTIVES:

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 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.

METHODOLOGY:

The fate of pharmaceuticals in the Pomperaug River will be assessed in the reach beginning at the Heritage Village Wastewater treatment plant and continuing to the Housatonic River. Samples will be obtained quarterly using standard stream tracer techniques to delineate a ‘packet’ of fluid at the outlet of the wastewater treatment plant. Five downstream sample locations have been identified from which to obtain stream water samples from this packet for pharmaceutical analyses by standard gas chromatography/mass spectrometry techniques. Sample analyses will include neutral and acidic high-use pharmaceutical compounds. Observed concentrations in the river will be compared to predicted concentrations from using a conservative transport model developed from the dye tracer. Decreases in pharmaceutical compounds from the conservative model will be used to calculate environmental degradation rate constants.

COMPLETED ACTIVITIES:

A field sampling trip was conducted in November 2005. A dye release was conducted to characterize the travel times and flow conditions in the Pomperaug River. No pharamaceutical compound analyses were conducted at the time. A second field trip will be conducted in July 2006 low-flow conditions to characterize travel times and pharmaceutical compound concentrations.

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

Basic Information

Title:	Handheld Light Meters and Anion Exchange Membranes to Reduce the Threat of Water Pollution from Turfgrass Fertilizers
Project Number:	2003CT24B
Start Date:	1/1/2003
End Date:	8/31/2005
Funding Source:	104B
Congressional District:	2nd
Research Category:	Water Quality
Focus Category:	Nitrate Contamination, Non Point Pollution, Nutrients
Descriptors:	
Principal Investigators:	Karl Guillard, Karl Guillard

Publication

1. Mangiafico, S.S. and K. Guillard, 2004, Use of Anion Exchange Membranes to Estimate Turfgrass Growth and Quality, in Agronomy Abstracts: Proceedings of the National Meeting of the American Society of Agronomy, Madison, WI.
2. Mangiafico, S.S., and K. Guillard, 2006, Anion Exchange Membrane Soil Nitrate Predicts Turfgrass Color and Yield, Crop Science, 46, 569-577
3. Mangiafico, S.S., and K. Guillard, 2005, CateNelson models of turfgrass relative color and yield predict critical AEM soil NO3N concentrations, In Northeast Branch Agronomy abstracts, ASA, Madison, WI.
4. 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.
5. Mangiafico, S.S., and K. Guillard, 2006, Nitrate leaching from Kentucky bluegrass soil columns predicted with anion exchange membranes, Submitted to Soil Sci. Soc. Am. J, Vol, Pages.
6. Mangiafico, S.S., and K. Guillard, 2006, Cool-season lawn turfgrass color and growth calibrated to leaf nitrogen,Submitted to Crop. Sci.

Karl Guillard and Salvatore Mangiafico
Final Report of the Project:

Handheld Light Meters And Anion Exchange Membranes To Reduce The Threat Of Water Pollution From Turfgrass Fertilizers

Funded by the Connecticut Institute for Water Resources

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 that have been documented as experiencing frequent hypoxia events attributed to non-point 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 suggest that handheld meters and anion exchange membranes (AEMs) have potential in fine-tuning N management for turf. Establishment of a database utilizing tristimulus and reflectance meter readings and desorbed nitrate–N (NO_3–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 AEM soil NO_3–N and turf growth and quality responses.
- Determine the relationship between AEM soil NO_3–N and nitrate leaching from turf.
- Determine the relationship between AEM soil NO_3–N and nitrogen recovery by turfgrass.
- Determine the relationship between color and reflectance meter readings and NO_3–N leaching from turf.

Methodology

Field experiments were conducted across two years at the University of Connecticut's Plant Science Research and Teaching Facility using established plots of mixed-species cool-season turfgrass 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-400 tristimulus chroma meter and a Spectrum CM1000 chlorophyll meter were used to determine hue (greenness), lightness (brightness of color), chroma (saturation of color), and relative chlorophyll content of the turf. Measurements of the turf included shoot growth (clipping yield), color (hue, lightness, chroma), relative chlorophyll content (Spectrum CM1000 index), and total N concentration. These variables were correlated to nitrate–N desorbed from AEMs. Curvilinear models were used to suggest critical values for soil nitrate–N corresponding to optimum turf responses.

