Water Resources Center

Annual Technical Report

FY 2000

Introduction

Two research projects that started with the FY1999 are completed. Two new research projects started with the the FY2000 annual research program of the Rhode Ilsand Water Resources Center. One of them, Water Data Management Systems Integration with Models, works towards a development of a statewide information and decision tool for the management of water resources in Rhode Island. The second project, Realistic Restoration of Streamflow in the Chipuxet Basin, studies the water demands in the Chipuxet water basin to determine the feasibility of returning the used water to the aquifer without transporting it outside of the basin for treatment and discharge. An information transfer project was aslo started. The goal is to develop an updated website for the Rhode Island Water Resources Institute.

Research Program

Basic Information

Title:	Acid Phosphates Activity as an Indicator of Phosphorus
Project Number:	B-04
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	Nutrients, Wetlands, Methods
Descriptors:	Phosphorus, Soil Biochemistry, Runoff, Riparian Forests, Acid Phosphatase
Lead Institute:	University of Rhode Island
Principal Investigators:	Jose A. Amador, Josef Gorres

Publication

1. Savin, M. C., H. Taylor, J. H. Gorres, and J. A. Amador. 2000. Seasonal variation in acid phosphatase activity as a function of landscape position and nutrient inputs. Agronomy Abstracts (92) 391.

Problem and Research Objectives

Increased phosphorus concentrations have accelerated the eutrophication of inland lakes and reservoirs in the northeastern U.S. (Frink 1991). Forested riparian areas are among the best management practices (BMPs) recommended for amelioration of nutrients and other pollutants in runoff (National Research Council 1993). Riparian wetland areas, because of their flatter slopes and high surface roughness, tend to accumulate **sediment-bound P that originates from** upland areas (Lowrance et al. 1984; Peterjohn and Correll 1984; Vought et al. 1994). In addition to sediment trapping, P removal in riparian areas occurs via plant and microbial uptake and adsoprtion to soil particles (e.g. Lyons et al., 1998). Long-term exposure of riparian areas to elevated P levels can affect the ability of plants, microorganisms, and soil particles to act as sinks for P. There is a need for sensitive, fast, and inexpensive method to evaluate the performance of riparian forest soils with respect to P status. The National Research Council's committee on Long-Range Soil and Water Conservation has identified the long-term effectiveness of riparian zones in nutrient and sediment removal as a major concern (National Research Council 1993).

Soil acid phosphatases catalyze the hydrolysis of organic phosphate esters to orthophosphate, and thus constitute an important link between biologically unavailable and bioavailable P pools in the soil (Speir and Ross 1978). Acid phosphatase is ubiquitous in soil and is produced by microorganisms in response to low levels of inorganic P, and its production and activity are inhibited by elevated levels of inorganic P. To test the performance of acid phosphatase as an indicator of P status, we evaluated: (1) the sensitivity of acid phosphatase activity to inputs of inorganic P, and inorganic P and N in simulated runoff over the course of a
variation (within and between seasons) of the response of acid phosphatase activity to inorganic P, and inorganic P and inorganic N. We investigated the effects of inorganic P, and P and N, on short and long-term turnover pools of acid phosphatase activity.

This research addresses Research Priority Area A, Watershed/Ecosystem Management, and specifically subsection d, Effective management strategies for riparian zones and wetlands protection and assessment of their role in the retention and recycling of nutrients and toxicants. We evaluated soil acid phosphatase activity as an indicator of the P status of soil, and thus of potential P saturation and reduced biological removal in riparian forest soils. To the best of our knowledge, the only study on phosphatase activity in riparian forest soils is the one published recently by Amador et al. (1997). Thus, the present study is the first one on the potential use of phosphatase activity as an indicator of P status of riparian forest soils. The results of this study will be of use to land and water managers and land-use planners in monitoring the performance of riparian areas and in assessing their role in water quality enhancement.

Methodology

The study was conducted in moderately well drained (MWD) and somewhat poorly drained (SPD) soil within a drainage catena in a forested riparian area of the Peckham Farm research area of the University of Rhode Island in Kingston, RI (approx. 41˚30' N, 71˚45' W). The soil in the upland portion of the catena is mapped as a Hinckley sandy loam (sandy-skeletal, mixed, mesic

Typic Udorthent), whereas the soils in the lower portions of the catena are mapped as Walpole sandy loam (sandy, mixed, mesic Aeric Haplaquept) and Scarboro mucky sandy loam (sandy, mixed, mesic Histic Humaquept) (Soil Survey Staff 1981).

The experiment consisted of three treatments: (I) control amended with distilled deionized water; (II) simulated runoff containing P only; and (Ell) simulated runoff containing P and N. Both drainage classes received all three treatments. Within each drainage class, each treatment was replicated four times in a randomized block design. Treatment replicates consisted of 1 m X 1 m square plots separated from each other by a 0.5-m wide buffer. Plots received 1 cm of simulated runoff. Application of simulated runoff was made monthly from September through November 1999 and April through October 2000 for a total of eight applications. Simulated runoff was applied evenly to the surface of the plot using a watering can. In all treatments the litter layer was placed on a removable screen that was replaced after the treatments were applied. Nutrients were applied at a rate of 0.75 kg P04-P/ha (Treatment II) or 0.75 kgP04_P/ha and 3 kg N03-N/ha (Treatment III) on every application.

Soil cores (2-cm dia.) were collected below the litter layer (0-5 cm) from each plot in September, October, November, and December 1999 and March, April, May, June, July, August, September, October, and November 2000 approximately four weeks after simulated runoff treatments were applied. In April 2000, soil samples were collected one, two, and four weeks after treatments were applied. Four samples were collected and bulked randomly from within each plot. Soil samples were screened through 2-mm-mesh sieve, placed in sealable plastic bags, and stored in the dark at 4˚C for no more than one week. Storage of soil samples for six to eight weeks under these conditions has been shown to have no significant effect on phosphatase activity (Speir and Ross 1975; Gerritse and van Dijk 1978).

Phosphatase activity was assayed twice for each sampling time: once using field-moist soil samples immediately after collection ("Total" activity, TPASE) and a second time using soil samples that were air-dried for two months ("Recalcitrant" activity, RPASE). The difference between Total and Recalcitrant activity is referred to as "Labile" activity (LPASE). Phosphatase activity was assayed using the method of Tabatabai and Bremner (1969), modified as described by Duxbury and Tate (1981) and Amador et al. (1997) for soils with a high organic matter content. Soil organic matter content was determined by loss-on-ignition for 4 h at 550˚C (Karam 1993). Soil moisture content was determined gravimetrically at 105˚C (Parent and Caron 1993). Soil pH was measured using a 1:10 soil/water (wt:vol) ratio and a pH meter (Hendershot et al. 1993). The amount of bicarbonate-extractable inorganic P was determined colorimetrically (Alpkem 1986) after extraction of soil (Olsen and Sommers 1982).

Principal Findings and Significance

Total phosphatase activity (TPASE) was higher in MWD than in SPD soil throughout the course of the study (Fig. 1). Both MWD and SPD soils exhibited the highest levels of TPASE in April and May of 2000, with minima apparent in October of 1999 and in July of 2000. No statistically significant differences were observed in TPASE activity between the control treatment and treatments that received either P or N + P applications on any of the sampling dates in either soil. Temporal trends in TPASE were identical for all three treatments in both MWD and SPD soil.

Levels of bicarbonate-extractable phosphate (Fig. 2) were significantly higher in MWD than in SPD soil on all sampling dates. The highest levels of phosphate were observed in June of 2000 and the lowest levels in April of 2000 in both MWD and SPD soils. No statistically significant differences were observed in levels of phosphate between control treatments and treatments receiving either P or N + P applications on any of the sampling dates in either soil. Temporal trends in phosphate levels were identical for all three treatments in both MWD and SPD soil.

Recalcitrant phosphatase activity (RPASE) was higher in SPD than in MWD soil throughout the course of the study (Fig. 3). RPASE followed the same temporal trend in MWD and SPD soil, with the highest levels of activity observed in April of 2000 and the lowest levels in October 1999 and July 2000. No statistically significant differences in RPASE were observed between the control treatment and treatments receiving either P or N + P on any sampling date for either soil. Temporal trends in RPASE were identical for all three treatments in both MWD and SPD soil.

Labile phosphatase activity (LPASE) was higher in MWD than in SPD soil on most sampling dates, particularly after December 1999 (Fig. 4). LPASE appeared to have a different temporal trend in MWD and SPD soil. LPASE maxima in SPD soil were apparent in October 1999 and April and July 2000, with the lowest levels observed in December 1999. By contrast, in MWD soil LPASE activity was highest in May 2000 and lowest in October 1999. There were statistically significant differences in LPASE between the control treatment and treatments containing P or N + P in either MWD or SPD soil. Temporal trends in LPASE activity were similar for all three treatments within a particular soil.

None of the phosphatase activities tested appeared to respond to additions of either P or N+P at any time during the course of a year. The levels of P and N+P applied are on the order of those found in runoff waters in the Northeastern U.S. Thus, it appears that phosphatase activity may not be a good indicator of P pollution at the levels normally found in runoff in this region. Examination of the levels of bicarbonate-extractable phosphate shows that additions of either P or N+P had no significant effect on P levels in either soil. The absence of an effect of either P or N + P inputs on soil P levels can be attributable to rapid uptake by both plants and microorganisms and/or complexation by iron and aluminum oxides in the soil. The latter mechanism would be expected to be more important in MWD soil because of the presence of higher levels of metal oxides in these soils (e.g. Lyons et al., 1998).

