

Salt and nitrate contamination of the shallow unconfined aquifer at Great Swamp, South Deerfield, Massachusetts

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INTRODUCTION

Great Swamp covers approximately 5.5 km² along Interstate 91 near South Deerfield, Massachusetts. The swamp is bounded to the northwest by a drumlin and hay field, to the north by homes and fields, and to the east by I-91. Route 5/10 bisects Great Swamp, running northeast-southwest. A small developed area exists near the intersection of I-91 and Rt. 5/10 in the east central section. The surficial geology of Great Swamp is unconsolidated sands overlying glaciolacustrine varved silts and clays, as is the case throughout much of the Connecticut Valley Lowlands (King, 1997). These sediments were deposited by Glacial Lake Hitchcock, which covered the area from 14,000 years ago until its catastrophic drainage 10,700 years ago (Liu, 1989). The resulting system of a permeable sand unit over impermeable clay is an excellent hydrologic resource, and a number of Great Swamp residences use wells screened in this shallow aquifer. While the groundwater in aquifers such as that below Great Swamp were historically of high quality, there is now concern of contamination, specifically from road salting and agricultural practices. This study pinpointed impacted portions of the Great Swamp aquifer, identified groundwater flowpaths, and predicted contaminant plume movement.

METHODS

Aquifer hydrochemistry was assessed using groundwater samples collected from 24 well sites in a series of transects across Great Swamp. Wells were drilled with a hand auger, and a 5.1 cm diameter PVC pipe, screened at the lower 25 cm and capped at the bottom, was inserted as the well casing. Groundwater was collected from depths of approximately 100 and 160+ cm. Samples were analyzed at the Smith College Aqueous Geochemistry lab for specific conductance, total alkalinity by Gran titration, silica concentration by spectrophotometry, and major ion concentrations by atomic absorption and ion chromatography. Data were used to create concentration contour plots on a map of Great Swamp, by which contaminated regions, possible sources and direction of contaminant travel were determined.

Hydraulic properties of the aquifer were estimated using aquifer material samples collected from well sites, and by calculation of the regional potentiometric surface. Grain size analysis of aquifer material samples was performed on the Colorado College particle size analyzer, and hydraulic conductivity was calculated using Shepherd's (1989) adaptations of the Hazen method. This empirical method estimates hydraulic conductivity as a function of grain size and sorting. The regional potentiometric surface was determined by constructing three sets of permanent wells in the east and southeast reaches of Great Swamp (Fig. 1), and laser surveying elevation changes between wells using a total station. Water table data from medium depth permanent wells were used in a three point problem to find the potentiometric surface orientation. Finally, clay mineralogy of varved clay samples was analyzed on the Colorado College X-ray diffractometer to predict effects of clay particles on aquifer hydrochemistry.

RESULTS

Hydrochemistry. Hydrochemical analysis showed very few dissolved solids in the western half of the Great Swamp aquifer, but very high amounts in the east. Total alkalinity ranged from -100 to 2647 $\mu\text{eq/L}$, with the highest values near the development by the I-91/Rt. 5/10 interchange. Silica values varied from 1.62 to 20.57 mg/L, weakly concentrated in two areas: the northeast corner of Great Swamp and parallel to Rt. 5/10 through Great Swamp. Specific conductance ranged from 28 to 2155 μS , with two plumes clearly evident (Fig. 1). One plume originated near the development and extended south-southwest along Rt. 5/10, and the second plume began along I-91 in the southeast corner of Great Swamp, and also extended south-southwest. Atomic absorption and ion chromatography results show concentration trends of Na^+ , K^+ , Ca^{+2} , Mg^{+2} , and Cl^- closely follow that of specific conductance, as expected since these ions are the main contributors to groundwater conductance. Sodium and Cl^- were found in concentrations higher than any other ion analyzed, reaching 385 and 591 mg/L, respectively, along I-91 in southeast Great Swamp. Potassium

showed a similar distribution pattern, but with concentrations generally two orders of magnitude below those of Na⁺ and Cl⁻. A second, minor K⁺ anomaly was detected in the northeast corner of the study area. Plumes of Ca⁺² and Mg⁺² were found along I-91 in southeast Great Swamp and near the developed area, similar to that of specific conductance. Concentrations of Ca⁺² and Mg⁺² reached 30.3 and 8.00 mg/L, respectively, generally highest near the development. Nitrate anomalies were detected at the northern tip of Great Swamp and also near the development, where the maximum concentration of 11.9 mg/L was detected. Sulfate values ranged from 0.28 to 53.6 mg/L, and no trends were apparent. At almost every site where elevated contaminant levels were detected, ion concentrations increased with depth, indicating density stratification within the aquifer.

