Connecticut Institute of Water Resources
Annual Technical Report
FY 2004

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 Managment 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 become better aquainted.

Research Program

The USGS 104B program is the financial core of the CT IWR. The Institute does not receive discretionary funding from teh 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 researh projects. When selecting projects for funding, the Institute considers three main areas: 1. technical merit, 2. state needs and 3 CT IWR priorities. An external proposal review process is conducted to ensure that the work will be of high quality and relevant to state water needs. A technical review panel makes recommendations to the Advisory Board, and the Board evaluates the proposal with respect to state needs. CT IWR priorities include student support, new researchers or "seed projects."

In addition to its 104B research work, the CT IWR is administering the UConn Fenton River study, funded by the University of Connecticut. This integrated study analyzes 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 include: 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 is being administered through the CT IWR under the direction of Glenn Warner and Fred Ogden, and involves 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. Total cost of the project is approximately $ 571,000 over three years. A draft preliminary report is currently being reviewed internally and will followed by submission to State agencies for public review and comment.

Chaotic Advection Enhanced Remediation

Basic Information

Title:	Chaotic Advection Enhanced Remediation
Project Number:	2004CT31B
Start Date:	5/1/2004
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. Citation 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).
2. Citation 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).
3. Citation Bagtzoglou, A.C., 2005, Chaotic Mixing and Enhanced Biological Growth: Implications for Wastewater Treatment, Proceedings of International Material Research Congress (accepted).
4. Citation 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.

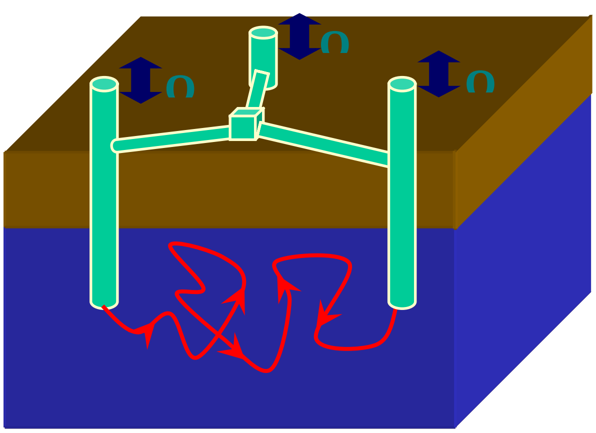

Figure 1. Proposed system

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.

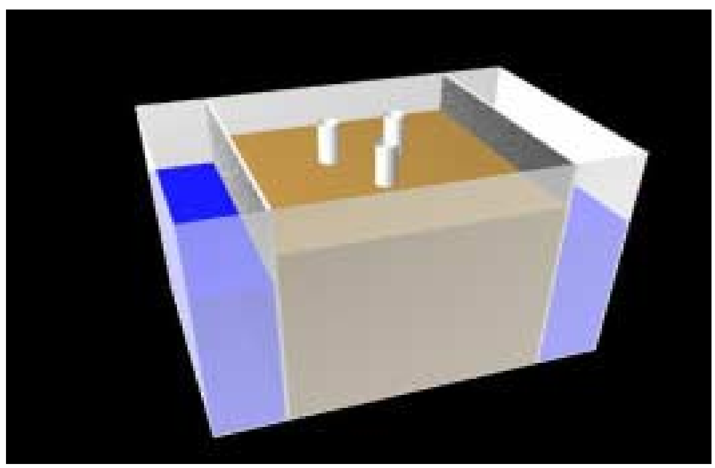

Figure 2. Schematic of experimental facility

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 influence of Alewife, Alosa pseudoharengus, on inland water quality

Basic Information

Title:	The dual influence of Alewife, Alosa pseudoharengus, on inland water quality
Project Number:	2004CT38B
Start Date:	4/1/2004
End Date:	3/30/2005
Funding Source:	104B
Congressional District:	third
Research Category:	Water Quality
Focus Category:	Water Quality, Nutrients, Ecology
Descriptors:	
Principal Investigators:	David M Post

Publication

1. Citation Post, D.M., A. Walters, and W. Foreman. In prep. Anadromous alewive, Alosa pseudoharengus, as a vector of marine derived nutrients.
2. Citation Post, D.M., E.P. Palkovacs, S.R. Gephard, T.V. Willis, and K.A. Wilson. In prep. Ecological and evolutionary implications of restoration of anadromous alewife, Alosa pseudoharengus.

Introduction

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 (Hrbácek et al. 1961, Brooks and Dodson 1965, Carpenter et al. 1987) and because they transport, store, and recycle large quantities of nutrients (Kitchell et al. 1975, Durbin et al. 1979, Kitchell et al. 1979, Kraft 1993, Schindler et al. 1993, Vanni 2002). 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 (Carpenter et al. 1995, Carpenter et al. 1996). 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 (e.g., Schindler et al. 1993, Vanni 2002) or, in the case of anadromous fishes such as alewife, shad, and salmon, import large quantities of new nutrients into lakes (e.g., Donaldson 1969, Durbin et al. 1979), further increasing rates of eutrophication in the lakes they inhabit.

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 growing concern by local lake associations and land owners that the recovery of anadromous herring, in particular alewife, will cause water quality problems in their 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 anadromous 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 populations of alewives. Yet, river herring were a natural part of these ecosystems for thousands of years, and are an important prey for fish, birds and mammals (Loesch 1987). 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 alewife populations, which feed year round in lakes and ponds. 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; Graham 1956). 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.