The absence of enhanced levels of Pin these soils may explain the lack of response in phosphatase levels to nutrient additions. Phosphatase production is halted by the presence of elevated levels of phosphate in the soil. Since nutrient additions failed to increase P levels, phosphatase levels -- especially those for the total and labile enzyme activity - would not be expected to decrease. The absence of a response to nutrient inputs by recalcitrant activity was not unexpected, since this activity is attributable to enzyme that is complexed by soil particles and thus not subject to metabolic control by either microbial or plant cells.

In conclusion, total, labile, and recalcitrant phosphatase activity in soil from a riparian forest failed to respond to P and N and P inputs at levels commonly found in runoff in southern New England. As such, it appears that phosphatase activity may not be a good indicator of P pollution in these landscape features.

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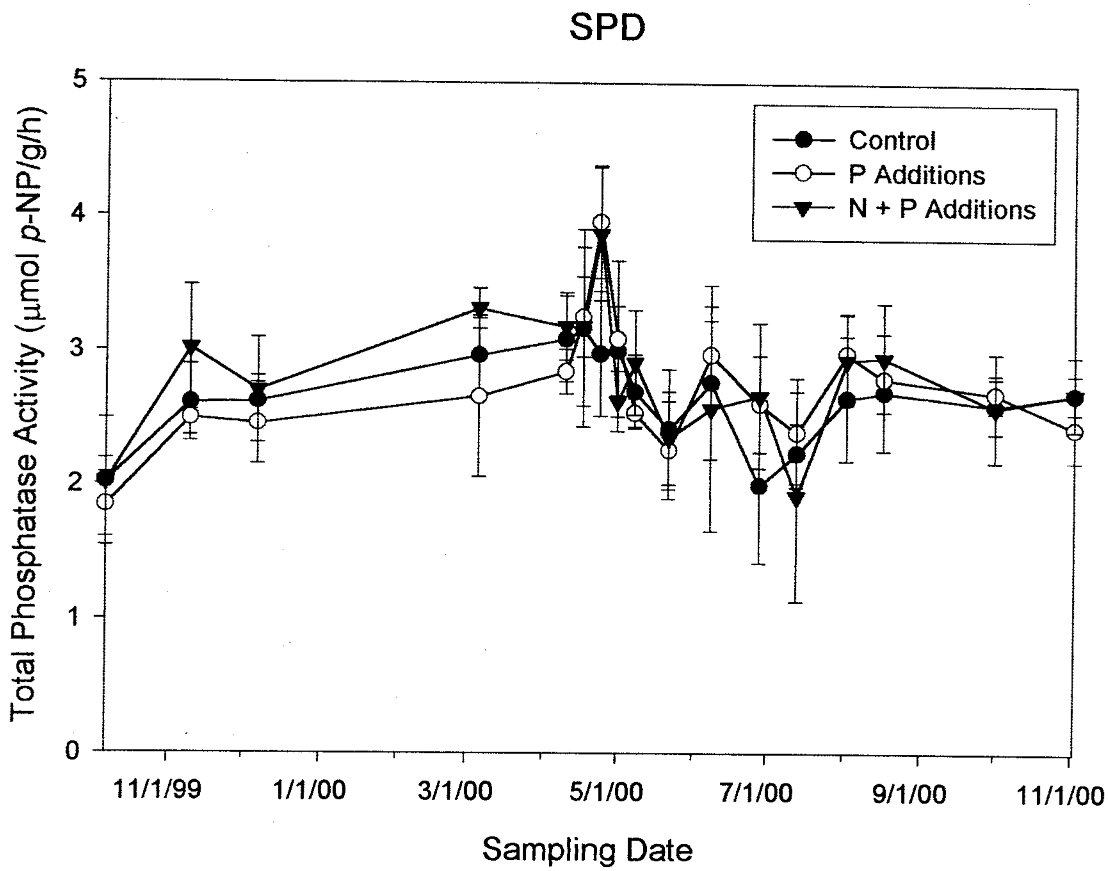
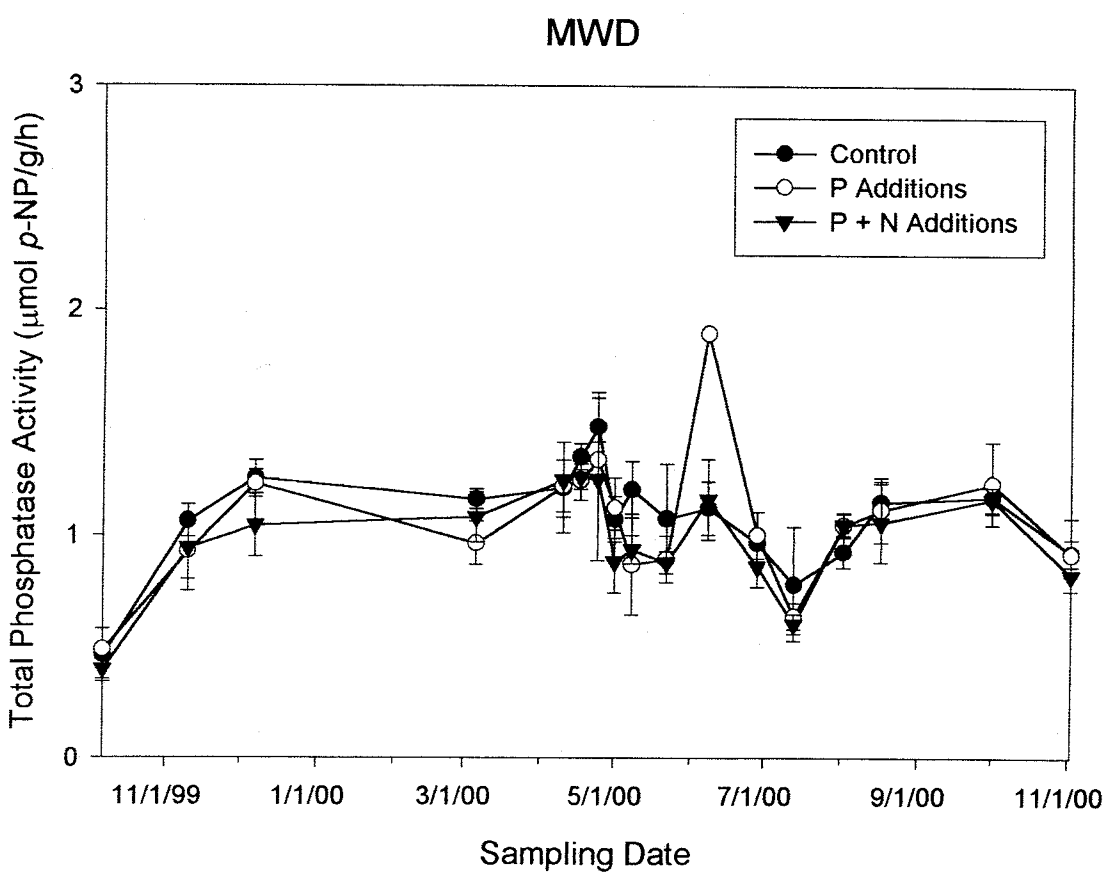
Application of Results

The data collected in this study willbe of use to state and federal agencies charged withmonitoring and enhancing water quality (e.g. RIDEM and USEPA). It may also be of use to land managers involved in making decisions about landscape features and their importance of riparian areas to water quality. Our resultsindicate that the threshold for a statistically significant response of soil phosphatase activity to either P or N + P additions has not been reached. Higher levels of P may be required to saturate the capacity of these ecosystems to take up P. These data will be used to establish a threshold for response of phosphates activity to P inputs in these soils.

