WATER RESOURCES ON VINALHAVEN, MAINE

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INTRODUCTION

Vinalhaven, located in Penobscot Bay, Maine, includes 46 islands over 3 acres and covers an area of ~15,000 acres (Fig. 1). Topographically the island is relatively low lying with a maximum elevation of 200 feet. The bedrock geology is mostly granite locally covered with a thin layer of soil (Gates, 2001) (Fig. 2). Water resources on Vinalhaven have been an issue of considerable concern for many decades (Gerber 1989). Vinalhaven groundwater is an 'island aquifer' – a lens of fresh water bounded on all sides by the ocean. The main sources of water for the 1300 year-round residents and ~4000 summer residents are private wells and the Vinalhaven Water District that obtains its water from Round Pond. Water supply is particularly problematic during the drier summer months when the demand is highest due to the increased

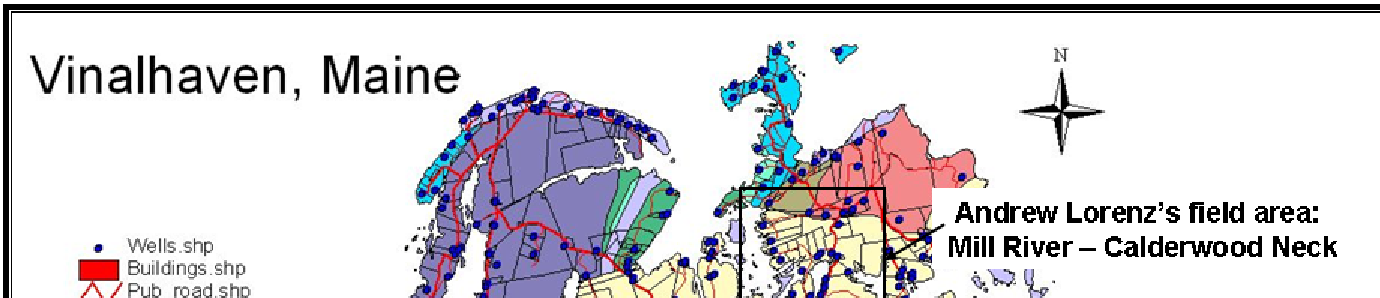

Figure 1: Map of Vinalhaven showing the bedrock geology, groundwater wells, and field sites.

summer population. Saltwater intrusion, septic systems, a landfill, and increased consumption in the future, all pose challenges to the future supply of sufficient clean water for the island.

Figure 2: Coarse-grained biotite-hornblende granite with widely spaced vertical open fractures, Mill River, Vinalhaven, ME.

Vinalhaven recently completed a Comprehensive Plan (Vinalhaven Comprehensive Plan, 2005) that integrated the 1989 Gerber report and more recent information gathered by local authorities, consultants and non-profit organizations. The Comprehensive Plan identified water as one of the main issues facing Vinalhaven despite the fact that average residential consumption is 35% below state and national usages (Welch, 2003). It is estimated that water demand will increase 100% by 2025, placing increased pressure on this limited resource (Vinalhaven Comprehensive Plan, 2005). Several recommendations, including restrictions on development, were put to a vote of the local community over the summer of 2005 but were defeated. Clearly the community was aware that water is an issue but was not yet ready to take steps to address this without more information.

This study is partly a response to the need for more information about the water resources on Vinalhaven to support more informed policy decisions but Vinalhaven is also an excellent location for a study focused on water supply for other reasons. The water resource is hydrologically and physically constrained (island aquifer surrounded by ocean). There is an excellent GIS database available for the island that includes essential information to support a water supply study (Vinalhaven Comprehensive Plan, 2003). Results of the Keck study will in turn be integrated into the existing GIS database to be used for future land-use and water management decisions.

PROJECT OBJECTIVES

There were three primary project objectives: 1) collecting detailed information about the bedrock characteristics; 2) sampling surface and ground water to build a baseline dataset on water chemistry; and 3) obtaining information about the characteristics of the aquifer. Basic issues included assessing the link between fracture patterns and salt-water intrusion in wells, linking land-use and water quality, and quantifying the depth and seasonal variability of the water table. The three Keck students completed similar projects in three different locations on the island (Fig. 1).