A soil monolith lysimeter experiment was conducted across two years 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 CM1000 chlorophyll meter were used to determine turf color quality, and clipping yield and total N concentration were measured every two weeks. The columns were irrigated weekly at 2.5 cm per week. The upper 1.5 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 continued 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. Curvilinear models were used to relate nitrate leaching to AEM soil NO_3–N and reflectance meter measurements.

Principle Findings and Significance

Results from the field study suggest that AEM desorbed soil NO_3–N can be used to predict a critical soil nitrate level needed for maximizing turf color and growth (Fig 1). Little change was noted in greenness of the turf (CIE hue), relative chlorophyll content (CM1000 index), and growth (clipping yield) above an AEM desorbed NO_3–N value of approximately 3 $\mu g/cm^2$/day. Any further increase in available soil N did not increase turf greenness, but presumably increased the chance of N losses with excess soil NO_3–N.

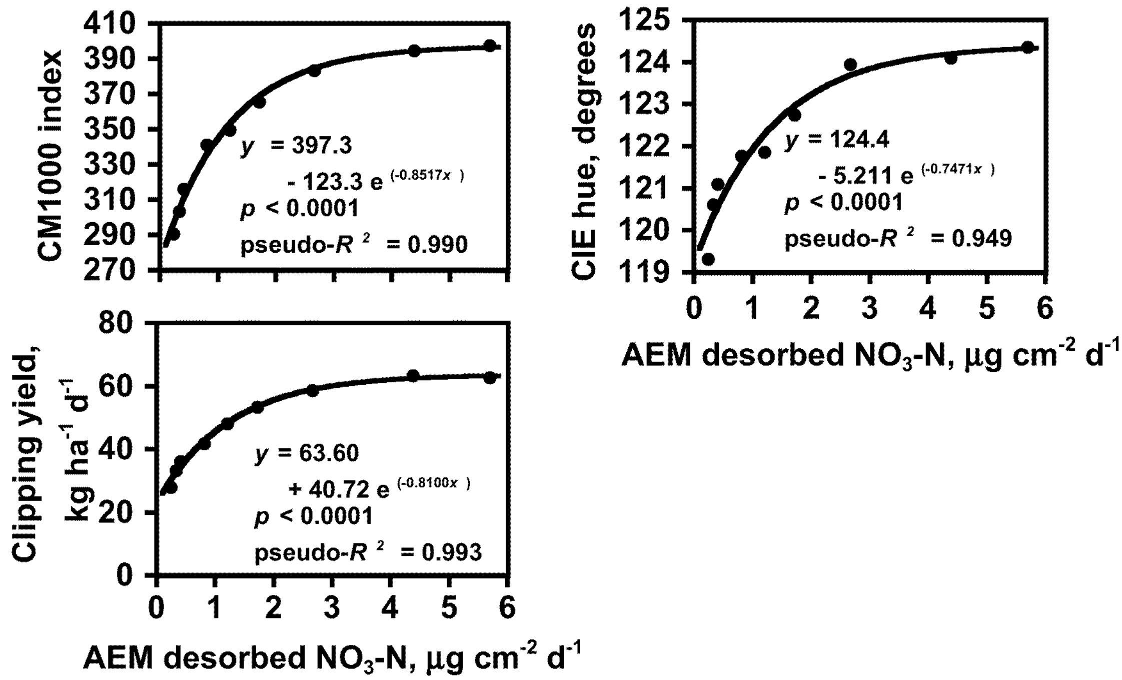

Fig 1. Relationship between soil nitrate–N desorbed from anion exchange membranes (AEMs) and CIE hue (greenness), CM1000 index (relative chlorophyll), and clipping yield (growth) collected from a Kentucky bluegrass–perennial ryegrass–creeping red fescue lawn. Each data point represents the mean of three replications averaged across two growing seasons.