Fig. 1

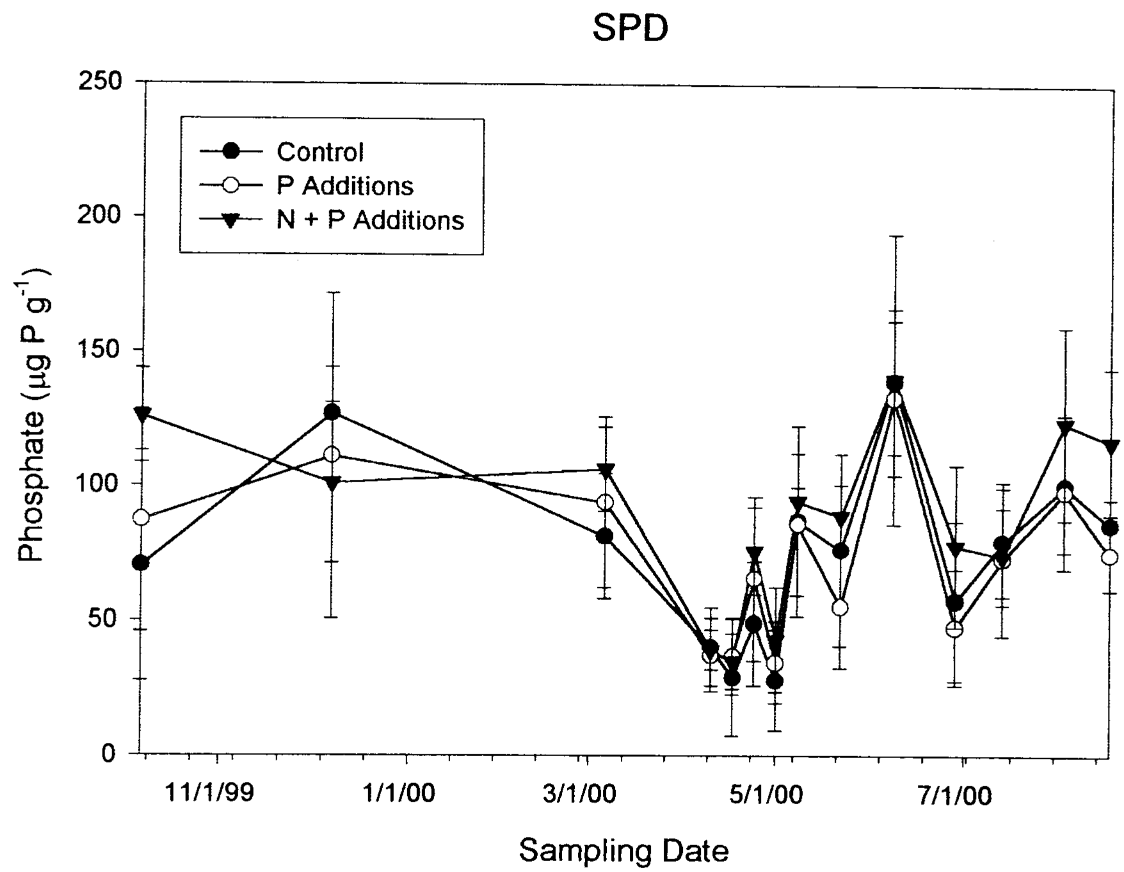


SPD
Control
P Additions
N + P Additions
Total Phosphatase Activity (µmol p-NP/g/h)
0
1
2
3
4
5
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
9/1/00
11/1/00
Sampling Date



MWD
Control
P Additions
P + N Additions
Total Phosphatase Activity (µmol p-NP/g/h)
0
1
2
3
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
9/1/00
11/1/00
Sampling Date

Fig. 2


SPD
Control
P Additions
N + P Additions
Phosphate (μg P g-1)
250
200
150
100
50
0
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date

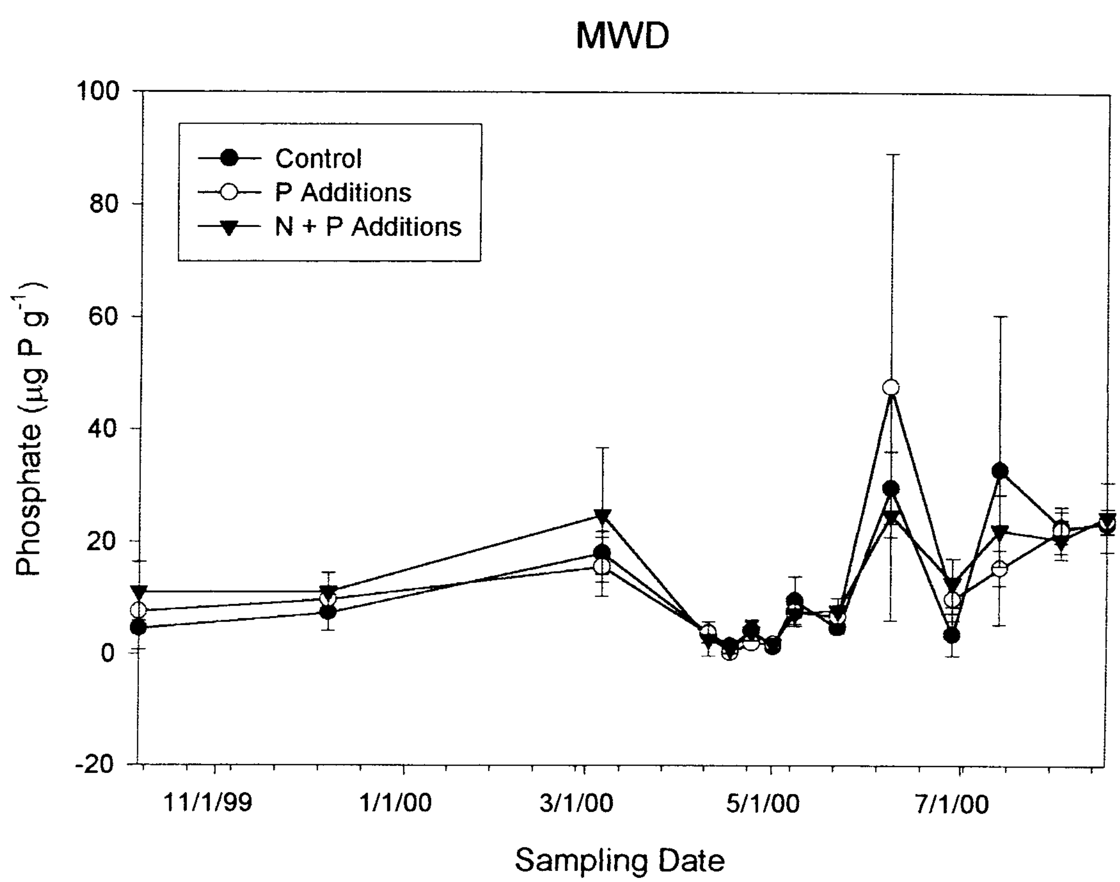

MWD
Control
P Additions
N + P Additions
Phosphate (μg P g-1)
100
80
60
40
20
0
-20
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date