Fractured granite and gabbro are the main reservoirs of groundwater on the island. A photolineament map of the island has been completed (Vinalhaven Comprehensive Plan, 2005), but detailed information about fracture patterns was lacking. There is excellent bedrock exposure along much of the coastline and in numerous quarries (Fig. 2). Detailed information about the fracture patterns, orientations, and characteristics was collected to understand the nature of the bedrock aquifer. Fracture type (joint or fault), host lithology (granite etc.), orientation, frequency etc. was mapped using aerial photographs and GPS and then integrated into the GIS database. This information was then correlated with well locations, well yields, and wells with salt water intrusion, in order to better understand the relationships between bedrock characteristics, water contamination, and well yields.

Until recently information about the existence, location and characteristics of most of the wells on the island was incomplete (Fig. 1). In 2006 Sean Gambrel (Island Institute GIS Fellow) completed the mapping of over 700 wells. This information formed the basis for the sampling and analysis of the wells in this study. Information on water levels, yield, well depth, and water chemistry was gathered for numerous wells in each of the Keck student study area. Three dataloggers were used to measure the changes in water levels over time at 10 different wells. Well water quality information collected by Vinalhaven high school student volunteers, and data from one continuously monitored well, were also incorporated into the Keck project.

Water quality data was collected from some of the island's surface water bodies, including Folly Pond and Round Pond (public water source for the Town of Vinalhaven). This information complimented the well water chemical data. Water samples were analyzed for pH and TDS in the field. Other analyses (chloride and nutrients) were completed at the local high school during the field season. Many samples were returned to F&M for further analysis using an ICP.

STUDENT PROJECTS

Sam Tuttle, Williams College, focused on the islands to the north-west of Vinalhaven Town – Dog Point, Dyer Island and Barton Island (Figure 1). Residents of this fairly densely populated area obtain their water from wells and have experienced problems with low well yields and poor water quality, particularly salt-water intrusion. Here the bedrock is fairly homogeneous coarse-grained biotite-hornblende granite with widely spaced, open fractures. Sam mapped the orientation, density and characteristics of the fractures in the granite and correlated them with wells with salt-water intrusion problems. Water samples were collected from numerous active and abandoned wells, and surface water bodies, to determine water quality problem areas. Several wells were monitored for water fluctuations and interval sampled for chemical analysis.

Andrew Lorenz, Carleton College, worked in the Calderwood Neck – Mill River area. This area has similar bedrock geology, but a lower population density, compared to the area studied by Sam Tuttle. Andy mapped the fracture characteristics of the bedrock and sampled numerous wells for water quality. Several wells were monitored for water level fluctuations and one well (Calderwood Neck Well 1) has an almost complete water level record since September 2005. Interestingly, despite similar geology and population density, the western Calderwood Neck area (Mill River) has experienced lots of problems with saltwater intrusion while none of the wells in the southern Calderwood Neck area have 'gone salt'.

Nate Pritchard, Franklin & Marshall College, focused on the geologically complex area between Round Neck and Clam Cove to the south-east of Vinalhaven Town. The bedrock includes complex interfingering of gabbro and granite, and as a result the fracture patterns vary dramatically over short distances. Several sheared and brecciated zones also occur in this area. This topographically flat area has a low population density but numerous 'salt' wells. Given the complexity of the fracture patterns, Nate focused on characterizing the fractures in this area and assessed if there was any structural control on the occurrence of salty wells.

PROJECT RESULTS

In most locations there is one dominant vertical fracture orientation and a sub-horizontal 'unroofing' fracture orientation. The sub-horizontal fractures parallel the topography and are laterally fairly continuous but decrease dramatically in frequency with depth (as seen in numerous granite quarries across the island) (Fig. 3). These sub-horizontal fractures probably dominate the recharge of dug and shallow wells and raise the possibility of contamination from relatively unfiltered surface water. The distribution, orientation and pattern of the vertical fractures is complex and varies across the island. These fractures probably dominate recharge to the deep wells. Faults and shear zones are relatively uncommon.

Figure 3: Sub-horizontal 'unroofing' fractures in coarse-grained granite on Barton Island, Vinalhaven, Maine.