Linear plateau models were found relating deviations from plateau values for clipping yield, CIE hue, and CM1000 index to leaf N concentration, for data pooled across sample dates, for the field experiment (Fig. 2). Critical concentrations in leaf N ranged from 29.2 to 31.7 g N kg^{-1} across clipping yield, CIE hue, or CM1000 index measurements. Approximate 95% confidence intervals constructed for estimates of the critical concentrations from these models were 26.9 to 31.6; 25.7 to 37.7; and 27.6 to 32.4 for clipping yield, hue, and CM1000 index, respectively. These confidence intervals may give some further indication of reasonable optimum ranges considering the variability of the pooled data. These models indicated small marginal improvements in growth or color when leaf N exceeded 28 g kg^{-1}, suggesting that a leaf N test can separate turf with optimum leaf N concentrations from turf with below optimum leaf N concentrations. Plateaus in leaf N concentrations with increasing N fertilizer rates suggest, however, that this test may be unable to identify sites with excess N.

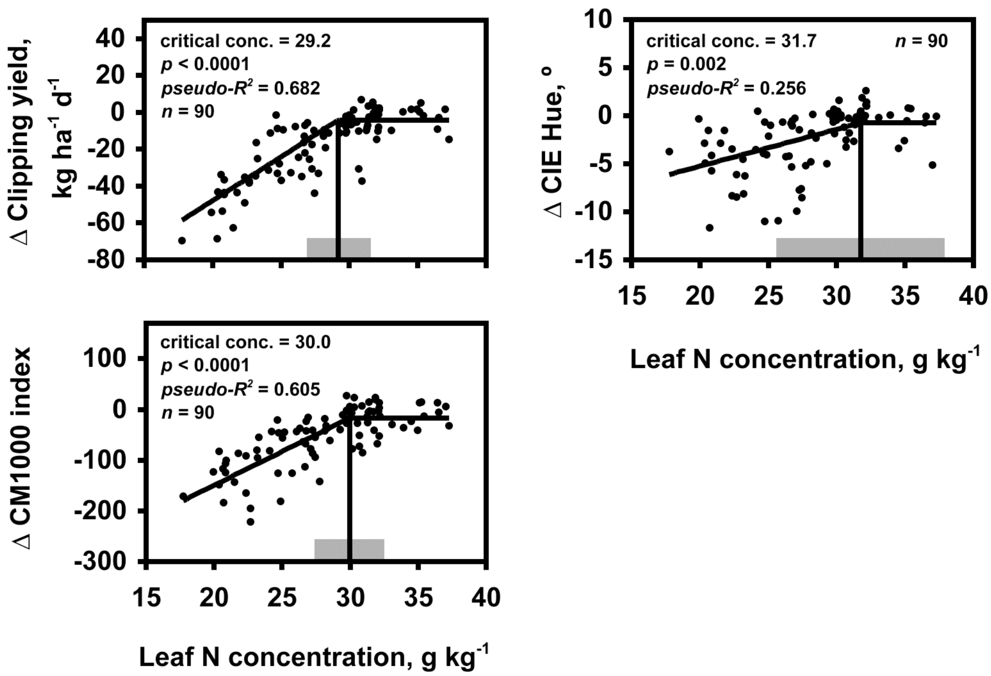

Fig. 2. Deviations from plateau turfgrass clipping yield, CIE hue, and CM1000 in relation to leaf N concentration for a mixed cool-season species lawn in Connecticut. Data are pooled from 10 sample dates across two growing seasons. Linear plateau models are shown. *Critical conc.* and vertical lines to the *x*-axes indicate critical concentrations from linear plateau models. Gray boxes on the *x*-axes indicate the extent of approximate 95% confidence intervals for the critical concentrations. Number of observations per plot is indicated by *n*.

In the column study, significant exponential ($p < 0.05$) models were found relating percolate flow-weighted mean NO_3–N concentration (Fig. 3A), cumulative NO_3–N mass in percolate (Fig. 3B), and cumulative mass as fraction of N applied (Fig. 3C) to AEM desorbed soil NO_3–N. A mean percolate NO_3–N concentration below the EPA maximum contaminant level (MCL) for drinking water of 10 mg NO_3–N L^{-1} was found for a mean AEM soil NO_3–N value of 2.9 μg cm^{-2} d^{-1} (Fig. 3A). Similarly, based on the curvature of the model, Fig. 3B suggests moderate cumulative percolate NO_3–N mass when AEM soil NO_3–N values did not exceed about 3 μg cm^{-2} d^{-1}. The fraction of applied N collected as NO_3–N in percolate generally increased as AEM soil NO_3–N increased (Fig. 3C). As a percent of N applied, mass loss in percolate predicted by the exponential model ranged from about 7% to 28% across treatments (Fig. 2 C). Because percolate NO_3–N concentrations of environmental concern may be much lower than the US EPA MCL for drinking water, target soil NO_3–N values should probably be lower than those producing percolate concentrations close to the US EPA MCL.