Fig. 3

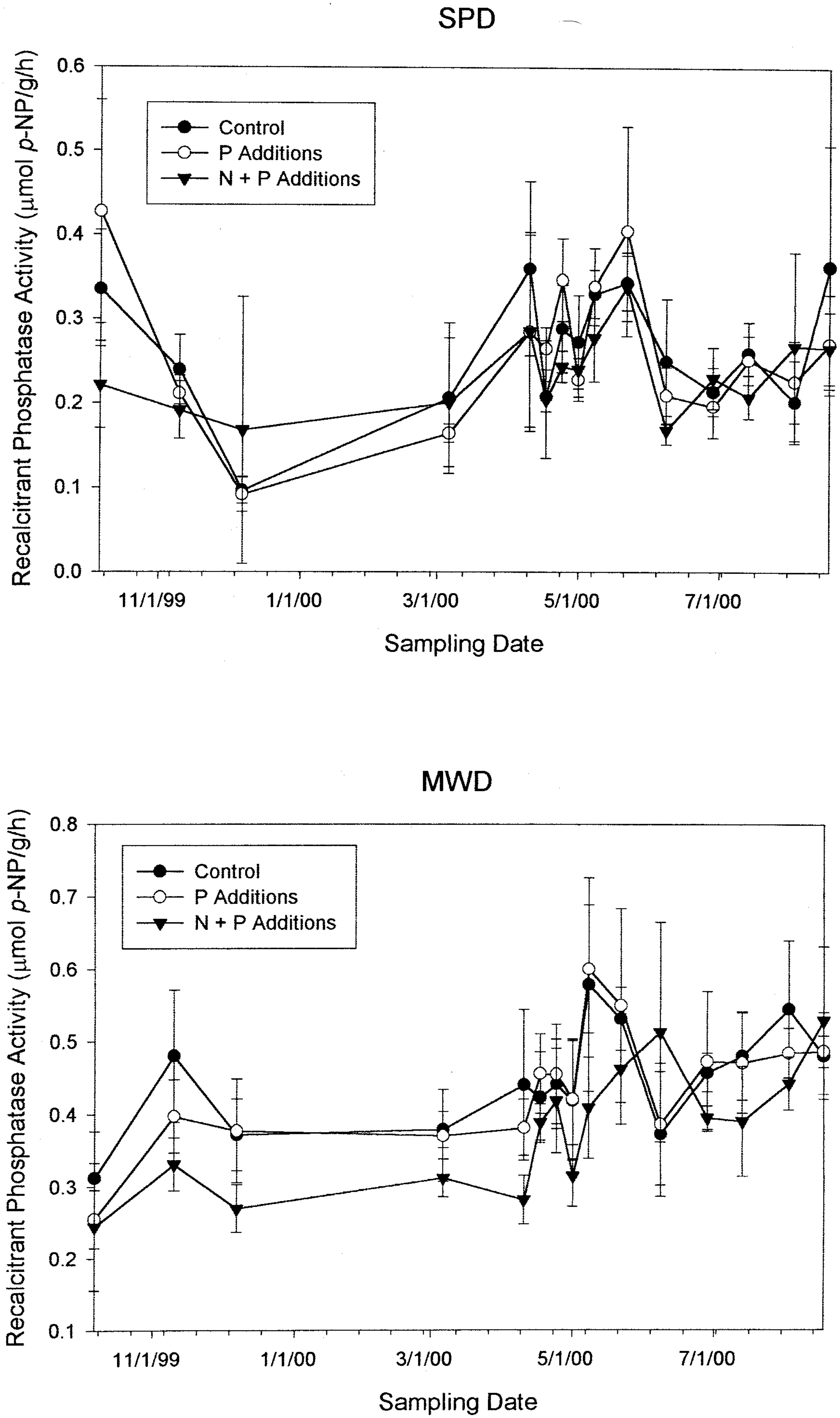
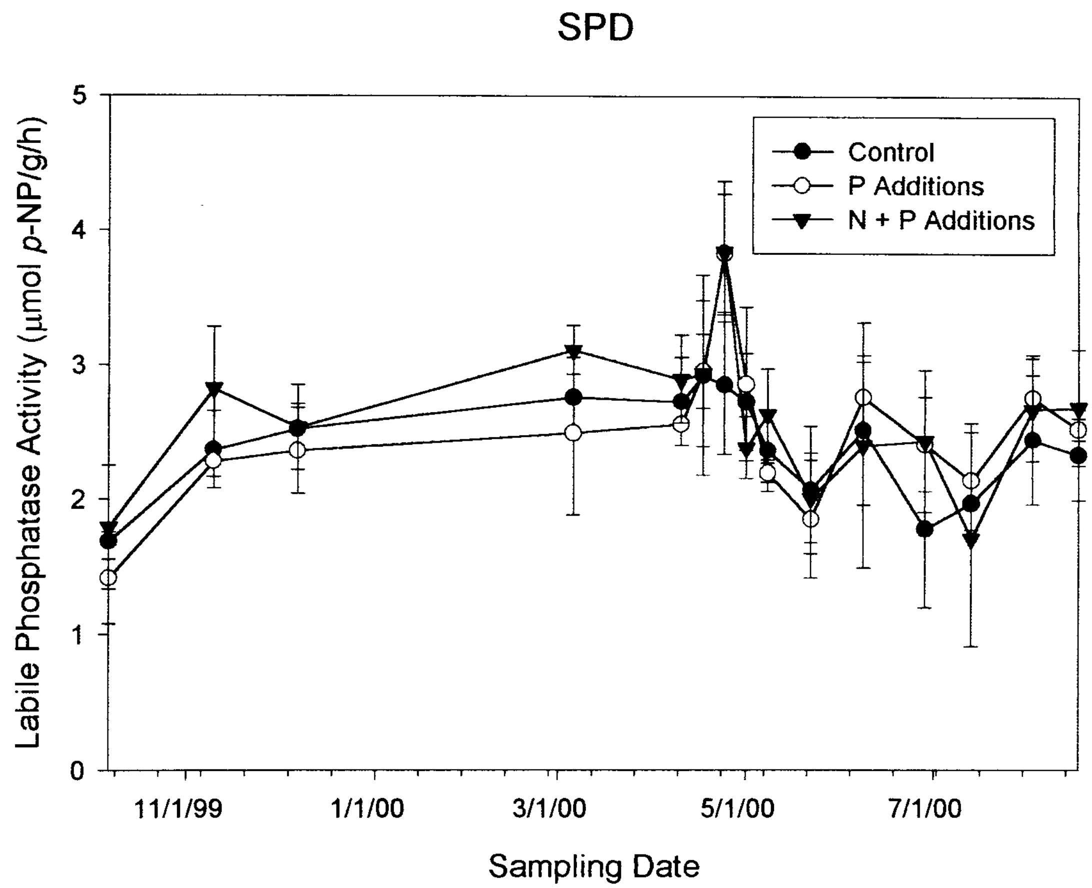
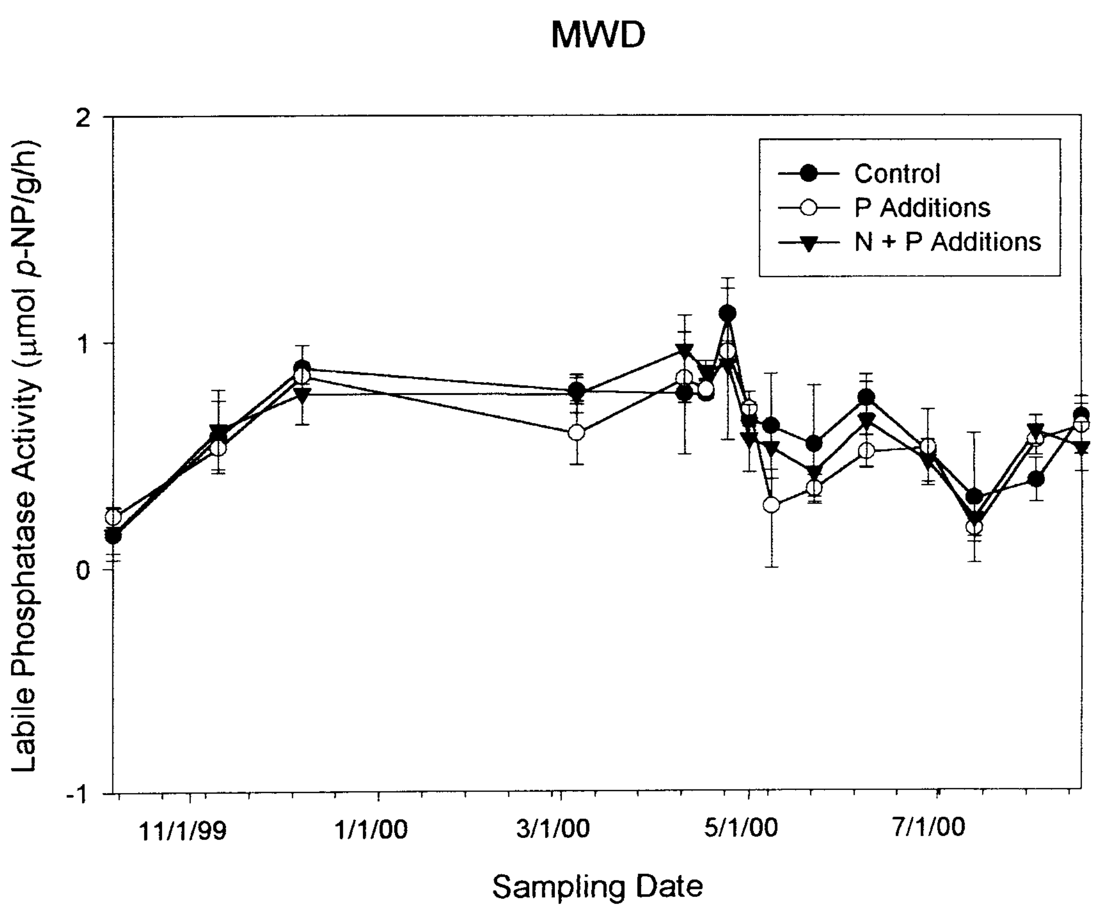

SPD
Recalcitrant Phosphatase Activity (µmol p-NP/g/h)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Control
P Additions
N + P Additions
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date
MWD
Recalcitrant Phosphatase Activity (µmol p-NP/g/h)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Control
P Additions
N + P Additions
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date

Fig. 4



SPD
Control
P Additions
N + P Additions
Labile Phosphatase Activity (μmol p-NP/g/h)
5
4
3
2
1
0
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date



MWD
Control
P Additions
N + P Additions
Labile Phosphatase Activity (μmol p-NP/g/h)
2
1
0
-1
11/1/99
1/1/00
3/1/00
5/1/00
7/1/00
Sampling Date

Basic Information

Title:	Isotope Hydrology Investigation of the Pawcatuck Watershed
Project Number:	B-02
Start Date:	3/1/1999
End Date:	2/28/2001
Research Category:	Not Applicable
Focus Category:	Hydrology, None, None
Descriptors:	Groundwater, geochemistry, isotopes, water quality, water-use, water supply
Lead Institute:	University of Rhode Island
Principal Investigators:	Anne Veeger

Publication

1. Veeger, A.I., D. Meritt, and I. Cole., 2001. Isotope Hydrology of the Pawcatuck Watershed, Southern Rhode Island. Rhode Island Water Resources Center, University of Rhode Island, Kingston, RI, 19 p.

Problem and Research Objectives

The Pawcatuck Watershed of southern Rhode Island and southeastern Connecticut covers approximately 300 square miles. The watershed is comprised of the Pawcatuck River and its tributaries, including the Chipuxet, the Queen, and the Wood Rivers of Rhode Island. Significant ground-water resources underlie portions of the watershed including aquifers designated as sole-source aquifers by the US Environmental Protection Agency in 1988. The watershed is experiencing rapid population growth, increasing from 100,000 in 1970 to over 140,000 by 1990 and is the focus of an interagency and interstate effort to collect and disseminate information on the natural resources of the watershed for the purpose of fostering effective resource management (Pesch, 1998).

Water-resources management in Pawcatuck River Watershed, and New England as a whole, is complicated by the complex nature of the ground-water/surface-water system. Ground water occurs in two distinct types of aquifers here: fractured bedrock aquifers, predominantly of igneous and metasedimentary origin, and unconsolidated sedimentary aquifers of glacial origin. These aquifers are spatially heterogeneous resulting in complex flow relationships (Veeger and others, 1997; Dickerman and others, 1997). Surface-water bodies including wetlands, ponds and streams are often in hydrologic connection with the ground-water system.

