Groundwater Discharge to Long Island Marshes: Theory, Inferences, and Data

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Groundwater discharges in an unconfined aquifer in locations where the head elevation for the aquifer is greater than its corresponding sediment surface elevation (Freeze and Cherry, 1979). On Long Island, where the Upper Glacial aquifer is intersected by the ground surface, streams and ponds occur.

USGS modeling suggests 28 percent of annual recharge discharges to stream systems in Suffolk County (Buxton and Smolensky, 1999). This discharge to streams impacts the water table, causing lower head pressures in the near vicinity of streams. The measurable effect, especially for smaller streams, is often extremely local. At Connetquot Brook, the difference in heads was detectable only 30 vertical feet below the creek and approximately the same distance from each bank (Prince et al., 1989). However, other modeling has suggested that even modest streams can drain large portions of individual watersheds (the freshwater portion of Meetinghouse Creek collected 25 percent of the recharge of that area) (Schubert, 1999). Research on coastal plain streams fed by groundwater indicates that the upper stretches are often receiving recently recharged groundwater (which thus is from the immediate vicinity of the stream). This changes for downstream reaches, where discharge from the banks or stream bottom close to the banks may have been recharged locally, but discharge into the central portions of the stream bottom often have long aquifer residence time (and thus may be from areas of the watershed that are not particularly close to the stream) (Modica et al., 1998).

At the shoreline, the elevation of the aquifer is greater than the surface of the sediment. Groundwater discharges through the saltwater interface. USGS modeling suggests that 43 percent of recharge discharges at or near the shoreline in Suffolk County (Buxton and Smolensky, 1999). This phenomenon has begun to receive attention.

Bokuniewicz (1980) was one of the first to quantify aquifer discharge to the nearshore environment. His studies suggested that most of this submarine discharge from the Upper Glacial aquifer occurred within a hundred feet or so of the shore. Follow-up work by others, especially Paulsen, has shown that the discharge rates are highly variable. They are a function of tidal cycles and sediment characteristics. Generally, higher tides impede discharge, and low tides allow for greater discharge rates, as would be expected. This pulsing of flow creates a mixing zone between the fresh aquifer and the saline marine waters in the sediments (Paulsen et al., 2001). It has been noted that the mixing of the waters often results in altered characteristics of the discharging groundwater compared to the nature of the groundwater measured just onshore (Sanudo ref).

Salt marshes are found on the periphery of the shoreline (Chapman, 1960). It is not clear whether they should be classified as “on-shore” or “off-shore” in terms of aquifer discharge. The surface of the marsh tends to lie above mean sea level (Teal and Teal, 1969). The marsh surface can be incised by natural marsh creeks or man-made mosquito ditches. The bottom of natural creeks may or may not lie above mean low water, and so some creeks retain salt water in them throughout the tidal cycle, and some drain completely (Pomeroy and Imberger, 1981). Most mosquito ditches were designed to drain through tidal cycles, meaning the elevation of their bottoms is above mean low water (Richard, 1938), but this is not necessarily the case on the south shore of Long Island, where micro-tidal ranges mean the typical three foot depth of mosquito ditches can leave their bottoms well below mean low water.

The marsh sediments are often saturated with saline groundwater, as a result of flooding tides. The salty groundwater lies above the fresh groundwater aquifer (Pomeroy and Imberger, 1981). The elevation of the freshwater aquifer has not been published for any salt marsh on Long Island known to us, but presumably is near to mean sea level.

Competing Theories

There are several theories regarding fresh groundwater discharge in salt marshes. One, presented by Howarth and Teal (1980), showed that fresh groundwater discharges occur at the base of the marshes in the bottoms of marsh creeks. The salinity of the salt groundwater system is controlled in these marshes by incidents of tidal flooding and dilution by rain (Teal, 1986). Evaporation may affect summer salinities, leading to elevated salinities in high marsh areas that are not flooded each tidal cycle. Teal's work has been primarily conducted in what are defined as New England salt marshes – the kind of salt marshes found from Maine through Long Island, whose histories were affected by glaciation and subsequent sea level rise.

Pennings and Bertness (1999) described salinity in the marsh soils and aquifer in New England-type marshes as decreasing with distance from the seaward edge of the marsh. This relates to distance from the salt water source, so that fewer inundations by tidal waters means that rainwater constitutes proportionally more of the perched salt marsh aquifer. Alternately, the source of fresh water in the upland edges of the marsh could be groundwater discharges. Harvey and Odum (1990), working in a fringing marsh in Maryland with a "hillslope" aquifer (the hills were six to 20 m. tall), found that maximal discharge into the wetlands peats was at the upland fringe, and decreased with distance towards the open estuary. Overall, the pore water flows in the marsh were dominated by tidal flows, meaning that groundwater had long residence time in the marsh peats and thoroughly mixed with saline waters prior to discharge through the marsh. The marsh peats, because the base of them is located lower (in relation to mean sea level) than the head of the freshwater aquifer, especially close to the toe of the hill slope, receive discharges from the aquifer.