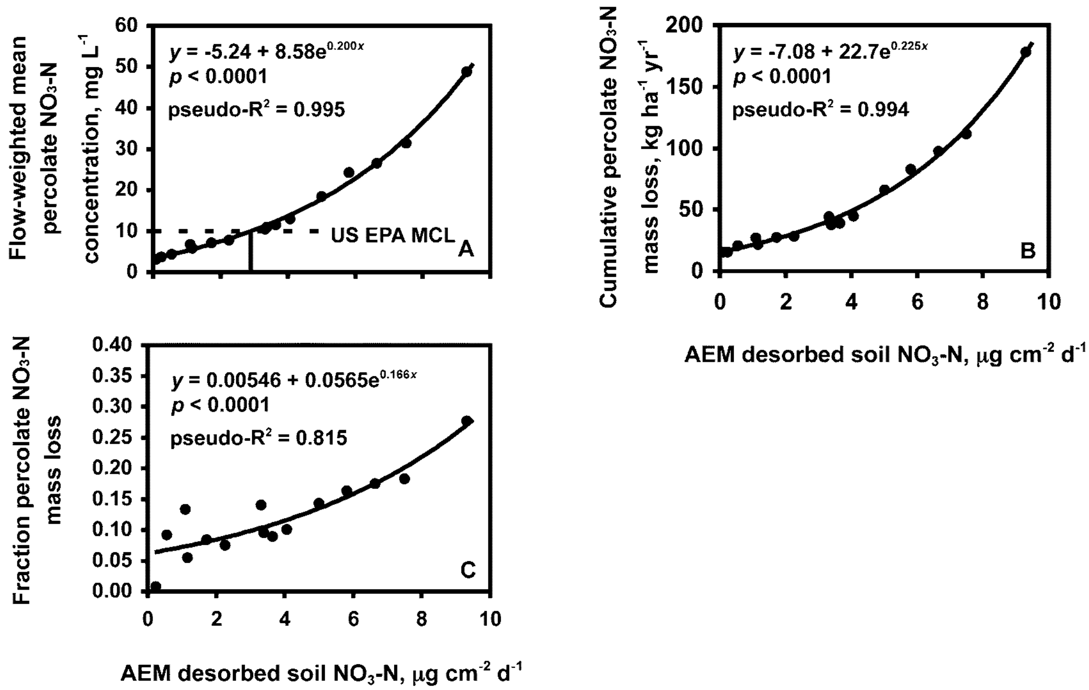

Fig 3. Flow-weighted mean NO_3–N concentration (A), cumulative NO_3–N mass (B), and cumulative mass as fraction of N applied (C) of percolate water from intact soil columns of fine sandy loam soil below Kentucky bluegrass (*Poa pratensis* L.) turf. Percolate data was collected on 54 dates across two yr, and is plotted in relation to mean soil NO_3–N desorbed from *in situ* anion exchange membranes (AEM). A fitted exponential curve is shown for each plot. Dashed horizontal line represents the US EPA maximum contaminant level (MCL) for drinking water of NO_3–N of 10 mg L^{-1}. Vertical line to the *x*-axis represents the soil NO_3–N value corresponding to the MCL.

Cumulative N uptake increased with increasing AEM soil NO_3–N, to a model-predicted maximum at 8.2 µg cm^{-2} d^{-1} of AEM soil NO_3–N (Fig. 4A). Apparent N recovery ranged from about 30% to 40% of applied N with a maximum corresponding to 4.7 µg cm^{-2} d^{-1} AEM soil NO_3–N (Fig. 4B). These results suggest that increased leaching losses may be a result of less efficient recovery of N by turf when AEM soil NO_3–N was above 4.7 µg cm^{-2} d^{-1}. Below this value, however, increased leaching losses occurred with increasing AEM soil NO_3–N leaching in spite of more efficient recovery.