With the removal of dams and the construction of fish passages, the recovery of anadromous alewives, in some cases, will occur in systems that currently contain landlocked populations. This *secondary contact* (when two species or populations that have had time to evolve separately come back into contact) has important implications for the reestablishment of anadromous populations. Where secondary contact occurs, anadromous populations may interbreed with landlocked populations – or they may not. Reproductive isolation, or the inability of co-occurring populations to interbreed, may evolve rapidly in populations where multiple traits are under divergent selection. For example, freshwater populations of threespine sticklebacks appear to have repeatedly evolved from anadromous populations (McKinnon and

Rundle 2002). If anadromous and landlocked populations are unable to interbreed, anadromous young-of-the-year will face strong competition with well-established landlocked populations. The ability of anadromous herring to compete with landlocked herring is unclear, but there are several interesting potential outcomes when populations with distinct life histories make secondary contact after decades of separation. Because of their greater number and/or because of local adaptations to life in freshwater lakes with low zooplankton densities (a result of the intense predation), landlocked alewives may strongly out compete young-of-the-year anadromous alewives. Alternatively, if young-of-the-year anadromous alewives can hold their own, the presumed advantages of greater growth and fecundity provided by migration to the coastal ocean could enable anadromous herring to rapidly increase in abundance and effectively swamp out landlocked populations. Finally, both landlocked and anadromous alewives could coexist in lakes, either ecologically, with distinct gene pools, or as a single gene pool with some individuals displaying an anadromous lifestyle and others remaining in freshwater their entire lives. Such polymorphisms (situations in which two or more traits are expressed simultaneously in a single population) with regard to anadromy are not uncommon among temperate fishes, especially salmonids (Northcote 1967).

Project goals and accomplishments:

The general goal of this research project is to test the ecological role and evolutionary history of river herring within the context of river restoration efforts. Lines of inquiry are designed to address both basic ecological and evolutionary questions while simultaneously providing information useful to local resource managers for restoration efforts. In the first year of this research I:

1) Developed methods in collaboration with the CT DEP for artificially rearing larval anadromous and landlocked alewives for research and restoration.
2) Tested for differences in the effects of anadromous and landlocked alewives in their first summer of life on water quality in Rogers Lake,
3) Collected much of the data required to develop a general model of nutrient loading by anadromous alewives,
4) Started collecting the landlocked and anadromous alewife samples required to evaluate the evolutionary origin of landlocked populations of alewives as a first step in attempting to understand the outcome of secondary contact between anadromous and landlocked alewife populations, and
5) Started monitoring Linsley Pond, Rogers Lake and two reference lakes to gather pre-manipulation data before fish ladders are installed and anadromous alewives recover into these lakes.

Below, I outline in more detail our accomplishments of our major goals.

Larval alewife aquaculture:

Because landlocked and anadromous alewives are nearly indistinguishable to the naked eye and extremely susceptible to mortality during capture and handling, I had proposed to use hatchery-reared alewives for our experiments in 2004 and 2005. At the time, there was limited expertise to draw upon because there had been few efforts to rear alewives in the lab. One goal of this effort, conducted in collaboration with the CT DEP, the Sound School (Hew Haven's Regional Vocational Aquaculture and Agriculture High School), and Sam Chapman at the

Waldoboro Shad Hatchery in Maine, was to develop alewife aquaculture to facilitate expanded research and restoration efforts.

Results from year one – Initial efforts to rear alewives were not successful. Our failure to rear alewives in captivity was disappointing, but perhaps not surprising – alewives are notoriously difficult to work with in the lab. We have, however, learned a considerable amount about rearing alewives. One of our biggest problems was rapid fungal formation that resulted in the loss of entire broods. By the end of the spawning season, we were making progress in reducing the loss of eggs to fungal infections, and we are confident that we can produce sufficient survival next spring to conduct our experiments. Because of our failure to rear alewives in the lab, experiments in 2004 were stocked later in the summer than originally planned, using alewives approximately 35-40 mm in length. These alewives were caught using a purse seine in lakes where the only alewives we could catch were from purely landlocked or anadromous populations. The disadvantages of using wild-caught alewives are that we were not able to control the genetic variability in our sample (it was likely high in our sampled fish, but ultimately unknown), and that we were unable to stock our experimental mesocosms until later in the summer than originally planned. The advantage was that we were able to capture and stock a sufficiently high density of landlocked and anadromous alewives to conduct our experiment.

Food web effects of anadromous and landlocked alewife:

The shift from an anadromous to an entirely freshwater lifestyle is a significant ecological shift that could strongly impact the potential for anadromous and landlocked populations of alewives to affect water quality through food web effects. There are widespread reports of water quality problems associated with landlocked alewife populations, but few if any reports of water quality problems caused by anadromous alewife populations (Stephen Gephard personal communication; Maine DEP fact sheet on alewife). The difference between landlocked and anadromous populations could emerge from two sources. First, there may be phenotypic differences between landlocked and anadromous alewives, such as feeding efficiency or gill raker size and spacing, which would increase the ability of landlocked alewives to suppress zooplankton populations. Indeed, given the large impact landlocked alewives can have on the size structure of zooplankton communities (e.g., Brooks and Dodson 1965), there is every reason to believe that there is strong evolutionary pressure on foraging ability in landlocked populations. Second, differences in ecological impacts might derive from the extended period of time landlocked alewives spend in lakes and ponds. Of particular importance is the presence of landlocked alewives in the spring of the year. In contrast to anadromous alewives, which do not feed in lakes and ponds in the early spring (Moring and Mink 2002), landlocked alewives can maintain high biomass year round and actively feed as water temperature increases and zooplankton populations emerge after the winter. Even relatively low predation in the spring or early summer can "cap" zooplankton populations at low densities through the summer, while extremely high levels of predation might be required to reduce zooplankton population late in the summer (e.g., Johnson and Kitchell 1996, Post et al. 1997, Post and Kitchell 1997). This pathway for food web impacts is not possible for anadromous populations because of their out migration and represents a potentially important phenotypic difference between landlocked and anadromous alewives.