Hydraulic Properties. Regional heterogeneities in unconsolidated aquifer material allowed only generalized conclusions regarding hydraulic properties. Sediment size ranged from clays to coarse sands, and in sorting from moderately well to very poor. Aquifer material appeared coarsest in southeast Great Swamp, while the northern reaches contain relatively uniform fine sands. Thin lenses of both coarse and fine sediments were found at nearly every sample site, but were too localized to correlate across the study area. Aquifer material thickness seemed to follow topography throughout much of the swamp, with the varve aquitard uniformly appearing at an elevation of approximately 54 m. As such, the aquifer is thickest in the northern reaches of Great Swamp, where the water table was farthest below the ground surface. The potentiometric surface dips S21W with a slope of 5.61×10^{-3} m/m. XRD analysis determined the main clay sized particles are chlorite, illite, vermiculite and muscovite.

INTERPRETATION

Non-anthropogenic groundwater ion sources were explored to explain contaminant trends in the Great Swamp aquifer. Mineral weathering and ion exchange between the groundwater solution and colloid particles are the most common natural sources of Na⁺, K⁺, Ca⁺² and Mg⁺². The unconsolidated sands overlying the Connecticut Valley Lowland varves consist mainly of amphibole, garnet, epidote, sillimanite, staurolite, kyanite, micas, opaques, quartz and feldspars (Liu, 1989), the weathering of which would release Na⁺, K⁺, Ca⁺² and Mg⁺² ions into groundwater. However, Na⁺ concentrations are two orders of magnitude above other cation concentrations, which is not expected from weathering of the unconsolidated sediments. Mineralogy appeared relatively homogeneous throughout the study area, so weathering alone should not create contaminant plumes like those observed in the Great Swamp aquifer. Ion exchange, which occurs on colloid particles generally 10^{-6} to 10^{-9} m in diameter, also affects groundwater chemistry (Freeze and Cherry, 1979). Groundwater may be enriched or depleted in charged ions such as Na⁺, K⁺, Ca⁺² and Mg⁺² by release from or adsorption onto negatively charged colloid surfaces. Ionic exchange generally adsorbs monovalent ions and releases divalent ions, so the relative Na⁺ anomaly eliminates this process as the principle source of dissolved ions. Furthermore, particle size analysis showed a deficiency in the necessary colloid sized particles, and the non-expandable clays and micas detected by XRD analysis exhibit only minor exchange capacities. Finally, very few non-anthropogenic sources contribute Cl⁻ or NO₃⁻ to groundwater, making these ions excellent indicators of contamination (Kegley and Andrews, 1998). Concentrations and patterns of dissolved ions in the Great Swamp aquifer, especially those of Na⁺, Cl⁻ and NO₃⁻ suggest contamination from anthropogenic activity.

Common anthropogenic contaminant sources were examined, and appear more likely than natural sources discussed previously. After snow events, I-91 and Rt. 5/10 are salted with NaCl at a rate of 240 pounds per lane-mile, or with CaCl₂ at temperatures below 20° F (Hoey, Jr., 1998). A strong correlation was detected between Na⁺ and Cl⁻ concentrations, suggesting road salt is a major contaminant source (Fig. 2). A study by Twitchell (1993) found that half of all Cl⁻ applied to roads reached nearby groundwater. Additionally, road salts may contain various other ions, including K⁺ and Mg⁺² (Howard and Beck, 1993). Because the plumes of Na⁺, K⁺, Ca⁺² and Mg⁺² were detected along I-91 and Rt. 5/10, road salt is the most likely source of these ions. The most common anthropogenic sources of NO₃⁻ are fertilizers, animal waste from farms, and discharge from septic systems, all of which are practiced along the borders of Great Swamp. One NO₃⁻ plume lies slightly south of a farm and small herd of cattle, and a second, larger NO₃⁻ plume containing elevated levels of every ion tested originates near the development, where a septic system is in operation. Thus, road salt run-off from I-91 and Rt. 5/10 and septic drainage from the development near the I-91/Rt. 5/10 interchange are the most likely sources of groundwater contamination in the Great Swamp aquifer.