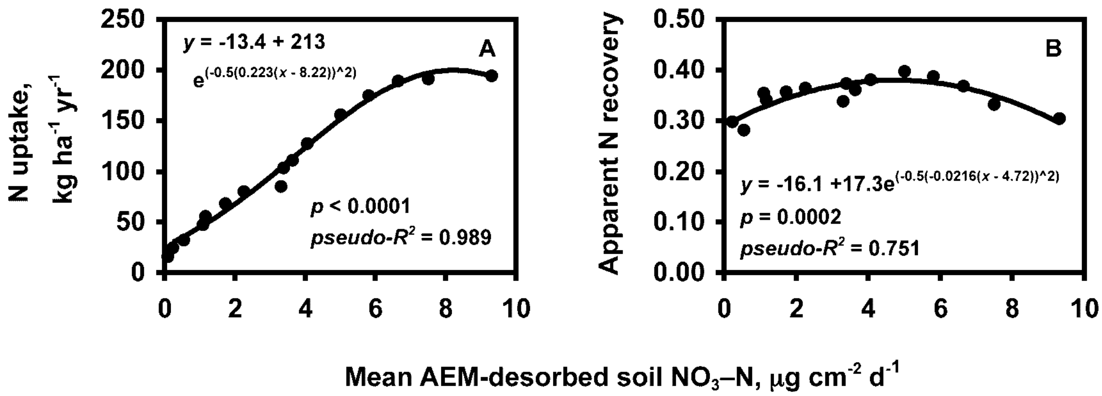

Fig 4. Cumulative N uptake (A), and apparent N recovery (B) of Kentucky bluegrass (*Poa pratensis* L.) turf in relation to soil NO_3–N desorbed from *in situ* anion exchange membranes (AEM). The turf was grown on a fine sandy loam soil in greenhouse conditions. A fitted Gaussian curve is shown for each plot. Data for AEM soil NO_3–N are averaged from 24 dates across two yr. Data for N uptake and recovery are from leaf tissue samples bulked from 24 dates across two growing seasons.

Significant ($p < 0.05$) Mitscherlich–Bray models were found relating mean chlorophyll index, hue, lightness, and yield measurements to mean AEM desorbed soil NO_3–N (Fig. 5). A higher CM1000 index implies a higher leaf chlorophyll concentration. A higher CIE hue in this range implies a greener leaf color. A lower CIE lightness implies a darker leaf color. Marginal changes in these variables with increases in AEM soil NO_3–N were greatest at low AEM soil NO_3–N values. However, these variables continued to change with increasing AEM soil NO_3–N at high AEM soil NO_3–N values. Color (Fig. 5C and D) and chlorophyll (Fig. 5A) development for our turf stand occurred at the expense of increases in NO_3–N leaching losses (Fig. 3). This effect was especially pronounced at high AEM soil NO_3–N values when incremental additions of soil NO_3–N increased turf color and chlorophyll only slightly but increased NO_3–N leaching losses exponentially. Considering this, water quality concerns would dictate that turf N application should be managed to achieve acceptable quality for intended turf use and conditions, and not to attempt to maximize turf color response.