Results from year one – In 2004 I conducted an experiment in Rogers Lake to test the effects of anadromous and landlocked alewives on food web structure and water quality. The goal of this experiment was to determine if anadromous and landlocked alewives in their first summer of life would have the same or different effects on zooplankton community structure and, therefore, on water quality. In the first week of June, 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 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. Final fish densities in the fish treatments were around 4 alewives per m^2 late August; about twice the density of alewives found in Rogers Lake at the end of August 2004. Densities were higher than found in Rogers Lake because survival of stocked fish was higher than expected. After a year of research I now know that survival rates of fish > 30 mm are higher than previously assumed. In each mesocosm we monitored temperature, dissolved oxygen, total nitrogen and total phosphorous concentrations, water transparency (secchi depth), zooplankton community structure, and phytoplankton biomass.

Figure 1. Experimental mesocosms in Rogers Lake in 2004.

To date, we have fully analyzed water transparency and phytoplankton biomass. Both show similar trends. Figure 2 shows mean secchi depth in each of the three experimental treatments. While there was some tendency for greater water clarity in the no fish treatments early in the experiment, there were no significant differences among the treatments across July and August. This indicates that 1) YOY anadromous alewives have similar effects on food web structure as anadromous alewives when found at the same densities, and 2) removing these pelagic planktivores from the Rogers Lake water column has little immediate impact on water clarity. The first result needs to be confirmed with lower densities of alewives (planned for 2005) and in lakes where landlocked alewives do not presently reside. 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

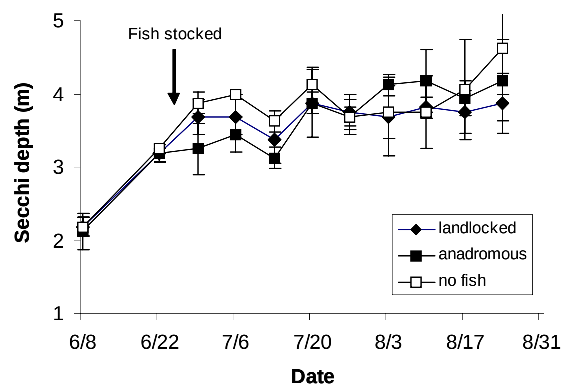

Figure 2. Secchi depth (a measure of light penetration) in the experimental mesocosms. Plotted are the mean +/- 1 standard deviation for each treatment.

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 (to this date) were *Cerodaphnia*, which are not as efficient grazers as are 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 we have observed in various lakes studied by Brooks and Dodson where alewives have recently gone extinct.

Nutrient loading model:

Direct nutrient loading is one of the multiple concerns for the reintroduction of anadromous alewives. Previous research suggests that large populations of anadromous alewives can have substantial effects upon water quality through nutrient loading (Durbin et al. 1979). The three mechanisms through which alewives may affect nutrient are 1) direct excretion of nutrients by spawning adults, 2) nutrient inputs by adult mortality and egg production, and 3) the export of nutrients by YOY alewives as they emigrate in the fall of each year (Figure 3). My goal is to produce a mass balance model to predict net nutrient addition to lakes, such as Rogers Lake, during different stages of anadromous alewife recovery. I am interested in a general model based on the trajectory of population recovery because some of the key parameters, particularly those related to YOY emigration, are likely a function of alewife density with a lake. 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 therefore will provide guidance for the management of lakes targeted for alewife restoration.

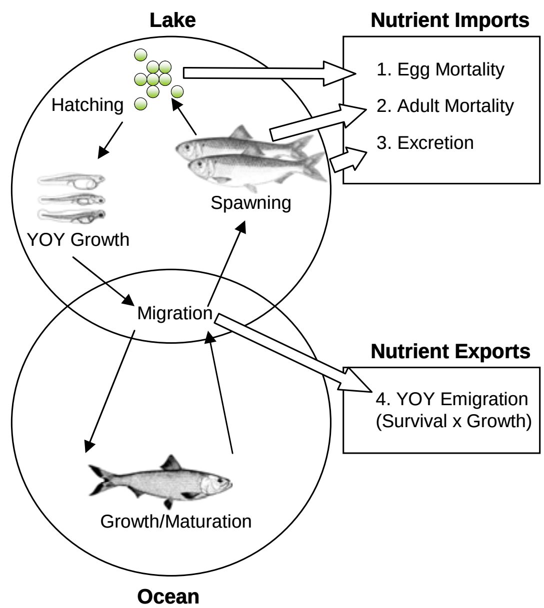

Figure 3. General life history of anadromous alewives highlighting sources of nutrient imports and exports.

Results from year one – In the spring of 2004, I worked with the CT DEP to directly measure nutrient excretion by anadromous alewives at Brides Lake, CT. 200 adult anadromous alewives were placed into the DEP's herring transportation truck (with a circulating water tank to minimize stress on the alewives) and samples were collected to measure concentrations of total nitrogen and phosphorus, nitrate, ammonia, and soluble reactive phosphorus at the beginning, middle (11hrs) and end of the experimental period (22hrs). Water for the experiment was dechlorinated water obtained from the New Haven drinking water supply. The nutrient samples have not yet been fully analyzed (I am waiting for a new nutrient autoanalyzer at Yale, expected in early November, to finish the sample analysis). This experiment will be repeated in 2005.

In addition to the amount of nutrients excreted by adults while in fresh water, the two key parameters needed to estimate nutrient loading are the number of adults entering a lake and the adult mortality rates. Adult mortality has been estimated to be around 50% in Brides Lake, CT (Kissel 1974), and a second study of adult mortality funded by the CT DEP is currently underway (Stephen Gephard, personal communication). Estimates of adult mortality are quite time consuming and these are, likely, the best estimates we will have for anadromous alewife populations. As part of the alewife restoration efforts on Rogers Lake, the CT DEP is planning to put in place a fish counter on the fish ladder. Over the course of the next several years, this fish counter should provide an accurate estimate of the number of anadromous adults entering Rogers Lake. Using allometric relationships between adult alewife size and fecundity, and estimates of the number of returning adults, we will be able to predict the mass of nitrogen and phosphorus added to Rogers Lake in eggs. Using mortality estimates (even though quite rough) we will be able to provide estimates of the mass of nitrogen and phosphorus added to Rogers Lake through adult mortality.