Baseline data was collected for numerous wells and surface water bodies. This information indicates that the main threat to the water quality of the island is salt water intrusion (this study did not look at pathogens in the water) (Fig. 4). Salt water intrusion at several wells was documented with interval depth sampling. The Ghyben-Herzberg relationship between the thickness of the freshwater zone above and below sea level was observed in several wells (Barlow, 2003). This important result reaffirmed the need to limit the depth and production of wells close to the shore. While the Vinalhaven aquifer is a typical island aquifer dominated by secondary porosity in fractured bedrock, in most areas there is no clear link between the observed fracture patterns exposed along the shoreline and salt water intrusion inland. Possible explanations for this lack of correlation include: 1) the dominant fractures appear to be laterally discontinuous thus fractures observed along the shoreline may not extend continuously inland and at depth; 2) fracture orientations evident in the shoreline region may not be representative of the orientation of fractures at depth and inland; and 3) well recharge may be dominated by relatively few but highly productive fractures. Sheared and brecciated zones may be better predictors of salt water intrusion problems. For example, a shear zone in gabbros in the Round Neck-Clam Cove area appears to have controlled the salt water contamination of the BenTre well.

One of the most interesting findings is that ocean tides influence many, but not all, of the wells tested. Ocean tides in the Vinalhaven Region vary between 8 and 12 feet. In response, water levels in wells up to 300 feet from the shore vary by between 1.5 and 4.5 feet.

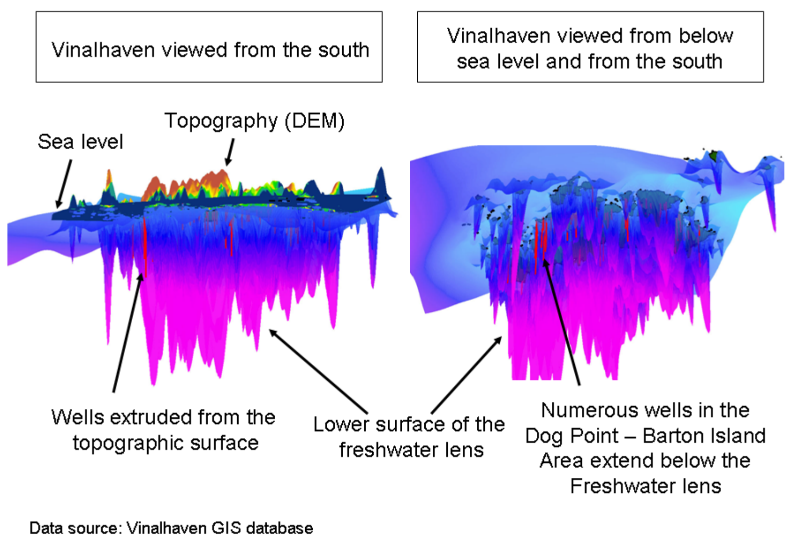

Figure 4: 3-D model showing wells extruded 'through' the Vinalhaven aquifer. The lower surface of the aquifer was estimated using the Ghyben-Herzberg relationship between the thickness of the freshwater zone above and below sea level. This relationship predicts a ratio of 40 to 1 between the thickness of the freshwater layer below sea level and above sea level (Barlow, 2003). This simple model used the topography as an indication of the groundwater table. It is interesting that the model predicts that the Dog Point – Barton Island area will experience the most problems with salt water intrusion.

With further monitoring, the extent and magnitude of this influence might provide important information about the characteristics the Vinalhaven aquifer. Over short time scales (hours to days) ocean tides have the biggest impact on water levels in wells hydraulically connected to the ocean, while over longer timescales (weeks to months) the hydrologic cycle is more influential (Fig. 5). Long term monitoring of water levels in selected wells will better characterize the water-budget for the island.

