



WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Isotope hydrology investigation of the Pawcatuck Watershed.

FOCUS Category: HYDROL Descriptors: Groundwater, geochemistry, isotopes, water quality, water-use, water supply.

Duration: 3/1/99 to 5.30/00 FY-1999

Federal Funds: Total: \$23,100 Direct: \$23,100 Indirect: \$0

Non-Federal Funds Allocated: Total: \$53,887 Direct: \$31,658 Indirect: \$22,229

Principal Investigator: Anne I. Veeger, University of Rhode Island, Kingston

Congressional District: No. 2

Critical Regional and State Water Problems

This is a proposal to apply environmental isotope techniques to the investigation of hydrologic relations between surface water, surficial-material ground water and bedrock ground water in Pawcatuck Watershed of southwestern Rhode Island and southeastern Connecticut. This 300-square mile 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).

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States has remained relatively constant over the past 10 years (Solley and others, 1998), the proportion of water withdrawn in traditionally rural areas is increasing as a result of the outmigration of urban populations.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; ground-water 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 water-table 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 is proposed herein to address these issues.

Statement of Results, Benefits, and Information Expected

Interpretation of the environmental isotope record of precipitation, surface water and ground water coupled with available information on stream flow, ground-water levels, and water chemistry will provide a detailed picture of the hydrologic system. The Pawcatuck Watershed of southern Rhode Island and southeastern Connecticut is an ideal study area for the application of environmental isotopes to watershed-scale hydrogeologic investigations in New England. Interpretation of the environmental isotope composition of ground water, surface water and precipitation in this watershed will provide detailed information on the flow dynamics of the system. Specific focus areas include 1) the influence of seasonal precipitation on ground water recharge, 2) the hydrologic relationship between the glacial aquifers and the underlying fractured bedrock, and 3) the degree of hydrologic connection between aquifers and surface-water bodies. The application of environmental isotope techniques to the Pawcatuck River Basin promises to provide detailed information on the hydrology of the watershed. These data will permit a rigorous evaluation of ground-water and surface-water resources that can be used to effectively manage the water resources of the watershed. Preliminary data demonstrate that sufficient isotopic variability exists to justify a watershed-scale investigation. Upon completion this study will serve as a model for future hydrologic investigations in New England.

Nature, Scope and Objectives of the Research

This is a proposal to apply environmental isotope techniques to the investigation of hydrologic relations between surface water, surficial-material ground water and bedrock ground water in Pawcatuck Watershed of southwestern Rhode Island and southeastern Connecticut. This 300-square mile 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).

1. The application of isotope hydrology techniques to the Pawcatuck Watershed will achieve the following objectives:
2. Develop a database of the isotopic composition ((D and (18O) of precipitation, surface water and ground water in the watershed.
3. Assess the degree of interaction between the surficial materials aquifers and surface water.
4. Assess the degree of interaction between the surficial materials aquifer and the bedrock aquifer.
5. Assess the influence of seasonal precipitation on recharge to both the surficial material and bedrock aquifers
6. Develop a conceptual hydrologic model of the watershed incorporating hydrologic, chemical and isotopic data from the watershed.

Due to differences in atomic mass, isotopes of elements have slight variations in their physicochemical properties (e.g. freezing temperature, vapor pressure). In water, the most common isotopes are oxygen with a mass of 16 (^{16}O), oxygen with a mass of 18 (^{18}O), hydrogen with a mass of 1 (^1H) and hydrogen with a mass of 2 (^2H , also called deuterium). Partitioning, or fractionation of these isotopes occurs during phase and chemical transformations (e.g. vapor to liquid, liquid to solid). The resulting fractionation is particularly evident in the water cycle, where repeated episodes of evaporation and condensation produce dramatic variations in the relative abundance of heavy (^{18}O and ^2H) and light isotopes (^{16}O and ^1H) in precipitation, surface water and ground water across the continents. The variation in isotopic composition is expressed as a per mil (‰) between the heavy/light isotope ratio in a sample and that in a standard. The standard for oxygen and hydrogen isotopic measurements of water is VSMOW (Vienna standard mean ocean water).

Environmental isotopes have been applied successfully to a wide range of hydrologic investigations. (^{18}O of precipitation across North America varies by as much as 16 ‰ (Rozanski and others, 1993); with seasonal variations ranging from 2 to 15 ‰, increasing at high latitudes due to seasonal temperatures variations (Clark and Fritz, 1997). The isotopic composition of surface water may be further modified by the enrichment effects of evaporation. Ground water generally exhibits little seasonal variation in isotopic composition due to the dampening effects of mixing during infiltration (Darling and Bath, 1988; Eichinger and others, 1984). The resulting shallow ground-water isotopic composition is close to that of mean annual precipitation. If a recharge occurs seasonally, the isotopic composition of ground water may differ from that of average annual precipitation. This is most likely to occur in areas where ground water recharge occurs during predominantly during the spring, with little additional influx during the balance of the year (Clark and Fritz, 1997). Isotopic signatures of precipitation and ground water have been used to identify of recharge derived from snowmelt (Moser and Stichler, 1975) and Pleistocene glaciers (Siegel, 1991), to perform hydrograph separations (Hinton et al., 1994), and to quantify import recharge water and surface-water contributions to well discharge (Muir and Coplen, 1981; Maloszewski, 1987).