Although total water use in the United States has remained relatively constant over the past 10 years (Solley and others, 1998), the proportion of water withdrawn in traditionally rural areas is increasing as a result of the outmigration of urban populations. In Rhode Island, total public-supply withdrawals have decreased from 116 million gallons per day in 1985 (Mgal/d) to 114 Mgal/d in 1995; groundwater withdrawals by rural self supplied domestic users, however, have increased by 30% over the same period, from 5.6 Mgal/d to 7.3 Mgal/d (Johnston and Baer, 1987; Solley and others, 1998). Developers, farmers and conservation groups in these rural areas are often at odds over what constitutes a "safe yield" and what the environmental impacts of a proposed withdrawal or development will be. Because the surface water and ground water systems form an integrated hydrologic unit, withdrawals from aquifers affect not only watertable elevations, but stream flows and wetland habitat as well. Environmentally sound resource management must be based on detailed information about the interaction between surface water and ground water, and the dynamics of recharge/discharge relationships in complex aquifer systems. Acquisition of these data requires a more detailed investigation of watershed hydrology than has typically been conducted in many watersheds. An isotope hydrology investigation was therefore conducted to address these issues.

The objectives of this study are:

1. Develop a database of the isotopic composition (δD and $\delta^{18}O$) of precipitation, surface water and ground water in the watershed.
2. Assess the degree of interaction between the surficial materials aquifers and surface water.
3. Assess the degree of interaction between the surficial materials aquifer and the bedrock aquifer, and
4. Assess the influence of seasonal precipitation on recharge to both the surficial material and bedrock aquifers.

This report presents the isotopic data, and a brief discussion thereof, for surface and groundwater samples collected during June 1999 - November 1999. These data are the basis of an ongoing Master's thesis (D.L. Merritt, Department of Geosciences.

Methodology

This project is designed to assess the hydrologic relations between precipitation, surface water, wetlands, glacial aquifer ground water and fractured bedrock ground water using isotopic and hydrogeochemical indicators. To this end, samples of ground water, surface water and precipitation were collected over a one year period from sampling stations located throughout the watershed. Surface water samples were collected approximately monthly during summer and fall 1999 from a network of ponds and streams. Streams were sampled at USGS gaging stations to permit correlation with stream discharge rates. Ground water samples were collected from 21 existing domestic wells. Numerous domestic supply wells penetrate the fractured bedrock, permitting extensive sampling of the bedrock aquifer without the associated costs of drilling new wells. A well survey was sent to homeowners in the study areas to identify wells suitable for sampling as part of the study. Only those wells for which depth and aquifer material information are available were used. Precipitation samples were collected in a rain gage located in the village of Usquepaugh in the eastern portion of the watershed. Although, determination of average annual isotopic composition of precipitation requires a long term record, these data mark the start of such a data-collection effort.

Water samples were collected for laboratory analysis of inorganic constituents including: calcium, magnesium, sodium, potassium, manganese, iron, chloride, sulfate, nitrate, orthophosphate, alkalinity, and dissolved silica. Appropriate sample preservation techniques were used in accordance with Standard Methods for the Examination of Water and Wastewater (Clesceri, 1989). Field data will include temperature, electrical conductivity, dissolved oxygen, and pH.

Water samples were analyzed for $\delta^{18}O$ and δD under the direction of Dr. Chris Eastoe at the Environmental Isotope Laboratory at the University of Arizona. Chemical analysis of major dissolved constituents is ongoing at the University of Rhode Island hydrogeology laboratory.

Principal Findings and Significance

Precipitation

Precipitation sampling was initiated in June 1999 and is ongoing to generate a long-term stable-isotope database for precipitation in southern New England. Data for the period June 1999 to August 2000 are included in this report. These data exhibit a strong seasonal variation with winter precipitation on average yielding significantly lighter isotopic compositions than summer precipitation. Precipitation during the period mid-October to mid-February is generally at least 6 per mil lighter in $\delta^{18}O$ and 15 per mil lighter in δD than summer precipitation. Interestingly, several precipitation events during the balance of the year (e.g. September 1999 and May 2000) yield isotopically light precipitation compared to the seasonal average. This may be attributable to storm track and/or temperature over the vapor source. Precipitation as heavy as -2.0 per mil $\delta^{18}O$ and -8 per mil δD was recorded in September, 1999 during tropical storm Dennis, and as light as -31.1 per mil $\delta^{18}O$ and -226 per mil δD during a January, 2000 snowfall. The isotopically heavy signature of precipitation during tropical storm Dennis reflects the rapid advection of moisture from the warm late-summer ocean. The markedly depleted snow sample collected on January 20, 2000 is consistent with late-stage precipitation from a cold air mass that originated inland without deriving additional moisture from the Atlantic Ocean.

The $\delta^{18}O$ and δD composition of precipitation varies as a function of the evaporation and condensation history of the water. Temperature, vapor source, and distance from vapor source produce the distinctive signature of precipitation from a given storm event. The relationship between $\delta^{18}O$ and δD, however, is relative constant and is described by the meteoric water line. The local meteoric water is described by the relationship $\delta D = 7.47\ \delta^{18}O + 8.56$. If the outlier at -31.1 per mil $\delta^{18}O$ and -226 per mil δD is excluded from the correlation the local meteoric water line becomes $\delta D = 7.25\ \delta^{18}O + 7.28$. The global meteoric water line is $\delta D = 8.17\ \delta^{18}O + 11.27$ (Rozanski et al., 1993).

Surface Water

Surface-water samples were collected from 18 sites in the Pawcatuck Watershed during the period June 1999 to November 1999. The measured isotopic compositions range from -1.3 $\delta^{18}O$, -21 δD to -6.8 $\delta^{18}O$, -40 δD. The Wood River (at Skunk Hill Rd) and the Queen-Usquepaugh River (at Rte 2) yielded on average the most depleted samples with averages of-6.3 $\delta^{18}O$, -39.4 δD and -6.7 $\delta^{18}O$, -39.3 δD respectively. Worden Pond yielded the most isotopically enriched samples with an average of -2.67 $\delta^{18}O$ and -21.9 δD.

Many of the surface water samples plot along the local meteoric water line indicating little or no evaporative enrichment. A number of samples, most notably the pond samples, are isotopically enriched and fall below the meteoric water line. This trend is consistent with evaporative enrichment. The resulting distinctive signature will make it possible to identify surface-water contributions to ground-water withdrawals using an isotope mass-balance approach.

Ground Water

Ground-water samples were collected from 21 wells in the study area. The isotopic composition of the ground-water samples ranges from -6.2 $\delta^{18}O$, -40 δD to -8.1 $\delta^{18}O$, -49 δD. The ground-water samples fall along the local meteoric water line and correspond to a fairly narrow range of precipitation values.

The average isotopic composition of the ground-water samples (-7.3 $\delta^{18}O$, -44 δD) is consistent with the isotopic composition of precipitation during the period October to March, suggesting a strong seasonal bias in ground-water recharge. The average ground-water isotopic composition is also significantly lighter than all the surface-water samples collected during the June

1999 November 1999 surface water sampling period. Isotopic fingerprinting of ground-water contribution to surface-water bodies is therefore possible, including identification of base-flow contributions and storm hydrograph separation.

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Basic Information

Title:	Water Data Management Systems Integration with Models
Project Number:	B-02
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Engineering
Focus Category:	Management and Planning, None, None
Descriptors:	Water Recources Management, GIS, Modelling, Planning, Database
Lead Institute:	University of Rhode Island
Principal Investigators:	George Tsiatas, Leon T Thiem

Publication

1. Vitale, M., 2001, Water Data Management Systems Integration with Models, MS Thesis, Department of Civil and Environmental Engineering, College of Engineering, University of Rhode Island, Kingston, RI, 143 p
2. Thiem, L., M. Vitale, G. Tsiatas, and C. McGreavy, 2001, Water Data Management Systems Integration with Models, Rhode Island Water Resources Center, University of Rhode Island, Kingston, RI, 145 p.

Problem and Research Objectives

A critical management issue faced by government is to improve the availability and usefulness of water-related information, regardless of whether it is generated by government or other contributing sectors. Currently, several state and federal agencies collect information for research and/or resource management purposes. These organizations do not necessarily plan together regarding computer architecture, decision support systems, or the manner in which information is classified, stored and/or electronically shared. In the absence of a single overarching authority or a master plan to integrate existing data, the ability to maximize water use decisions is significantly compromised.

In order to facilitate decision making, there is a lot of development towards integrated decision support systems which combine advanced modeling techniques with software engineering to create integrated solutions for water and natural resources management. Such systems support integration of databases, GIS, models and analytical tools into a common, easy to use, framework.

There are several problems in developing such an integrated management system. First, there are various database models available including relational, spatial and geo-relational databases. There are various formats of GIS based systems (MapInfo, ARC/VIEW, etc). There are many sources of information related to water resource management but these may be in paper format or various nonconforming electronic formats. Finally, there are various analytical tools which can be used to model and analyze the information included in the databases.

In Rhode Island, there are many agencies and groups involved with water resources data collection and management issues. The RI Water Resources Board (WRB) is in the process of developing a long-range technology plan that has as one of its most significant features, the establishment of electronic systems to accommodate water supply system management data. In 1999, the WRB entered into a cooperative agreement with the US Geological Survey to study and amass data in the Wood Pawcatuck watershed. Partners in Resource Protection (PRP), a local stakeholder group, is implementing the RI Watershed Approach in the Wood-Pawcatuck watershed early in 2000. This has been identified as a "Priority Watershed" according to the Unified Watershed Assessment developed under the federal Clean Water Action Plan.