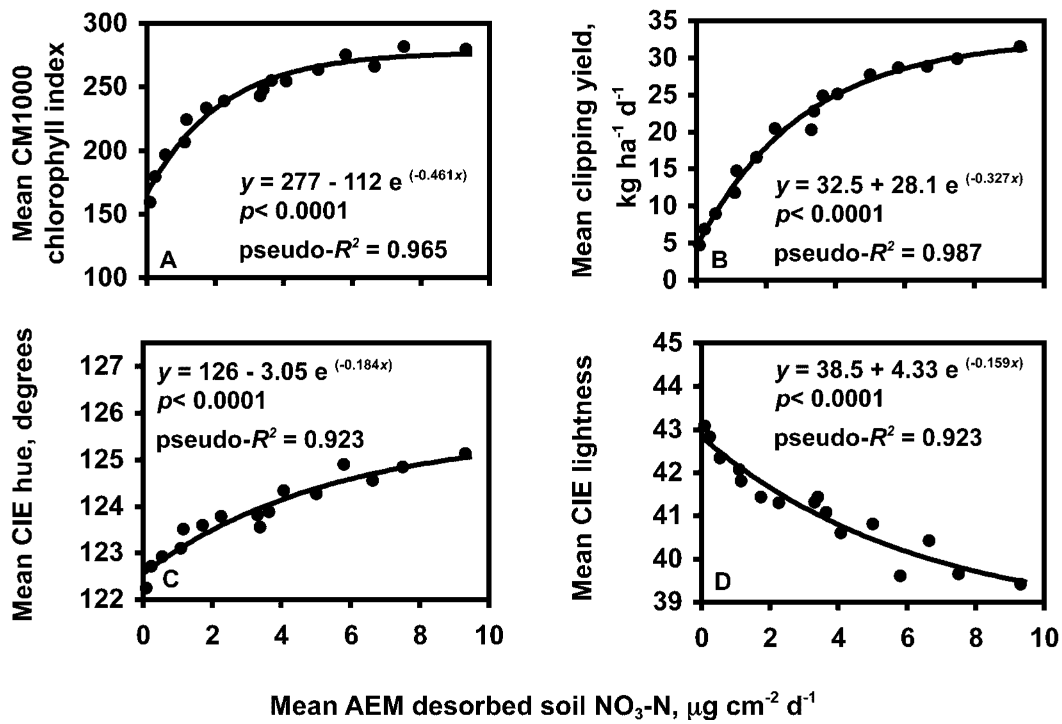

Fig. 5. Mean CM1000 chlorophyll index (A), clipping yield (B), hue (C), and lightness (D) measurements from a Kentucky bluegrass (*Poa pratensis* L.) turf plotted against mean soil NO_3–N desorbed from *in situ* anion exchange membranes (AEM). All measurements were averaged by treatment from 24 dates across two seasons. A fitted Mitscherlich–Bray model is shown for each plot. A higher CM1000 index implies a higher canopy chlorophyll content. A higher CIE hue in this range implies a greener leaf color. A lower CIE lightness implies a darker leaf color.

The chlorophyll meter was useful as well in predicting N leaching losses in the column study (Fig. 6). Nitrate–N leaching increased exponentially as turf greenness (CIE hue) and relative chlorophyll content (CM1000 index) increased. However, increases were moderate up to a CM1000 index value of approximately 250 and a CIE hue value of approximately 124. These data suggests that turf may be fertilized to some level of color quality with moderate NO_3–N leaching losses, beyond this incremental color changes will be achieved at the expense of exponentially higher NO_3–N leaching.

