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June 9, 2009
08340

Ms. Anne Krieg, Planning Director
Town of Bar Harbor
93 Cottage Street
Bar Harbor, ME 04609

Completion of Groundwater Model for Western Portion of Bar Harbor

Dear Anne:

This letter documents Sebago Technics' completion of the development of a 3-dimensional groundwater model of the Town Hill area of Bar Harbor, including the entire watershed of Northeast Creek, in accordance with our proposal of June 26, 2008. The development of this new model was aided by the work of Lissa Robinson, P.E. & C.G. My former company, Stratex, LLC, had previously constructed a groundwater model covering the Hadley Point area of Bar Harbor and evaluated some scenarios of existing and future development and their impact on nitrate concentrations in groundwater and in inducing saltwater intrusion. The report on that prior effort was issued on June 27, 2007. Recent development activity in the vicinity of the Town Hill area (another part of Bar Harbor with no public water or sewer system) was not covered by the Hadley Point model. In addition, the US Geological Survey has focused effort on determining nutrient inputs to the Northeast Creek watershed. As a result, the Town requested us to develop a groundwater model that covers a larger area of the Town so that the Northeast Creek watershed and the Town Hill area could be covered.

Model data sets were prepared using ArcGIS 9.2 and Surfer. The model is constructed using the Maine State Grid, East Zone, in feet, NAD83. The vertical datum is NGVD29 in feet. MODFLOW-2000[1] was used to develop the flow model.

The latest model covers the area shown in the attached Figure 1. It extends to the head of Somes Sound so that the model could calculate where the groundwater divides lies between the Northeast Creek headwaters and the Somes Sound headwaters. This model is a finite-difference model with cells that are 100 feet square. There are six layers to the model including 2 soil layers and 4 layers in bedrock; the top layer is layer 1 and the bottom layer is layer 6. The soil layers are variable in thickness based on existing surficial geologic mapping and inference. The bedrock layering from top to bottom has a 25' layer, underlain by a 75' layer, underlain by a 200' layer, underlain by a 300' layer for a total bedrock thickness of 600'. There are 323 rows and 331 columns of finite-difference cells with the Y-axis rotated 20 degrees counterclockwise from grid north. There are 440,474 total active cells in the model.

[1] Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald, 2000, *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model—User Guide to Modularization Concepts and the Ground-Water Flow Process*. U.S. Geological Survey Open-File Report 00-92

Boundary conditions in the model include no-flow zones along the major watershed divides on the eastern boundary and mid-way through the saltwater bays on the north and northwest boundaries and under the bottom of the model. The bays are simulated as constant head boundaries up to current mean sea level which is about 0.4 feet NGVD29. The zone between Mean High Tide and Mean Sea Level is covered with "drains" that allow discharge from the aquifer, but will not put water into the aquifer. If later simulations are constructed to use something like Mean High Tide or a varying tidal surface, these boundary conditions will have to be modified. Wetlands and streams were simulated at their estimated ground surface elevations as "drains", which allow discharge but do not put water back into the aquifer. Figure 2 shows the distribution of boundary conditions within the model area. Detailed modeling in small subsets of the larger model area may require further detail in placing "drains" within the area of interest.

As with the previous model, the aquifer recharge rates, soil thickness, and soil hydraulic conductivity were estimated from interpretation of the NRCS soil map. The distribution of these units is shown in Figure 3.

Figure 4 shows the distribution of soil hydraulic conductivity in layer 4. The top layer is everywhere a thin layer of soil with a uniform hydraulic conductivity in the X-axis and Y-axis directions of 0.5 feet per day and the vertical hydraulic conductivity of 0.05 feet per day. The second soil layer reflects the underlying native materials from which the topsoil is derived and has variable permeability according to origin and grain size distribution. The marine muds in the deeper bay waters have the lowest permeability as described in the original report.

The bedrock geologic map[2] for the area was digitized and zones were set up to permit the assignment of unique values of hydraulic conductivity to each zone if sufficient data were ever developed to justify that. Figure 5 shows the zonation. The zones are defined as follows: 1) Ellsworth Schist; 2) Dg4 or medium-grain granite; 3) Bar Harbor Formation; 4) Dsz or shatter zone around Cadillac Mountain granite; 5) potential high-yield bedrock fracture zones interpreted from DEM maps and aerial photos (see next Figure 6); 6) Dsg or Somesville medium grain granite; 7) Dsg1 or Somesville fine grain granite; 8) Dcg or Cadillac Mountain coarse grain granite; 9) Dcg1 or recrystallized Cadillac Mountain granite; and 10) Dgd or gabbro/diorite.