The mass of nutrient export by juveniles is perhaps the most important and most difficult parameter to estimate for our mass balance nutrient budget because it requires both estimates of adult immigration and of the mean size and number of YOY leaving a lake. Both the number and mean size of YOY depend, in part, upon the timing of emigration by alewives. My lab spent a considerable amount of time and effort this summer studying growth and mortality dynamics of YOY anadromous alewives in Brides Lake. We obtained estimates of densities of alewives in Brides Lakes through the summer using a purse seine that samples 100 m^2 of lake area. To increase the reliability of our estimates, sampling was conducted using replicate purse seine sets at night when alewives are higher in the water column and maximally dispersed. A subset of fish was measured to estimate length and mass. Figure 4 shows estimates of YOY alewife densities, body size and an estimate of potential phosphorus export from Brides Lakes in 2004. The final sampling date shown in Figure 4, 29 September, was the first possible date of alewife emigration from Brides Lake because there was no flow out of Brides Lake into Brides Brook between the middle of the summer and 28 September (Brides Brook was dry during that period). Densities on 29 September likely represent a "best" estimate of the number of alewives leaving Brides Lake. Sampling planned for October should further resolve emigration patters in 2004.

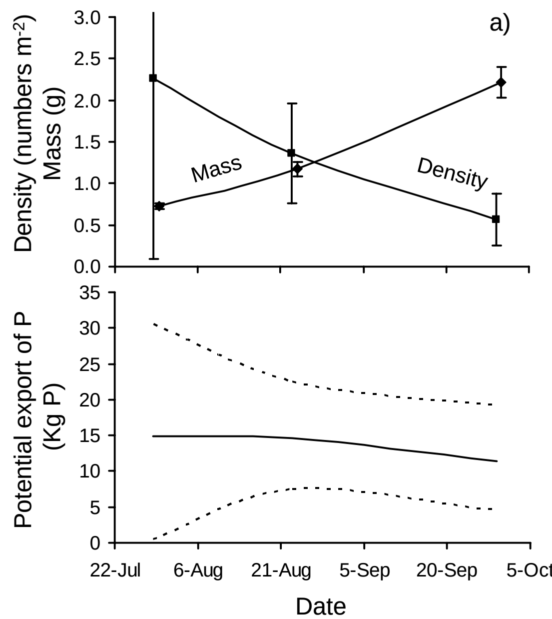

Figure 4. a) Growth, density and b) biomass trends for YOY alewives in Brides Lake, CT, in 2004. The error bars for density and mass are one standard error. Potential export of phosphorous is the product of mass times density times lake area (18.2 ha) times an estimate of percent P (0.42% of wet wt). The dotted lines provide the range biomass estimates possible based on error estimates around mass and density. Biomass, and therefore the potential for nutrient export by YOY, likely peaked near the end of August

The general model for nutrient loading is nearing completion. I have already produced a basic population model and parameterized it using general assumptions about mortality and emigration. The next step in model development is to include density-dependent feedbacks in YOY growth and survival. Preliminary analyses suggest that density dependence among YOY has the greatest potential to influence net nutrient loading.

Evolutionary origins and secondary contact:

One major 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. The origin of landlocked herring is not clear. We are collecting alewives in watersheds where both anadromous and landlocked populations are found (e.g., above and below a dam) to test two different models of the evolution of landlocked alewives. At one extreme, landlocked alewives may have evolved in just one or a few populations and humans may have spread them across the landscape. The alternative model is that landlocked alewives have evolved repeatedly in each watershed as dams eliminated access to the ocean. It is likely that aspects of both models are valid, but determining the relative importance of each mode of life history evolution is important to answering residents concerns.

Data on the evolutionary origins of landlocked alewives also provides information on the possible outcomes of secondary contact. The level of relatedness has important implications for whether anadromous populations may interbreed with landlocked populations in lakes where secondary contact may occur. If anadromous and landlocked populations are unable to interbreed, anadromous young-of-the-year will face strong competition with well-established landlocked populations which could hinder restoration efforts and exacerbate nutrient loading (competition would reduce growth rates, increase mortality rates, and reduce the export of nutrients from the lake). Alternatively, both landlocked and anadromous alewives could coexist in lakes with a single gene pool with some individuals displaying an anadromous lifestyle and others remaining in freshwater their entire lives. Both the evolutionary origins and potential outcome of secondary contact can be addressed using molecular genetic markers that provide powerful tools for reconstructing historical population processes (Avise 2000). Mitochondrial DNA (mtDNA) is commonly used to examine population differentiation and to investigate population-level genealogical relationships. Nuclear microsatellites may be used to assess genetic diversity within populations and to estimate rates of gene flow between populations.

Results from year one – In 2004 we collected landlocked alewives from > 20 populations in CT (including Rogers Lake) and expect to receive fish from the Finger Lakes, Laurentian Great lakes, and the St Crox watershed in Maine before December. We also collected anadromous alewives from about 10 populations in CT and expect to collect fish from another 10-15 populations next spring. Initial analyses are planned for the winter of 2004-2005.

Lake monitoring:

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.