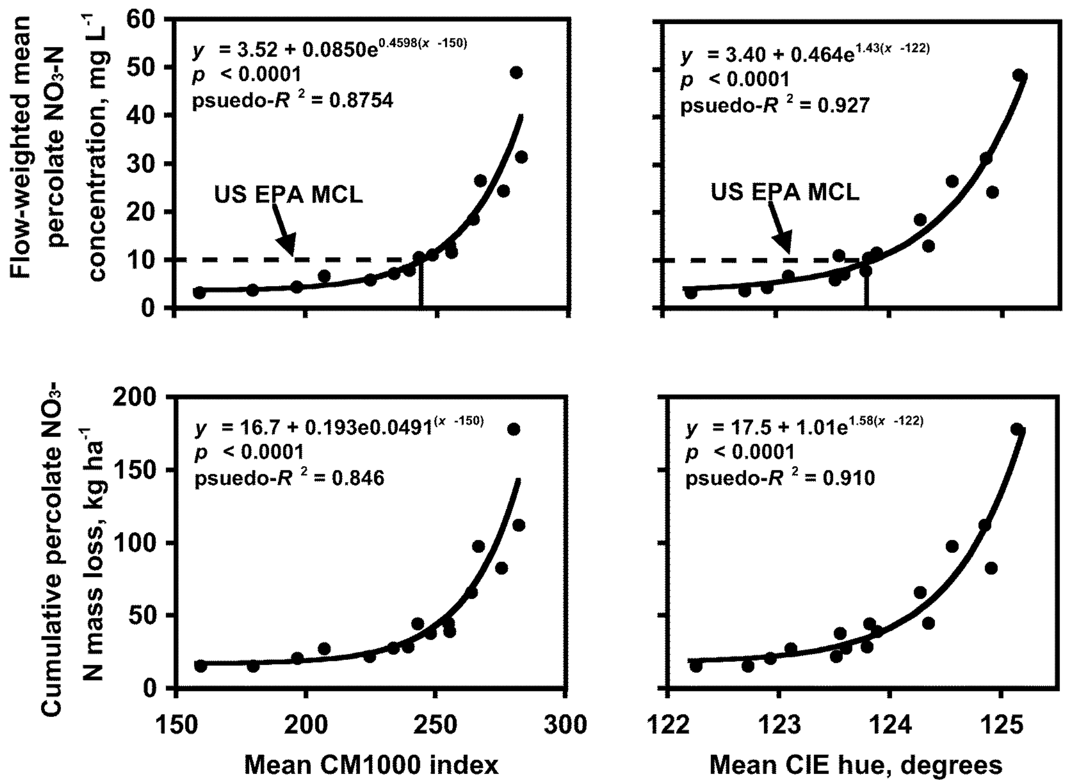

Fig 6. Relationship between CM1000 index (relative chlorophyll) and CIE hue (greenness) and flow-weighted nitrate–N concentrations and leaching losses of percolate collected from Kentucky bluegrass grown in soil columns. Each data point represents the mean of four replications averaged across two growing seasons.

Results from the field and column studies suggest that N management of turf can become less subjective and more reliable with the use of handheld reflectance meters and AEMs. The current N fertilization method for turf that relies on set schedules and set application rates increases the likelihood of over-application and a greater threat to water quality. These results caution against managing nitrogen applications to achieve color development beyond the requirements of the intended use of a specific turf stand. More objective-based tests need to be used to guide N fertilizer recommendations for turf.

Information Transfer Program

The Connecticut Institute supports information transfer supports information transfer projects through its competitive RFP process as well as through ongoing internal information transfer project "Water Resources Technology Transfer Initiative," described below.

There were no outside proposals submitted to the institute in FY 2005 for information transfer projects.

In addition, Pat Bresnahan concluded her work with the Connecticut SEAGRANT program on developing the Connecticut Aquatic Nuisance Species Management Plan. The plan has been submitted to the Connecticut Department of Environmental Protection for approval, and once accepted by the U.S. Fish and Wildlife Service, is will enable the state to be eligible for federal funds for ANS projects.

Water Resources Technology Transfer Initiative

Basic Information

Title:	Water Resources Technology Transfer Initiative
Project Number:	2002CT5B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	2nd
Research Category:	Not Applicable
Focus Category:	Water Quality, Water Quantity, Water Supply
Descriptors:	
Principal Investigators:	Glenn Warner, Patricia Bresnahan

Publication

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. Liaison Work

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.

Publications: A new special report was added to our site this year, describing the results of the Fenton River study (described under "Research"). When final edits are complete, this will be submitted to the Digital Commons archive.

Seminar Series: The theme of our 2005-2006 Seminar Series was "The Fenton River Study." The results of the study (described in the "Research" section above) were presented in a series of four talks given by the principle investigators:

- "Geology and Geophysics of the Fenton River Well Field." Dr. Lanbo Liu, Dept. Civil and Environmental Engineering, UCONN.

- "Fenton River Measurements: Surface Hydrology, Flow and Statistical Analysis." Dr. Glenn Warner, Dept. Natural Resource Management and Engineering, UCONN and Director, CT IWR.

- "Groundwater Modeling of the Fenton River Well Field." Dr. Ross Bagtzoglou, Dept. Civil and Environmental Engineering, UCONN.

- "The Fenton River Fisheries Study." Rick Jacobson, Dept. Natural Resource Management and Engineering, UCONN.

The series concluded with a presentation on water conservation given by Amy Vickers, an engineer and internationally recognized water conservation expert. The Institute is now formally changing the name of its seminar series to the "William C. Kennard Water Resources Lectures" to honor the founding director of our Institute. The Vickers talk, listed as the Inaugural Kennard Lecture, was held in conjunction with a reception for Dr. Kennard, who established the Institute in 1964 and served as its director for twelve years. Current and former board members and colleagues of Dr. Kennard attended the event, where Tom Callahan, special assistant to UCONN's President Austin, presented Bill with a plaque. State Representative Denise Merrill obtained a citation from the legislature for Dr. Kennard, which was presented to him after the event.