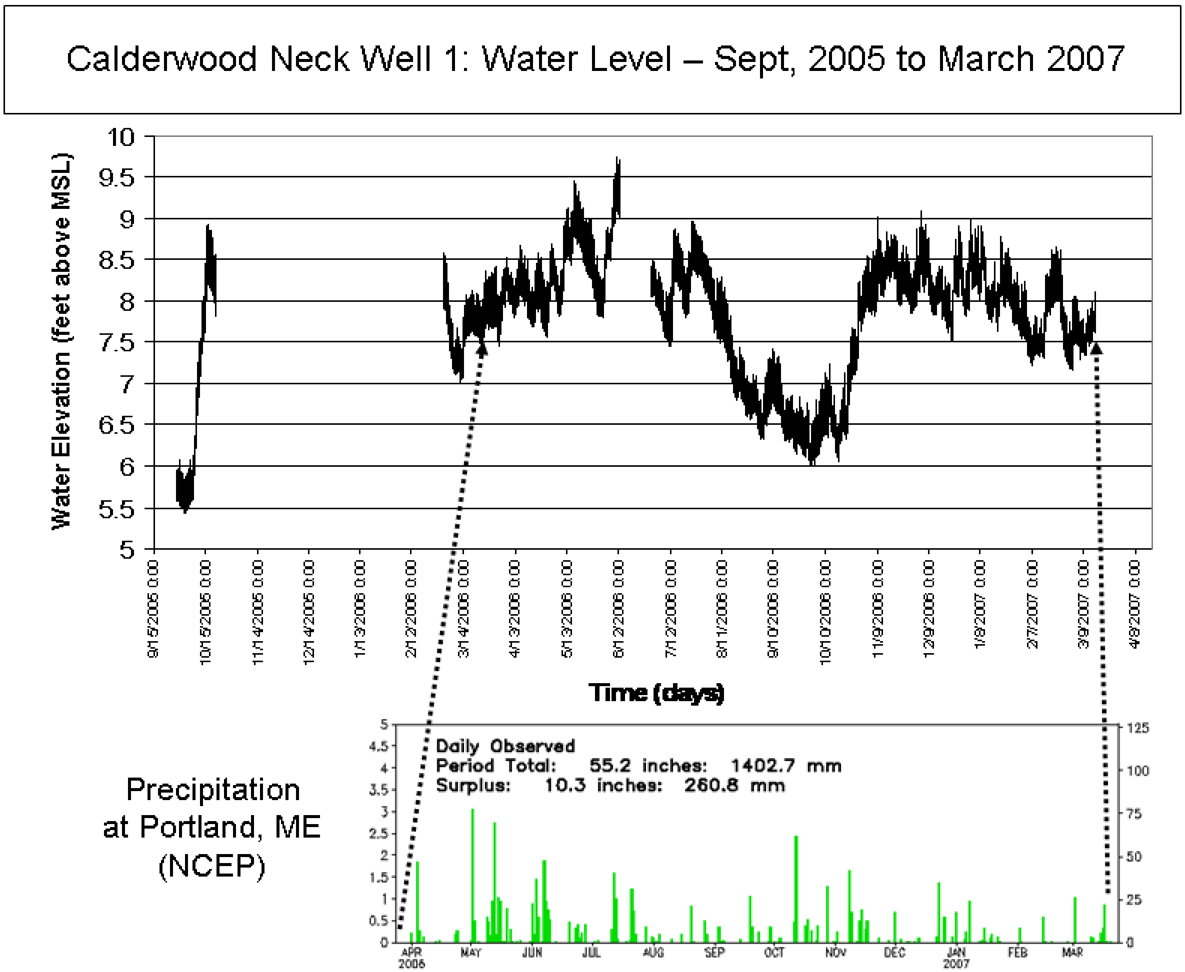

Figure 5: The upper graph shows the water level fluctuations in the Calderwood Neck well 1 between September 2005 and March 2007. The short timescale fluctuations are due to ocean tides while the longer timescale fluctuations can be correlated with precipitation (lower graph). The rainfall data is for Portland, Maine.

Only a few inland wells were measured but these observations suggest that the Vinalhaven aquifer is surprisingly thin (perhaps only 500-600 feet maximum). This information, combined with evidence of very low porosity, implies a very restricted water resource that will require careful conservation as the island population rises in the future.

CONCLUSION

Water quality and supply is a major issue for Vinalhaven Island residents. The issue has been broadly addressed by previous studies, however little detailed information has been collected about the island. Until recently, no comprehensive well database existed, there was no reliable water-table elevation map of the island, the location and severity of salt water intrusion was unknown, and it was unclear how connected the groundwater system is on the island. The Keck study is the beginning of a systematic effort to collect detailed information that will address these issues. The results of this Keck project will be integrated into the Vinalhaven GIS database. Ultimately this research will lead to better informed policies that address water resources on Vinalhaven.

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