Results from year one – In the summer of 2004, we initiated basic limnological sampling of Linsley Pond and Rogers Lake both to complement our experimental research in Rogers and Linsley, and to provide data on ecosystem condition prior to alewife recovery. We also started sampling two lakes, Pattaganset and Quonnipaug, which will provide reference systems against which future changes in Linsley and Rogers can be compared. In each lake, we measured zooplankton community structure (including body size), secchi depth, chlorophyll *a* concentrations, the abundance of bluegreen algae (cyanobacteria), and standard physical-chemical parameters (TN, TP, DO, temperature, etc.). TN and TP were measured in mixed epilimnetic samples taken through the summer, and will be measured from the entire water column early in the spring during spring mixis. We collected samples of the phytoplankton community, but will only enumerate phytoplankton community structure (biovolume) if the chlorophyll *a* and bluegreen algae data suggest further analyses is warranted. Sampling was conducted every two weeks from the end of May through September, and will be taken once a month when lakes are ice free from Oct. – April.

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

Basic Information

Title:	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:	Ground-water Flow and Transport
Focus Category:	Groundwater, Water Quality, Toxic Substances
Descriptors:	
Principal Investigators:	Gary a Robbins

Publication

1. Citation Robbins, G.A., Metcalf, M., and Budaj, R., Evaluation of Purging and Sampling Bias in Conducting Remediation Compliance Monitoring, Geol. Soc. of Amer., Northeastern Section Meet., March 2005, Saratoga Springs, NY

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 is still on-going. Our preliminary 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.
- None of the common sampling methods provide samples that are representative of formation concentrations as would be predicted by concentration averaging.
- Statistical analysis indicated the three sampling methods tested provide similar results for inorganic constituents and MTBE.
- The first sample taken from a well, irrespective of method, provides the highest concentration.
- 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.

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:

Portable fluorometers for monitoring the dye tracer have been purchased and calibrated. One dye release activity was undertaken to finalize the field sampling logistics. The first field sampling campaign is scheduled for mid-August 2005. During these low flow conditions, the wastewater treatment plant contributes the maximum annual fraction of flow to the Pomperaug River and pharmaceutical compounds are expected to be at their highest 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, Anion Exchange Membrane Soil Nitrate Predicts Turfgrass Color and Yield. Submitted to Crop Science.

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 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 (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 soil nitrate–N (desorbed from anion exchange membranes) and turf growth and quality responses.

- Determine the relationship between soil nitrate–N (desorbed from anion exchange membranes) and nitrate leaching from turf.

- Determine the relationship between soil nitrate–N (desorbed from anion exchange membranes) and nitrogen recovery by turfgrass.

- Determine the relationship between tristimulus and reflectance meter readings 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 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-200 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 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 NO_3–N can be used to predict a critical 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.

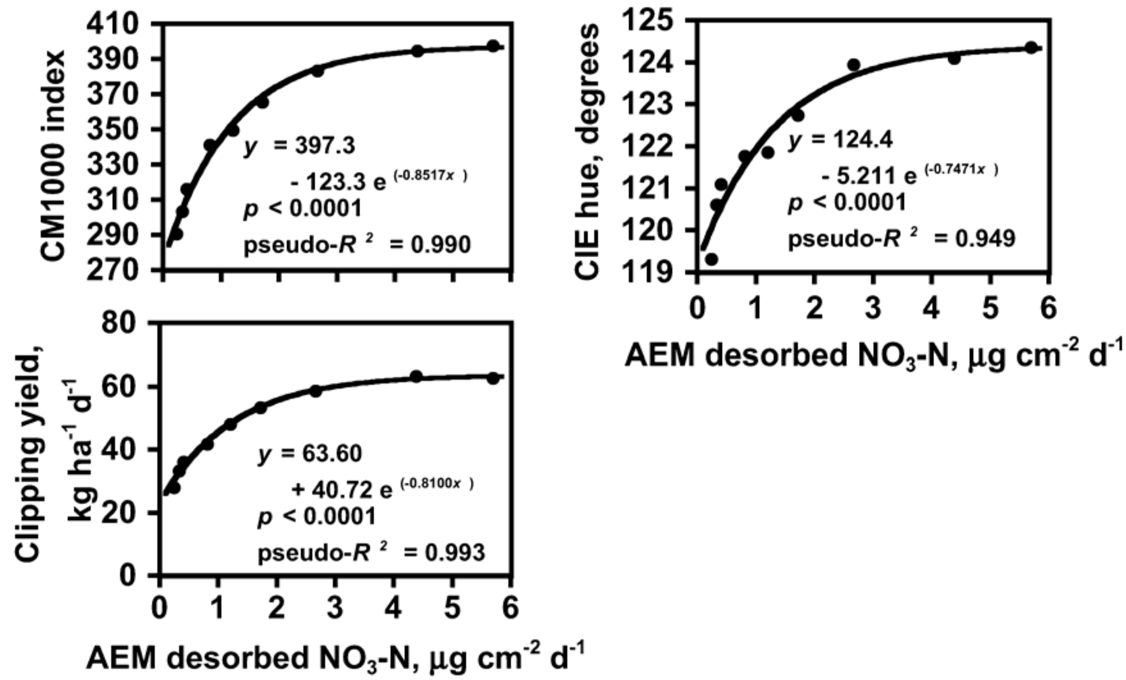

Fig 1. Relationship between soil nitrate–N desorbed from anion exchange membranes (AEMs) and CIE hue (greenness), CM1000 index (relative chlorophyll), and clipping yield (growth) collected from a Kentucky bluegrass–perennial ryegrass–creeping red fescue lawn. Each data point represents the mean of three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

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. Little change was noted, however, in relative chlorophyll content (CM1000 index), and growth (clipping yield) above an AEM desorbed NO_3–N value of approximately 4 µg/cm^2/day (Fig. 3). This suggests that NO_3–N leaching losses will increase if turf is fertilized beyond the point of N sufficiency in the soil, even though turf quality will not improve beyond this point.