The ultimate goal of the proposed research is to build a statewide water information network containing water data pertinent to all watersheds. This will be eventually containing physical, spatial and even financial criteria. It will be accessible online to multiple users and the public. The main idea is to improve upon the existing knowledge base and information architecture already in place, to join or integrate systems wherever feasible, and design new network components that are likely to be necessary. This approach will help government and users of information operate more efficiently by eliminating data redundancy between information providers, by linking multiple databases to their respective geographic data and centralizing or sharing the maintenance and distribution points of water-related data.

The proposed research project consists a first phase towards achieving the overall goal. The objectives of this first phase are to provide the background information needed for the successful integration of management data and various analytical models. Specifically, the following objectives will be pursued:

a. Collect information on water data management systems employed in various states.
b. Collect information on various models available for the analysis, visualization and use of the data to support management decisions.
c. Investigate the integration of such models with data management systems.
d. Identify the water resources related data available in Rhode Island including their format.
e. Recommend additional data needed for a sound decision making system.
f. Provide a recommendation on an integrated data management system.

Methodology

A state-of-the-art literature review is carried out on models used for hydrologic studies. Their usefulness and limitations are evaluated. The linkage and support of GIS is examined. Agencies are surveyed to collect information on water resources management systems employed and to determine the degree of information technology currently available to Rhode Island water suppliers. Risk assessment models and the use of the MANAGE model are investigated with regards to water resources management.

In order to understand the status of local data management and technology, information is gathered on the water supplier's data collection systems, data transfer methods and use of modeling and GIS. The data collection methods range from manual collection of data, such as meter reading, to advanced systems like a supervisory control and data acquisition system (SCADA). The SCADA system automatically collects information from remote transfer units (RTU's) such as water pressures and tank levels, and can either display the information or place it in a spreadsheet ready for analyses. Modeling for the water suppliers is limited to hydrologic modeling, hydraulic modeling, or both. The GIS capabilities among the modelers are investigated to determine questions of scale and the applicability of the existing Rhode Island Geographic Information System (RIGIS). The use of programs such as AutoCAD and other drafting tools are also investigated among the suppliers.

The use of risk assessment and screening level models is investigated. Most water suppliers and state agencies do not have the time or money to perform extensive field investigations to determine pollution hotspots or which tracts of land should be purchased for open space acquisition. These groups benefit from the capabilities of a screening level model approach, such as the MANAGE model. This model was created by the University of Rhode Island Cooperative Extension (URICE) as a screening level model that uses existing GIS databases as input to target potential pollution hotspot areas. The use of less complex, screening levels models for water resources management is investigated. Special attention is focused on model applications and their benefits when compared to more complex models.

Principal Findings and Significance

Various hydrologic models for use in water resources planning and management are reviewed. Lumped parameter and distributed parameter models are investigated for their uses, strengths and limitations. Geographic Information Systems (GISs) can support these models by generating automated input, increasing the accuracy of the system modeled and displaying model output graphically. Spatial Decision Support Systems (SDSSs) provide the framework for the integrated model-GIS system. This system allows the designer to more effectively judge how the model should be geared to the system.

GIS is a beneficial tool for working with geographical data, but modeling is limited to complex overlays. Most models for water resource planning do not have well-developed capabilities for analyzing and displaying spatial data. Combining GISs with SDSSs strengthens both of these technologies. Typical model set-up encompasses a significant amount of time and effort for the modeler, who can increase the model set-up time by taking advantage of GIS functionality. Models utilizing GIS, such as urban runoff analyses, wetland effects on flood volumes and urban development effects on runoff, are investigated.

However, when any real system is generalized in a modeling exercise, there are inherent inaccuracies. Concerns with modeling in water resources, such as issues with scaling, calibration and verification, and the simplification of parameters versus overparameterization are examined herein. The more complex model systems are compared to more generalized model efforts, such as screening level assessments. The usefulness of the screening level assessments is demonstrated by a study of pollution risks in Wickford Harbor, in East Greenwich, Rhode Island, using the locally derived MANAGE model system.

The smaller scale assessments reviewed indicate the benefit of GISs and models, which aid planners and engineers, but it is first necessary to understand the level of technology locally. Therefore, types of data collection, model systems and level of GIS use among the major water suppliers in Rhode Island are investigated.

Most of the suppliers are moving towards the more automated data collection systems and are implementing GISs and programs such as AutoCAD for more functionality. However, over fifty (50) percent of the suppliers still send crews out to collect data such as meter readings. The hard copy storage of this data impedes system-related investigations, such as detecting leaks more quickly. The most automated data collection system used by about thirty (30) percent of the suppliers is a Supervisory Control and Data Acquisition (SCADA) system that can control operations in treatment plants, as well as continuously check system water levels and pressures. This system also stores the data in a digital format ready for analyses. Modeling capabilities among the suppliers are limited to hydraulic modeling on their distribution system. Approximately two-thirds (2/3) of the suppliers are using a version of WaterCAD by Haestead Methods for management of their system. Newer versions of WaterCAD can utilize drawings in AutoCAD to run the model once the attributes of the system are added. In addition, WaterCAD also has GIS and SCADA interfaces for even more integrated analyses, which is important since many suppliers are implementing SCADA systems.

About thirty-five (35) percent of the suppliers have a functioning GIS. The use of GIS and level of automation differs among the towns. Some suppliers have created their own mapping system due to the resolution of existing, state GIS datasets. A recurring sentiment voiced by the suppliers is that they would advocate all of these technology upgrades for their system, but face opposition. The opposition is mainly due to the lack of trained personnel to work with the software, and budget constraints that allocate any additional funding towards capital improvements, such as replacing older pipes.

Models are simplifications of reality. They have certain limitations and it is difficult to determine how these limitations affect the prediction capabilities of the model. Many models treat systems as lumped systems where parameters are averaged over the study area. In reality, the different variables may be spatially heterogeneous throughout this area. The simpler, lumped models cannot account for these heterogenities, nor are they advanced enough to take advantage of more advanced technology, such as GIS datasets. GIS technology strengthens modeling since it is able to assimilate many datasets such as topography, land use and other spatial data. More complex models can utilize this technology, which accelerates the time it takes to set up the model. Conversely, these "complex," distributed parameter models require extensive input parameters and this contributes to reduced accuracy and increases the model set up time. Such models are generally inefficient for studies that require more rapid assessments. Therefore, it seems that neither type of model is inherently superior to the other, since both have certain limitations that can decrease their prediction accuracy.

Both types of models also use calibration and verification to indicate the accuracy of the model. However, there are misconceptions about the idea of validating a model. Since models produce non-unique results, it is difficult to definitively claim that a model is valid. The non-uniqueness of the results indicates that the model may be calibrated, but it may not be able to accurately predict future responses. Society can place too much faith in models that have been deemed verified or validated. It is easy to be mislead by the appearance of truth when a model claims to be valid and claims that it is able to make accurate predictions of the systems response in the future. No matter how much effort is undertaken, uncertainty can never be eliminated. Models are a good tool for critical analyses, and they can test ideas for reasonableness, indicate which parameters are sensitive and provide insight that may not have been previously considered, but their predictive accuracy is limited. Furthermore, the terms "validation" and "verification" are misleading with regards to modeling.

Use of a GIS can facilitate modeling for water resources applications by increasing model set-up time and the accuracy of the model. GISs are becoming more prevalent in state and local agencies for model support. Instead of trying to predict future responses absolutely, the use of GIS datasets can provide a more comprehensive look at an area. This is where the usefulness of screening level assessments, such as the ALOHA or MANAGE model approaches is applicable. It allows the modeler to use existing GIS datasets to obtain a general overview of the study area with "hotspots," such as areas contributing to non-point pollution, highlighted. Then, with this information, a modeler can then focus on the highlighted area for a more intensive analysis to arrive at an exact solution. This is a more integrated approach, which allows for more judgement to be introduced to the modeling process. Such an approach is especially important for analyses such as build-out analyses for towns and regions to make quick and informed determinations of how changes will affect the surrounding watershed areas.

Yet, these tools cannot currently be used to their full capacity because although many agencies collect water-related information, it is stored in different formats that are not easily shared. Once the data is put into a GIS database, it may be much more effectively utilized. Towns can design the GISs to include their parcel data and then add overlays such as water and sewer lines, which facilitates the ability to perform queries of their datasets such as sewer feasibility studies or generation of automated abutter lists. The models and GIS complement each other. Traditional model setup is very time consuming, but with data in a GIS format, the data can be inputted automatically into a model to simulate processes such as storm water routing. Towns and governmental agencies generally do not have sufficient time or funds to perform extensive, long-term studies and must be able to model and achieve rapid results. With advances in satellite technology and remote sensing, data in a GIS format (e.g., land use) is now accurate to within a few feet and can be used for efficient determinations, which are necessary for effective land-use decision making. The decision-maker can model different development scenarios and observe, in real-time, the impacts as the scenarios are changed. This is a much more practical approach for planners and decision-makers, who do not have wait until field studies, modeling, calibration and validation are complete to make a decision related to land use.