Conferences: The Institute co-sponsored and helped organize a conference with Yale's Center for Coastal and Watershed Systems and several other groups. The conference was entitled, "Water Law in Connecticut: Balancing Needs for Fish and Faucet," and featured presentations by many legal experts in the state as well as talks by representatives of affected parties.

Liaison Work: At the invitation of the DEP Commissioner’s office, Glenn Warner has been participating in the Scientific and Technical Standards Workgroup of the Stream Flow Advisory Group. The purpose of the group is to provide guidance for the development of flow regulations for streams and rivers in Connecticut. Pat Bresnahan participated in the "Water Allocation Policy Planning Models's Implementaion Workgroup" meetings last summer. In response to a strong need expressed by members of this group (formed at the request of the statewide Water Planning Council), the Institute listed "state-wide basin screening" as a priority in our request for proposals for FY 2006-2007.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	7	0	0	0	7
Masters	10	0	0	0	10
Ph.D.	7	0	0	0	7
Post-Doc.	1	0	0	0	1
Total	25	0	0	0	25

Notable Awards and Achievements

Project 2004CT45B: As a result of the work, we were able to get a follow up grant from the American Peteroleum Institute, entitled, Sources and Significance of On-Site Groundwater Infiltration at Service Stations, $32,092.

Project 2002CT3B: 1. The techniques developed in thes project are being incorporated into the next generation of the Impervious Surface Analysis Tool (ISAT), developed by the NOAA Coastal Services Center. 2. An ArcIMS website has been established portraying percent imperviousness at the subpixel level derived from four dates of Landsat data for teh period 1985-2002.

Project CT601: (Rain Garden Demonstration and Workshop). One of the attendees of the workshop was involved in the installation of a rain garden at the Kingston RI town hall, so the workshop has had regional impacts

Publications from Prior Projects

1. 2003CT25B ("Effects of Variation in Nitrogen and Phosphorus Ratios and Concentrations on Phytoplankton Communities of the Housatonic River") - Conference Proceedings - Klug, J.L., Boyle, S. and C. Worth, 2004, Spatial and temporal patterns of nutrient limitation in the Housatonic River estuary, Poster Presentation at the Ecological Society of America Annual Meetin, Portland, Oregon.
2. 2003CT25B ("Effects of Variation in Nitrogen and Phosphorus Ratios and Concentrations on Phytoplankton Communities of the Housatonic River") - Conference Proceedings - E., 2006, Impacts of experimental reduction of the TN:TP ratio on heterocyst production in and relative abundance of cyanobacteria, Oral Presentation at the Amierican Society of Limnology and Oceanography Annual Meeting, Victoria, British Columbia.
3. 2003CT25B ("Effects of Variation in Nitrogen and Phosphorus Ratios and Concentrations on Phytoplankton Communities of the Housatonic River") - Conference Proceedings - Three student posters at the Fairfield University Chapter of Sigma Xi annual student poster session (1 each in 2003, 2004 and 2005).

4. 2001CT621B ("Development of predictive tools to infer inhibition of biological nitrogen removal at POTWs via long term bench-scale and full-scale monitoring") - Articles in Refereed Scientific Journals - Hu, Z., K. Chandran, D. Grasso and B. F. Smets, 2004, Comparison of Nitrifiaction Inhibition by Metals in Batch and Continuous Flow Reactors, Water Research, 38(18), 3949-3959.
5. 2002CT3B ("Development of Regionally Calibrated Land Cover Impervious Surface Coefficients") - Conference Proceedings - Civco, D.L., A. Chabaeva, and J.D. Hurd. 2006. A Comparison of Approaches to Impervious Surface Characterization. IGARSS 2006, Denver, CO>
6. 2002CT3B ("Development of Regionally Calibrated Land Cover Impervious Surface Coefficients") - Other Publications - Hurd, J.D., D.L. Civco, S. Prisloe, and C. Arnold. 2006. Mapping and Monitoring Changes in Impervious Surfaces int the Long Island Sound Watershed, Project Completion Report. 58 p. US EPA Long Island Sound Study.