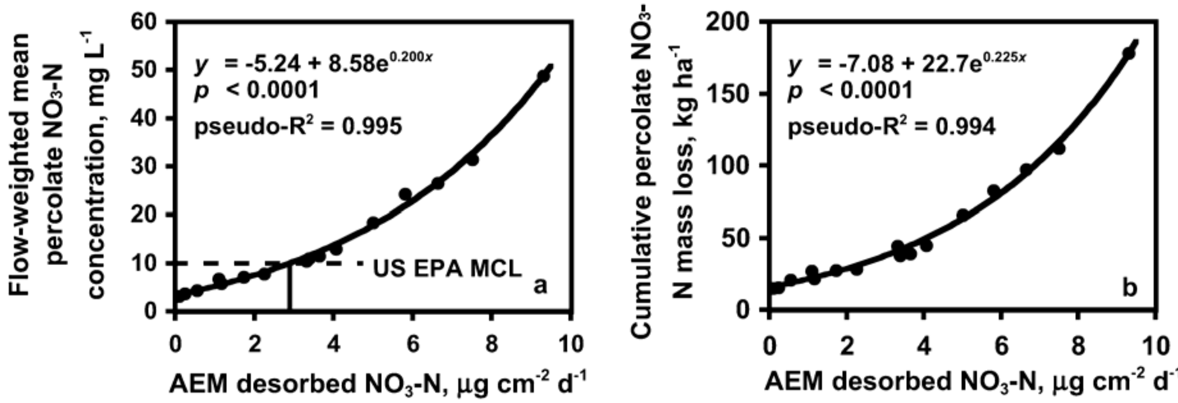

Fig 2. Relationship between soil nitrate–N desorbed from anion exchange membranes (AEMs) and flow-weighted nitrate–N concentrations and leaching losses of percolate collected from Kentucky bluegrass grown in soil columns. Each data point represents the mean of four replications averaged across two growing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

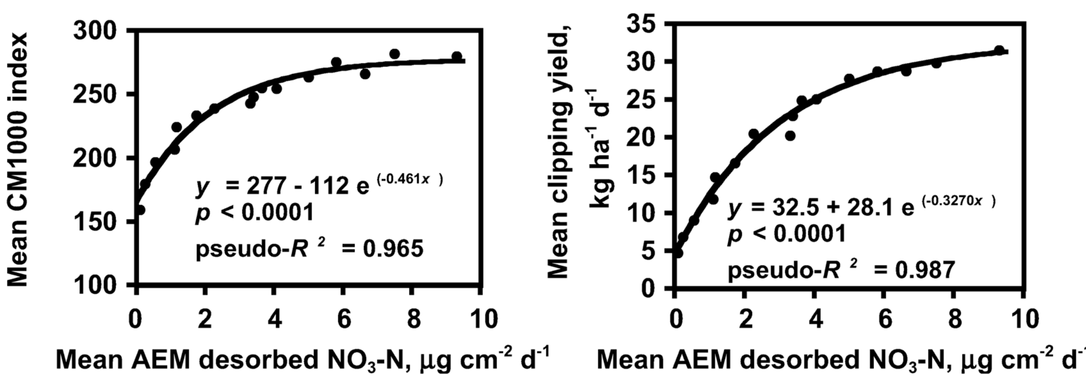

Fig 3. Relationship between soil nitrate–N desorbed from anion exchange membranes (AEMs) and CM1000 index (relative chlorophyll) and clipping yield (growth) collected from Kentucky bluegrass grown in soil columns. Each data point represents the mean of four replications averaged across two growing seasons.

The chlorophyll meter was useful as well in predicting N leaching losses in this study (Fig. 4). Nitrate–N leaching increased exponentially as turf greenness (CIE hue) and relative chlorophyll content (CM1000 index) increased. However, increases were moderate up to a CIE hue value of approximately 250 and a CM1000 index 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.