This integrated approach to modeling, with the concentrated involvement of the decision-maker is a better approach than traditional modeling strategies where a modeler typically searches for a numerical solution. Instead of merely inputting parameter data, the modeler is more involved in the modeling process to ensure that it accurately describes the system. The DSSs and SDSSs are links to the integrated model and GIS linkage. The decision-makers work from the beginning of the modeling process to structure the model to the problem at hand; it is not simply a case where a model attempts to "fit" the problem. This was clearly demonstrated by the AR/GIS system that allowed the different land-use decision makers view GIS data in real time and model different scenarios with combined input to determine the best lands to purchase for open space. This is the type of system necessary for use by state agencies and water suppliers to enable practical decisions to be made on a daily basis.

Models are useful in gaining a better understanding of the system, but it is also important to recognize the limitations of modeling. One concern with integrated models is the accuracy of existing GIS datasets, such as the RIGIS dataset of Rhode Island. Although RIGIS data is applicable to more broad study areas, problems arise when trying to perform analyses for towns or areas smaller than statewide or regional scales. The resolution of these datasets is still too large to be useful to the towns. Some of the water suppliers that had GIS capabilities created their own mapping system, such as the RIEDC and South Kingstown, which found the RIGIS system's data was too broad-scaled for their needs. Towns and suppliers typically require analyses at scales on the order of 1"=40'or 1"=80'. Generally, towns that were working with GIS data had skilled personnel, who were transferring hard copy information and orthophotos from the towns into GIS formats for their specific needs. The State's most recent orthophotos (at a scale of 1"=5000") are also too broad-scaled to be of use to the towns, which need GIS information to locate pipelines, right-of ways (ROWs) and survey boundaries. For the majority of the suppliers without adequate personnel for

GIS work, new staff would need to be hired that can both work with GIS software and also transfer data into a GIS format at larger scales than is currently available to the suppliers.

The water suppliers have compiled extensive amounts of data, however the use of many different formats hinder data sharing capabilities. Since most of the suppliers have not converted their data into GIS or CAD formats, use of the hard copy maps and data seriously limit the usefulness of the assembled information. The suppliers want to advance technologically, however, they face opposition when emerging technologies such as GIS compete against capital improvements such as repair of an old pipeline. The key factor is the understanding that, with the system in a GIS format, the suppliers can query their system to highlight, for example, pipes installed before 1975 to determine where the most necessary repairs or improvements are needed. This query takes only a few minutes, as compared to examining various maps to make a single necessary determination. The manual collection of data such as water tank levels also hinders the ability to view trend data. The SCADA systems in use by some suppliers solve this problem by collecting data automatically and storing it in a database format for different trend analyses.

In terms of modeling, none of the suppliers currently utilize hydrologic modeling; modeling was limited to hydraulic modeling on their distribution systems. One model utilized by most of the suppliers was a version of WaterCAD by Haestead Methods. However, most of the water suppliers retained the model via their consultant, who executed the model when necessary. The benefit of the WaterCAD program is that it has linkages to AutoCAD, GIS and even SCADA systems. Some of the suppliers had their entire system drawn in AutoCAD, and by using WaterCAD, they could run the model directly from the AutoCAD drawing. Going one more step, with the system's attributes in GIS, one can run the model, work with the drawing in AutoCAD, and also perform queries from the database created in GIS. This combination of elements produces a powerful system that can be used for decision making in towns, local and state agencies.

Complex modeling efforts are not yet common among towns, water suppliers and state and local agencies. Currently, the towns and state agencies have neither the data in a useable format nor the personnel to manipulate it into the correct format. The RIWRB was attempting to ascertain the needs of the suppliers and how it can help meet these needs. It was originally recommended that the RIWRB acquire a group license for the ArcView software, to best benefit the suppliers. However, GIS was not being used to its full capacity due to the lack of resolution of the available data, lack of trained personnel and budget constraints in the towns. The movement for GIS implementation can almost overshadow needs for more practical, everyday requirements from a "model system." Therefore, the RIWRB can best facilitate the suppliers by addressing their more practical needs. A more appropriate response may be to purchase the SCADA software for the suppliers. The suppliers can then begin incorporating their distribution systems into the SCADA for everyday system checks, work orders, trend analyses and treatment control. This action would create some common ground technologically for the suppliers to do some data sharing and other manipulations.

The next logical step is to incorporate the system into AutoCAD and use the functionality of WaterCAD to run the model from this level. It is important that the suppliers collaborate on sharing their experiences relative to the encountered difficulties and benefits of the programs. It is also recommended that the suppliers start on a relatively level field (e.g., using the same or similar model system) before trying to implement GISs. However, once the Water CAD model is implemented, they can incrementally add the GIS functionality to the AutoCAD drawing at a realistic pace rather than quickly transitioning to full GIS implementation in the next year or so. In addition, once the suppliers and towns have their information in a GIS format, they will be better able to take advantage of other tools such as the MANAGE model.

While the suppliers are automating their data collection, the state agencies can work on updating state GIS datasets to render them more refined and useful to the towns. It is important that this be a state effort, because it is impractical for the towns to create mapping for their owns needs that are neither in standard formats nor available to the public, which prevents data sharing efforts. Datasets will then be one continuous layer that will not be confined to town or supplier boundaries. If this effort were left to the towns, they may create their own mapping system. Transitioning from one town to another would result in individual digitized layers and scales that would not coincide. In addition, since most of the towns do not have internet access or the personnel to continuously provide information to the public, much of the mapping work already done by the suppliers/town is unavailable to the general public. For, example, the RIEDC started their own mapping system for their system at Quonset Point in Rhode Island. The scale is 1”=40’, which creates a very detailed view of the entire system; however, it is not available to the public. Data such as this may be beneficial to state agencies or developers looking to survey these areas. In addition, many state agencies have GIS information such as refined LUST sites and hazardous waste sites mapped on their system, available only to people in the agency through their intranet system. Again, some of this information could be shared, and could also be critical for town land use decision making. It is incumbent upon the state departments, such as the Rhode Island Department of Transportation (RIDOT), Rhode Island Department of Environmental Management (RIDEM), URI, the RIWRB and any other agency that stands to benefit from statewide GIS datasets to work together to produce more refined GIS datasets and make them available to everyone.

In terms of hydrologic modeling within the towns, the suppliers are quite removed from implementing or using any hydrologic modeling. However, the state agencies could also simultaneously work on developing a hydrologic model using the GIS data for the entire state, even down to the subwatershed level. This level of accuracy would be of significant use to the towns, which presently are without the capabilities for this type of effort. The state would also benefit, however, by providing data to the public and increasing data sharing and digital submission of data from the towns to the necessary agencies. Also, with maps formatted at the same scale, overlays can be directly accomplished without any manipulation. The state may then use these maps to evaluate watersheds at a large scale while separately incorporating the details from the town digitized systems. This would be a powerful mechanism that could be used to make more effective decisions for water resources planning and better management. To begin this collaborative effort, further research could include an inventory of various aforementioned state agencies and their current technologies. Also, development of the hydrologic model by the agencies could be the subject of a future study that focuses on a model like MANAGE or other more applicable model. Furthermore, in order to assist the RIWRB in determining what software should be purchased for the towns, it would be necessary to investigate the different SCADA software systems used by the suppliers and evaluate the benefits or problems associated with each. Since use of AutoCAD and GIS in the towns is anticipated in the future, a more focused study of the different drafting and mapping programs available would also benefit the towns as these technologies are added to their systems.

Basic Information

Title:	Realistic Restoration of Streamflow in the Chipuxet Basin
Project Number:	B-03
Start Date:	3/1/2000
End Date:	2/28/2001
Research Category:	Engineering
Focus Category:	Water Supply, None, None
Descriptors:	Water Supply, Aquifer Recharge, Water Reuse, Wastewater Treatment, Drinking ater Treatment, Irrigation
Lead Institute:	University of Rhode Island
Principal Investigators:	Leon T Thiem, Stanley Barnett, Vincent Rose

Publication

Problem and Research Objectives

The Chipuxet Basin is located in South Kingstown, RI, with smaller areas in Exeter and North Kingstown. The Chipuxet Aquifer is a source of drinking water for the University of Rhode Island (12,000 people) as well as the Kingston Water District (1,000 accounts). In addition to URI and KWD's withdrawals, United Water (a private company serving Wakefield, Narragansett and North Kingstown) owns a 27 acre parcel located along Plains Road which has been earmarked for future development. Currently, the annual average withdrawal from the aquifer is 1.1+ million gallons per day. This number is deceiving since it represents only an average demand over the entire year. During times of peak demands (summer for KWD, fall and spring for URI) the demands are considerably higher. Peak demands have exceeded the 7Q10 of the Chipuxet River. In fact, the demands are sufficient to dry up the Chipuxet River at times. Figure 1 serves to delineate the boundaries of the Chipauxet Basin. Figure 2 illustrates the low flows which occur in the Chipuxet River due to high water demands.