The degradation of groundwater quality in Great Swamp threatens domestic water supplies, existing development and vegetation. Certain regions have concentrations of Na⁺ and Cl⁻ greater than the 250 mg/L drinking water standard, consumption of which may cause vomiting, nausea, hypertension, and possibly congestive heart failure (Kegley and Andrews, 1998; Howard and Haynes, 1993). Additionally, dissolved road salt corrodes metals, weakens

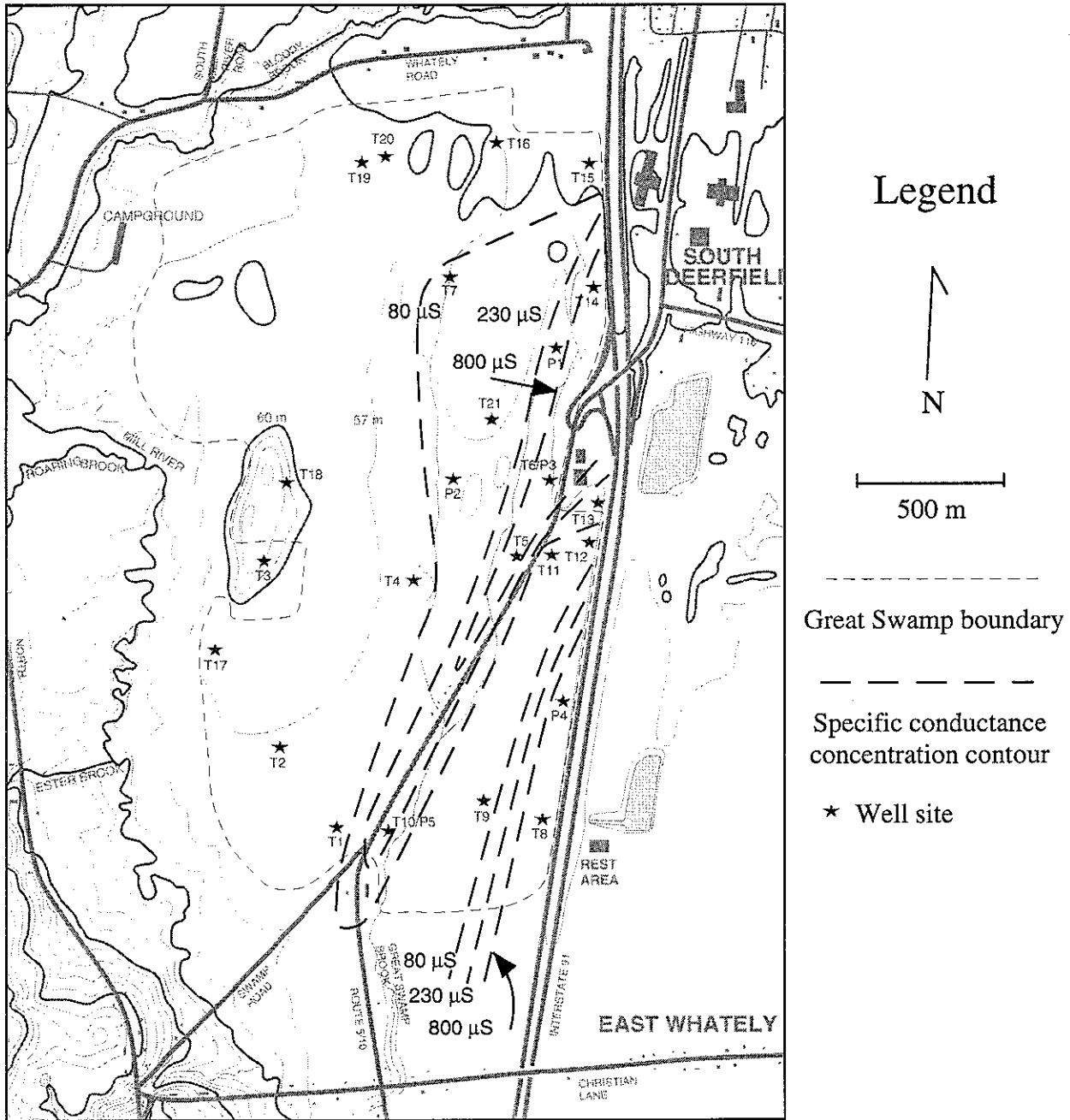


Figure 1. Specific conductance trends in the Great Swamp aquifer. Adapted from U.S. Geological Survey Williamsburg, Massachusetts Quadrangle topographic map, 1990.

concrete and kills vegetation. Nitrate ions pose serious health risks like methemoglobinemia (blue baby syndrome), and may form carcinogenic compounds (Howard and Beck, 1993). The maximum allowable NO_3^- concentration of 45 mg/L in drinking water is four times greater than the highest measurement taken in Great Swamp, so NO_3^- is not currently a major threat. Yet if current land use practices continue, this water resource will be further compromised.