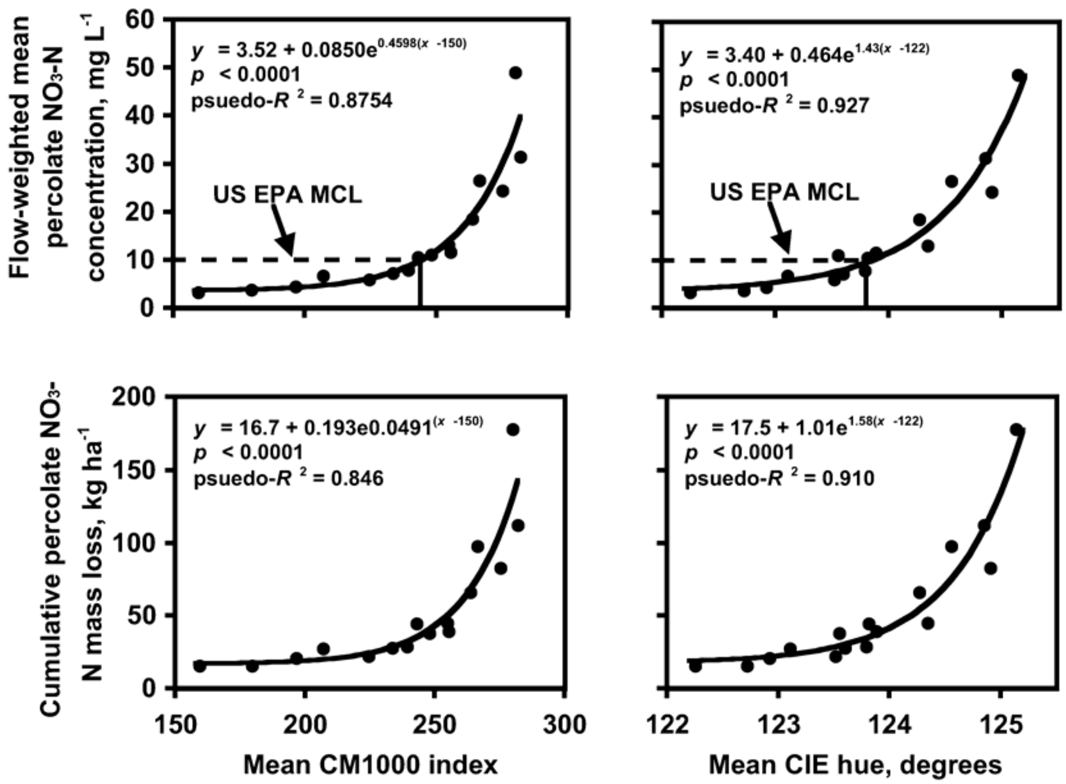

Fig 4. Relationship between CM1000 index (relative chlorophyll) and CIE hue (greenness) and flow-weighted nitrate–N concentrations and leaching losses of percolate collected from Kentucky bluegrass grown in soil columns. Each data point represents the mean of four replications averaged across two growing seasons.

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

Title:	Effects of Variation in Nitrogen and Phosphorus Ratios and Concentrations on Phytoplankton Communities of the Housatonic River
Project Number:	2003CT25B
Start Date:	1/1/2003
End Date:	12/31/2004
Funding Source:	104B
Congressional District:	4th
Research Category:	Water Quality
Focus Category:	Ecology, Nutrients, Water Quality
Descriptors:	
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. 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

The results from objectives 1 and 2 suggest that changes in nitrogen loading to the Housatonic River could impact the phytoplankton community by changing patterns of nutrient limitation. Bioassay experiments showed that 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. These results were presented at the Ecological Society of America meeting in Portland, OR in August 2004. A manuscript based on this part of the project will be submitted by the end of August 2005.

The data from objective 3 is still being processed and analyzed. Preliminary results suggest that the experimental reduction in N:P ratio increased algal nitrogen limitation but did not have a large impact on phytoplankton community composition over the short-term. I plan to finish working on this part of the project by the end of 2005.

Information Transfer Program

The Connecticut Institute’s information transfer program is conducted through a funded project, described below, "Water Resources Technology Transfer Initiative"

Pat Bresnahan is continuing to work with the Connecticut SEAGRANT Program on developing a document, the Connecticut Aquatic Nuisance Species Management Plan. Pat is acting as the plan writer, incorporating material submitted by a committee of subject matter experts and from other sources. The plan will be submitted to the Governor’s office, and when approved by the USFWS, it will enable the state to be eligible for federal funds for ANS managment projects.

Water Resources Technology Transfer Initiative

Basic Information

Title:	Water Resources Technology Transfer Initiative
Project Number:	2002CT5B
Start Date:	3/1/2002
End Date:	2/28/2006
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

1. Title Acid In The Environment: Lessons Learned and Future Prospects. Connecticut College. New London, CT. April 1 - 2, 2005.

The Connecticut Institute of Water Resources information transfer program has several components:

1. Funding of outside IT projects
2. IWR web site
3. Publications
4. Seminar series
5. Conferences
6. Liaison Work

We received no proposals for outside IT projects this year. Internally, however, our IT efforts are conducted through an ongoing 104B IT project, “Water Resources Technology Transfer Initiative” (WRTTI).

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. Our Institute has been selected to participate in the pilot program of the new UCONN Institutional Repository. Institutional repositories are web-based collections of digital items which showcase the writing, research and other intellectual output of a university community, potentially including journal articles and research reports, monographs, working papers, dissertations, honors theses, data sets, and sound and video files. The UConn Libraries are embarking on a pilot project to implement an institutional repository for the University of Connecticut, known as Digital Commons@University of Connecticut. The library has also given us a report on the number of “hits” each of our Special Reports publications has received on their web server. In the first 18 months of operation, there were almost 9000 total hits. Approximately 30% of those hits were on publications related to Connecticut Water Law (see: www.ctiwr.uconn.edu).

Publications: In the past year we finalized the publication of our latest special report, “Precipitation in Connecticut” - an analysis of the past 100 years of rainfal statistics for the state.

Seminar Series: The theme of our 2004-2005 Seminar Series was: “Five Years of CT IWR Sponsored Research.” Over a three-month period, we had presentations from most of the principal investigators sponsored by our program. Talks were arranged into the general categories of water quality, ground water and hydrology, and regional models.

Conferences: This past spring our Institute was pleased to co-sponsor a conference at Connecticut College in New London, entitled: “Acid in the Environment: Lessons Learned and Future Prospects.” Prominent researchers from around the country spoke, with one day devoted to science and the other to policy implications. CT IWR also donated 100 of its Special Reports CD’s to be distributed at the October 2004 meeting of the AWWRA.

Liaison Work: The state of Connecticut, through the work of its Water Planning Council, is undertaking an evaluation of its water policy and managment, paying particular attention to the policies, procedures and information that will be needed to fairly allocate withdrawals in potentially over-allocated basins. Our institute participated in the initial subcommittees that were formed to help define the problems and potential solutions, and we are again being asked to participate in the process of screening and selecting the basins that will initially be studied. Earlier in the legislative year, some members of the planning subcommittees drafted related legislation that mentions our Institute as potential coordinator for activities related to a statewide basin inventory. The legislation was not approved, however.