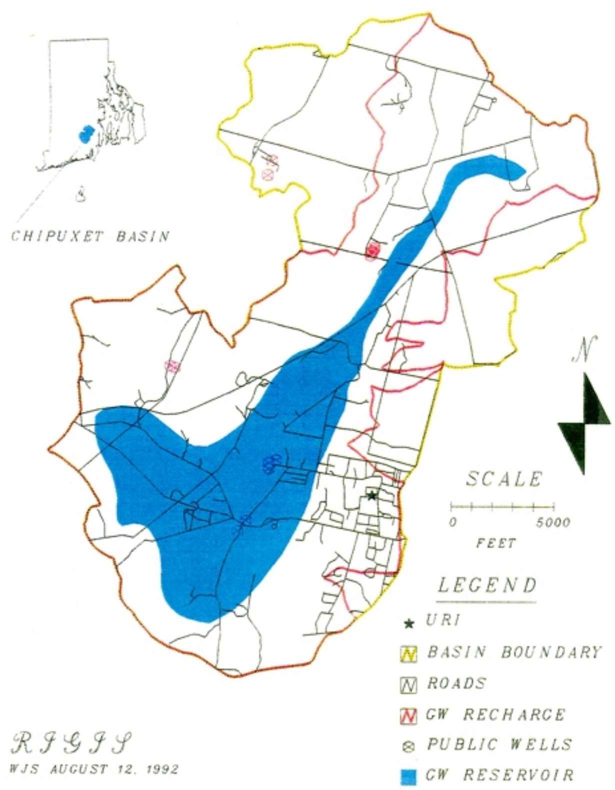

Figure 1 Chipuxet Basin Boundaries

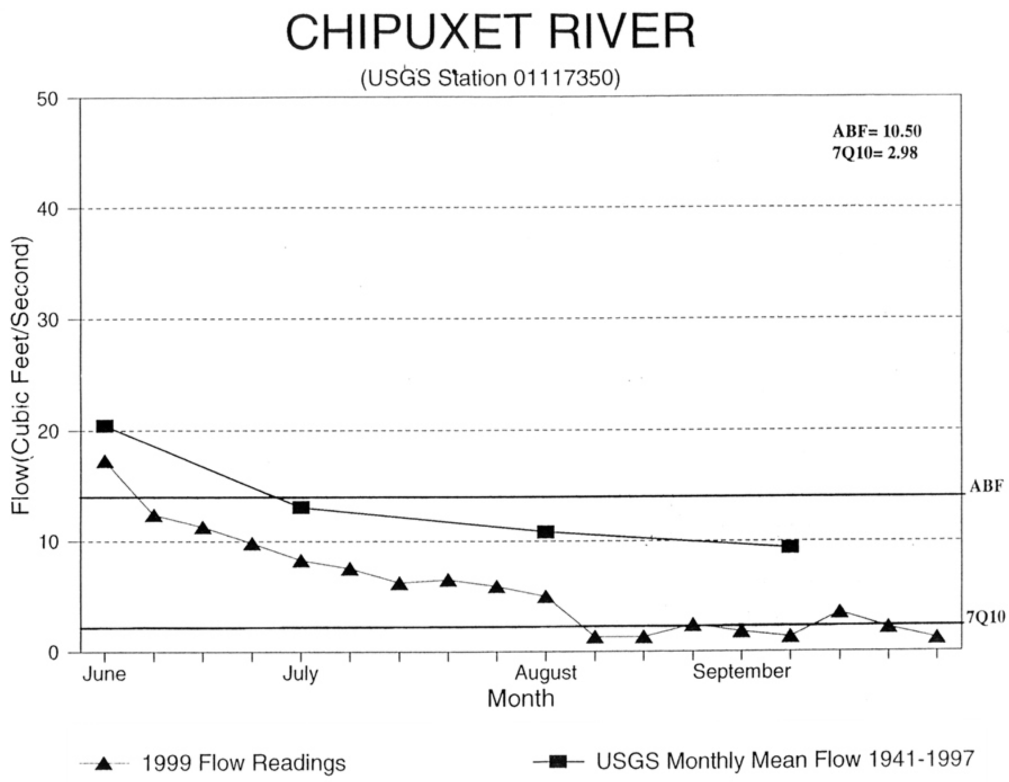

Figure 2 Chipuxet River Water Flows

Figure 2 illustrates the degree of depletion of the Chipuxet Basin. During the summer months the flow in the Chipuxet River can get below the 7Q10. Even this figure does not show the seriousness of the depletion because the gaging station that this flow is measured is above the location that water in the river is withdrawn for irrigation.

The objectives of this study included the following:

1. Quantify the water withdrawals from the Chipuxet Basin both spatially and temporally.
2. Estimate the water quality needs of the major withdrawers.
3. Characterize the quantity and quality of water discharges from the Chipuxet Basin.
4. Perform a feasibility study on conservation, wastewater separation and treatment with subsequent discharge within the Chipuxet Basin.

Methodology

This project first quantifies the current water demands on the Chipuxet Aquifer by reviewing pertinent records including well records and irrigation demands. Special attention is given to the elimination of the exporting of water out of the Chipuxet Basin. Since the largest user of water is URI, efforts to reuse their water are emphasized. One potential option is to separate the wastewater that is used by URI into Grey Water (from showers and washing in the URI athletic and housing complexes) and use this water for irrigation. Black water (sewage) currently being pumped to the South Kingstown Wastewater Treatment Facility in Narragansett, RI, could be treated by conventional processes (activated sludge) or by new technology (membrane processes). This treated water could be returned to the aquifer by irrigation or by direct injection.

An extension of the previous data on water withdrawals from the Chipuxet Aquifer is conducted by contacting existing users. Where detailed data does not exist, the types of uses and quantities are estimated either from records or observation. Future needs are calculated by analyzing past data as well as reviewing long-range build-out plans for the Town and for URI. Potential practices that would be candidates for conservation are analyzed and the savings are estimated. Preliminary designs and estimated costs of constructing and operating the facility for each treatment option are determined.

Principal Findings and Significance

Figure 3 illustrates the water usage in the Chipuxet Basin. The major users of the water are URI and the KWD. It is important to determine the water quality needs of the major withdrawers from the aquifer. Treated water could be utilized for agricultural irrigation since the major crop is turfgrass. Since turfgrass is not consumed, the degree of wastewater treatment is not as stringent as it would be for edible crops. Rather than sending the water out of the basin to the South Kingstown Wastewater Treatment Facility as is currently done the water can be treated on-site and remain within the basin.

Reverse Osmosis and Nano-filtration are being increasingly used in both drinking water and wastewater treatment. They can be used to provide water both for drinking purposes and for aquifer recharge. California is evaluating the reuse of wastewater to supplement surface potable supplies. A plant in Fountain valley, California produces high quality reclaimed water for direct injection in the aquifer. This plant has operated successfully and is scheduled for expansion. Several other communities in California and Oregon are investigating the use of reverse osmoses or nano-filtration for groundwater (aquifer) recharge. While the concept has gained acceptance in arid area of the west it has not been applied in the more water abundant areas along the East Coast.

The Membrane Bioreactor process is a recent development in wastewater treatment. In this process a membrane is used to separate solids from liquids. The membrane can be used directly in activated Sludge reactor or separately in the effluent stream from the activated sludge reactor. This process offers three benefits. The facility has a smaller foot print than the conventional process since it can be operated at higher suspended solids levels. Since the settling tanks are not necessary, the frequency of sludge wasting and equipment needed is further reduced. This reduction in operation significantly reduces the need for constant monitoring and testing. The disadvantages include requiring the need for membrane monitoring and cleaning.

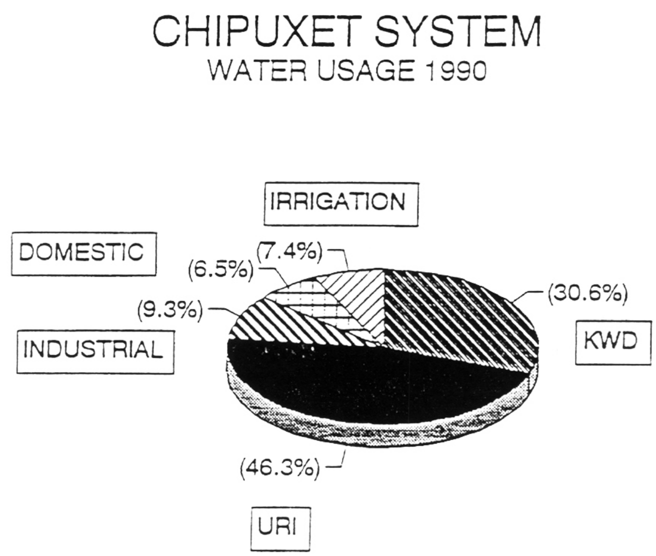

Figure 3 Water Usage in the Chipuxet Basin

Information Transfer Program

Basic Information

Title:	Development of a Website for the Rhode Island Water Resources Center
Start Date:	3/1/2000
End Date:	8/31/2001
Descriptors:	home page, information transfer
Lead Institute:	Water Resources Center
Principal Investigators:	George Tsiatas

Publication

Problem and Research Objectives

The objective of the project is to develop a website for the Rhode Island Water Resources Center. The website will inform the public about the functions of the Center including the activities of research, education and public service of the Center. In addition, information on funding agencies and research opportunities will be provided. The information posted will be updated periodically.

Methodology

Information on current and recent activities of the center is assembled, including background information on the mission of the center, research projects funded or currently under way, links to funding agencies, links to home pages of investigators funded by the center., etc.

Principal Findings and Significance

The Design of the Web Site for the Center is continuing. Some past reports are being scanned to be brought online.

USGS Summer Intern Program

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	6	0	0	0	6
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	9	9	0	0	9

Notable Awards and Achievements

None

Publications from Prior Projects

None