In southern marshes, where evapo-transpiration rates are much greater, the saltwater aquifers away from the estuary can have elevated salinities above those near the estuary. The salinity of the creek waters is usually the same as the water found in the bankside levees, but the marsh water table water is usually higher in salinity, according to work done in Georgia by Pomeroy and Imberger (1981). They suggested this showed natural creeks drain little water from the marsh, resulting in a consistent-head, perched water table. Hemond and Fifield (1982) also thought that seepage in the marsh peat is negligible except near creeks, and theorized that evapo-transpiration is the primary means for removing water from marsh peat away from creeks. Then, due to the loss of head, groundwater inflows would ensue to maintain the perched water table. Nuttle and Harvey (1995) expanded this argument by constructing a water balance for a marsh controlled by these kinds of flows. Using an assumption no loss of water to the creek from the interior of the marsh, they determined that groundwater upflow volumes were twice as great as tidal inflow volumes, for an irregularly flooded high marsh, because of large evapo-transpiration losses.

However, it is not clear that all peats do not transmit groundwater to creeks. A model by Harvey et al. (1987) found that, if the head in the marsh peat layers was great enough, horizontal flows to the creek bank occurred as the tide retreated off the marsh surface. The water balance indicated that two-thirds of the water infiltrating the marsh surface during any particular tide will drain out of the marsh during that same tidal cycle (note the study was made in a shallow, 20 m. wide, *S. alterniflora* marsh that was completely flooded each tidal cycle). Frey and Basan (1985) noted that the greater the height of the tide on the marsh surface, the more infiltration into the sediments would occur, due to greater head. And, generally, infiltration during a high tide is matched by discharge from the sides of tidal creeks during the following low tide; furthermore, it was found that the amount of water infiltrating into the marsh surface decreased with distance from the marsh creek (Burke et al., 1980), probably relating to reductions in inundation depths. These studies focused on regularly flooded low marshes. Williams et al. (1994), while focusing on high marshes, also suggested that water tables were more variable than consistent. The amount of variation in the water table height would depend on the frequency and duration of flooding, marsh elevation, proximity to and the number of creeks, depressions, and pannes, and the underlying sediment type.

Thus, in different settings, different forces may be at work, meaning that it is probably not possible to define one general theory regarding groundwater discharge in or near marshes.

Implications from Other Work

Bertness et al. (2202) found that increases in nitrogen concentrations, measured in plants, correlate with destabilized marsh vegetative regimes, especially resulting in *Phragmites australis* (*Phragmites*) expansions. These "excessive" nitrogen concentrations further correlated with the degree of development measured on the upland border of the studied marshes. The implication is that the development is delivering the nitrogen to the marsh.

Generally, on a coastal plain as was the case here, the nitrogen impacts from local development are found in groundwater. Although not explicitly stated by Bertness et al., it seems to be understood that the local groundwater flow is the source of nitrogen additions to the marsh.

Valiela et al. (1978) determined that groundwater was an important source of nitrogen to the total nitrogen budget for a Cape Cod marsh. The marsh had springs at its upland reaches; however, the finding depended on groundwater inputs to the marsh through the marsh creek bottoms. This was estimated by comparing incoming tidal salinities with the least salinities measured at ebb flow from the marsh, and determining how much inflow would have been required to dilute the inflow to this level. This seems to greatly overestimate the groundwater contribution, as it is not clear groundwater diluted the entire inflow. Nor is it clear that groundwater inflow occurs as rapidly at high tides (when the marsh surface is flooded, allowing for access to any dissolved nutrients) as the estuarine head is greater, and so is likely to restrict inflows from groundwater.

Wertheim National Wildlife Refuge Data

Particular Long Island marshes do and do not fit the particulars discussed above. *Phragmites* invasions on Long Island began on the East End at the turn of the last century (Lamont, 1997), and those marshes were not especially impacted by development (at least, not on the scale seen today). Marshes in parts of the Peconic Bay system and along the North Shore do have hilly uplands, and are therefore likely to have steeper groundwater tables in their immediate vicinity. The steeper slope to the water table suggests a greater chance that the underlying marsh peat will intercept the water table. The South Shore of Long Island, which generally has a microtidal regime, tends to host marshes with larger high marsh expanses. In such a setting, it may be possible to determine if variations in water table salinity are due to inundations, evapo-transpiration, or rainfall.

Cashin Associates, as part of a larger monitoring effort at Wertheim National Wildlife Refuge has analyzed pore water salinity data from a variety of high marsh sampling points. These data were compared to precipitation and tide records.

Data analysis to be presented at the conference, and inserted into the abstract.

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