Contaminants have entered the Great Swamp hydrologic system along I-91 and near the development in the east central region. Contaminants most likely migrate south-southwest in groundwater, as is evidenced by the direction of plume elongation and the potentiometric surface orientation. Groundwater flows quickly through the well sorted undconsolidated sands forming the aquifer, though accurate travel times could not be determined in this study. Though Na^+ and Cl^- are the only ions currently detected in hazardous concentrations, other contaminants like aromatic hydrocarbons and cleaning agents or chemicals from the development's gas station and septic system may also exist in Great Swamp groundwater. Unless protective measures like environmentally friendly road salt substitutes and septic drainage pattern alteration are enacted, groundwater in Great Swamp may reach levels of contamination toxic to humans, animals and vegetation.

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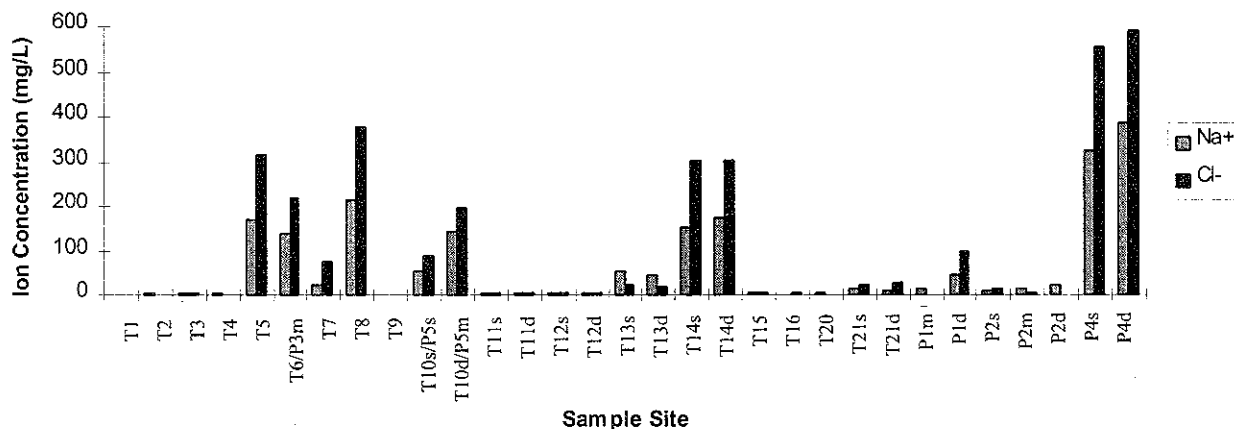


Figure 2. Correlation between Na^+ and Cl^- ion concentrations at all groundwater sample sites, which are shown in Figure 1.