	WATER QUALITY I:
February 9	• **"Handheld Light Meters and Anion Exchange Membranes to Reduce the Threat of Water Pollution From Turfgrass Fertilizers."** Principal Investigator: Dr. Karl Guillard, Plant Science, UCONN, Presenter: ***Salvatore Mangiafico***, Ph.D. Candidate, Plant Science, UCONN • **"Coupled Physical and Biogeochemical Processes in Ponds."** Principal Investigators: Dr. Tom Torgersen, Marine Sciences and Dr. Peter Rich, Ecology and Evolutionary Biology, UCONN, Presenter: ***Brett F. Branco***, Marine Sciences, UCONN
February 23	**WATER QUALITY II:**
	• **"Effects of Variation in Nitrogen and Phosphorus Ratios and Concentrations on Phytoplankton Communities of the Housatonic River."** Principal Investigator and Presenter, ***Dr. Jennifer Klug***, Dept. Biology, Fairfield University • **"The Dual Influence of Alewife, *Alosa pseudoharengus*, on Water Quality."** Principal Investigator and Presenter, ***Dr. David Post***, Dept. Ecology and Evolutionary Biology, Yale University • **"Occurrence and Fate of Pharmaceuticals in the Pomperaug River."** Principal Investigator and Presenter, ***Dr. Allison MacKay***, Dept. Civil and Environmental Engineering, UCONN
March 30	**REGIONAL MODELS:**
	• **"Development of Regionally Calibrated Land Cover Impervious Surface Coefficients."** Principal Investigators: ***Michael Prisloe*** (presenter), Cooperative Extension System, and Dr. Daniel Civco, Natural Resource Management and Engineering, UCONN • **"A Characterization of the Discontinuous Nature of Kriging Digital Terrain Models."** Principal Investigator and Presenter: ***Dr. Thomas Meyer***, Dept. Natural Resource Management and Engineering, UCONN
April 27	**HYDROLOGY**
	• **"Chaotic Advection Enhanced Groundwater Remediation."** Principal Investigator and Presenter: ***Dr. Ross Bagtzoglou***, Dept. Civil and Environmental Engineering, UCONN • **"Investigating the Influence of Purging on Long-Term Remediation Compliance Monitoring"** *AND* **"A Tracer Dilution Method for Deriving Fracture Properties in Crystalline Bedrock Wells."** Principal Investigator and Presenter: ***Dr. Gary Robbins***, Dept. Natural Resource Management and Engineering, UCONN • **"Monitoring Small Upland Watersheds to Determine Ground Water - Surface Water Interactions and Runoff Processes."** Principal Investigators: ***Dr. Fred Ogden***, Dept. Civil and Environmental Engineering (presenter) and Dr. Glenn Warner, Dept. Natural Resource Management and Engineering

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	4	0	0	0	4
Ph.D.	6	0	0	0	6
Post-Doc.	0	0	0	0	0
Total	13	0	0	0	13

Notable Awards and Achievements

Below is a draft of a press release to be issued by the University of Connecticut concerning the important implications of research conducted by Dr. Gary Robbins under his 104B grant, 2004CT45B:

STORRS, Conn. New University of Connecticut findings suggest that the billions of dollars needed to clean up sites contaminated with the gasoline additive MTBE may be wasted unless more states ban MTBE.

As U.S. lawmakers debate sweeping reforms to the nations energy policy this summer, the House and Senate are set to square off once again on how to handle pollution from MTBE and liability protection for its manufacturers.

To date, remediation efforts have focused on liquid gasoline spills but UConn Professor Gary Robbins found that groundwater contamination also occurs through MTBE vapor releases.

University of Connecticut Professor Gary Robbins, who has studied gasoline contamination of groundwater for nearly two decades, has determined that MTBE (methyl tertiary butyl ether) continued to re-contaminate groundwater through vapor releases for years following the successful 1995 clean-up of his study site on campus, the scene of a 1987 gasoline spill.

After Connecticut banned MTBE from gasoline sold in the state in January 2004, however, Robbins observed the presence of the contaminant at his study site plummet from roughly 1,200 parts per billion to nearly undetectable levels. The U.S. Environmental Protection Agencys safe range for MTBE is 20 to 40 parts per billion.

This is the first study, to my knowledge, that shows the tremendous benefit of banning MTBE in the state, Robbins said of the groundwater analysis he conducted from January 2004 through spring 2005. The good news is that, unlike the pollution from liquid MTBE leaks, the pollution from MTBE vapors seems to just dissipate over time, once you remove the source.

The bad news is that unless more states follow Connecticuts lead and ban MTBE, companies could spend all that money and clean up all the sites of past spills and you could still have re-contamination from vapors.

Estimates for cleaning up sites contaminated by MTBE nationwide range from industry figures of roughly $8 billion to environmentalists figures of $25 billion to $29 billion.

Robbins also points to a 2002 California study that showed nearly 60 percent of tested gas stations in the state experienced subsurface gasoline vapor releases, despite industry measures to prevent leaks including the use of double-lined storage tanks and pipes. That study, however, did not look specifically at the presence of MTBE, he said.

In 2003, a debate in the U.S. Congress over whether to grant MTBE manufacturers protection from lawsuits derailed efforts to overhaul the nations energy policy. Once again this year, the U.S. House version of the energy bill includes liability protection but the Senate version, approved by a 85-12 vote Tuesday, does not.

Regardless of the fate of this years energy bill, Robbins says his findings show the need for more states to ban MTBE or to address subsurface gasoline vapor releases.

A number of states, including Connecticut, New York and California, have passed MTBE bans in recent years but the majority of states still allow it.

Robbins conducted his study at the University of Connecticut Motor Pool, a site contaminated by a gasoline spill in 1987 and cleaned by the state in 1995, from January 2004 to March of 2005. His research was funded by a grant from the Connecticut Institute of Water Resources at the University of Connecticut.

Publications from Prior Projects

1. 2000CT721B ("Title") - Articles in Refereed Scientific Journals - Citation Meyer, T. H., 2004. The Discontinuous Nature of Kriging Interpolation for Digital Terrain Modeling, Cartography and Geographic Information Science 31(4): 209-216.
2. 2001CT741B ("Title") - Articles in Refereed Scientific Journals - Citation Brainerd, R. and G. A. Robbins, 2004, A Tracer Dilution Method for Fracture Characterization in Bedrock Wells, Ground Water Journal, v.42, No 5, P 774-780.