Ground water occurs in two distinct types of aquifers in New England: 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. Due to the complex nature of these systems, simple physical measurements of hydraulic potential are often inadequate for assessing flow dynamics. Geochemical and isotopic fingerprinting, however, can be used as an additional tool to identify hydrologically distinct zones within complex aquifer systems and provide information on the degree of hydrologic interaction between surface-water and ground-water systems (Yager and Kappel, 1998; Molloy and others, 1994; Veeger, 1991).

Although environmental isotopes have been used extensively in hydrologic investigations in other parts of the US and the world, little (^{18}O and D) work has been done in New England. Some preliminary work using ^{18}O has been done on determination of recharge areas (Abbot and others, 1996) and ground-water flow (Abbott and others, 1995) in Vermont and on the ^{18}O and D isotopic composition of deep ground water in fractured bedrock in New Hampshire (Delcore, 1987). The potential use of environmental isotopes to explore the hydrology of New England watersheds has therefore, not been fully explored. This study will mark the first comprehensive assessment of a New England watershed using environmental isotope techniques. The Pawcatuck Watershed of southern Rhode Island and southeastern Connecticut is an ideal study area for the application of environmental isotopes to watershed-scale hydrogeologic investigations in New England. The watershed has been the focus of a number of U.S. Geological Survey (USGS) water resources investigations (Dickerman and Bell, 1993; Dickerman and others, 1990; Johnston and Dickerman, 1985) addressing ground-water flow, and to a limited degree surface-water/ground-water interactions, through numerical simulation. Abundant data are therefore available on the glacial stratigraphy, ground-water levels and stream discharge rates. Interpretation of the environmental isotope composition of ground water, surface water and precipitation in this watershed will provide detailed information on the flow dynamics of the system. Specific focus areas include 1) the influence of seasonal precipitation on ground water recharge, 2) the hydrologic relationship between the glacial aquifers and the underlying fractured bedrock, and 3) the degree of hydrologic connection between aquifers and surface-water bodies.

In New England, ground-water recharge is commonly assumed to occur only during the period November to April when plants are dormant and evapotranspiration is at a minimum. Estimates of recharge based on annual water budget analysis suggest that close to 50% of precipitation reaches the water table in glacial-fluvial aquifers of southern New England (Veeger and Johnston, 1996). If this recharge is derived almost exclusively from winter precipitation, a measurable difference should exist between the average annual isotopic composition of precipitation and that of ground water. Recharge to the fractured bedrock aquifer will also be investigated to determine if the bedrock flow system is an extension of local ground-water flow, or if it is part of a regional flow system.

The hydrologic relationship between the glacial aquifers and the underlying fractured bedrock may also be clarified using isotope fingerprinting. The interface between the glacial aquifer and the fractured bedrock aquifer is assumed to be an impermeable boundary in the USGS investigations; however, no hydrogeologic assessment of this boundary was completed. Data collected in the Pawcatuck River Basin reveal that bedrock ground-water is geochemically distinct from surficial-material ground water (Ruderman, 1996; Holden, 1994). Zones of mixing between bedrock and surficial-materials ground water have tentatively been identified in a number of areas, indicating that significant discharge of bedrock ground water may occur through the base of some glacial aquifers (Veeger, Esquilin and Ruderman, 1996, Veeger and Orłowski, 1997). Mass-balance modeling using the stable isotope composition of the ground water may provide detailed information on the presence and degree of hydraulic connection. Clarification of the relationship between aquifers and nearby surface-water bodies has

important water-resource administration implications. Designation of aquifers as ground-water reservoirs and delineation of zones of contribution for well-head protection areas (WHPA) has generally been accomplished using simplifying assumptions because the detailed information on ground-water flow is lacking in many areas. WHPA's in Rhode Island were delineated using the uniform-flow equation which assumes an isotropic and homogeneous aquifer with no provision for induced infiltration of surface water in the zone of contribution. These assumptions are clearly violated given the complex geology of the glacial aquifers, making the protection afforded by the WHPA suspect. Isotope mass-balance calculations can be used to quantify the input from surface-water sources, thereby clearly evaluating the need for inclusion in the WHPA.

Successful application of isotope hydrology techniques to this complex hydrologic system will enhance our ability to manage the water resources and develop scientifically sound resource protection policies. This project will also provide a model for application of the method to other watersheds in New England.