The metasedimentary rocks (Ellsworth Schist and Bar Harbor Formation) were assigned the same value as in the previous model. All the granites were assigned the same value as was assigned to granites in the previous model. Rock in the top 25 feet is assigned higher permeability than the deeper rock, to reflect the effects of weathering and other near-surface forces that usually leave an upper zone of higher permeability. In the previous model the grid was rotated to permit a higher permeability along the Y-axis (which was oriented N20W) than along the X-axis, because of the interpretation that the prominent joints observed on the N20W strike were of higher permeability than the foliation which was wavy and variable in direction and did not appear as a major avenue of groundwater flow. Granites were assigned uniform hydraulic conductivities in all directions, although local studies may find from pumping tests, field mapping, and geophysics that another assumption might be justified. In fact, Appendix 2 of

[2] Gilman, Richard A., and Carleton A. Chapman, 1988, *Bedrock Geology of Mount Desert Island, A Visitor's Guide to the Geology of Acadia National Park.* Maine Geological Survey Bul. 38

Nielsen (2002)[3] reports azimuthal direct-current resistivity surveys in the Ellsworth Schist and in the shatter zone on the east end of Northeast Creek found that the Ellsworth Schist in that location had two different inferred directions of higher transmissivity: N30E and N75W. This illustrates the complexity of the Ellsworth Schist. In the shatter zone around the northwest end of the Cadillac Mountain granite, which is a thin but distinct zone here, two surveys suggested the major axis of the transmissivity ellipse is N60E. Our X-axis is oriented N70E, which is quite close to the field-measured direction, so detailed modeling in this area could use a higher permeability along the X-axis than along the Y-axis, if pumping tests or other evidence supports this.

Figure 6 shows a map of inferred linear bedrock fracture zones along with well yields from the Maine Geological Survey well database for Bar Harbor. We have not done any analysis of this data or tried to test any correlation. The linears are simulated in the model bedrock layers as one-cell width continuous zones of higher than average transmissivity. Additional field work and pumping tests are needed to determine whether these zones do in fact exist as high permeability zones.

The flow model is currently working in the both the steady-state and transient unconfined mode such that the top three layers of the model can run unconfined. The mass balance error for the entire model of the most recent run was a reasonable 0.08%. The predicted average annual positions of the groundwater head in Layer 1 (actually, the phreatic surface), Layer 3, and Layer 6 are given in Figures 7, 8, and 9, respectively. There are areas of "dry cells" in the top layers in the areas of higher elevation and relief as one might expect. The groundwater contours do a good job of conforming to the general topography.

There is no good set of well water level data available for calibration over the whole model area. The model will have to be locally calibrated when detailed data from local studies become available. We have tried to compare our predicted stream discharges with the USGS data[4] collected in 1999-2000 in the area (see Figure 1 for the gauged watershed locations). The problem with that stream gauging data set is that it was taken during a period of significant drought and most of the stations only recorded during the summer months. One station, 01022800, is on Old Mill Brook at Old Norway Drive and had a slightly longer period of monitoring so that data covering more than a year were gathered. The data show a high degree of variability from month to month with very low flows in the summer period. This watershed is a very steep, primarily forested, watershed and largely undeveloped with thin to no soils. Mean monthly discharge ranged from 0.02 cfs to 6.8 cfs, a factor of 340 between the high and low. The mean of 1999 and 2000 June flows was 0.49 cfs. The groundwater model predicts a mean baseflow of 0.60 cfs. June is often a month that has groundwater positions that match the "average annual" position, so the model prediction may be a reasonable match with the measured flows. A much longer period of stream flow measurement is necessary to provide the basis to do a hydrograph separation to understand base flow characteristics during normal or average periods of precipitation. Given the high variability of stream flow, groundwater levels in this watershed

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[3] Nielsen, M.G., 2002, *Estimated quantity of water in fractured bedrock units on Mt. Desert Island, and estimated ground-water use, recharge, and dilution of nitrogen in septic waste in the Bar Harbor area, Maine.* U.S. Geological Survey Open-File Report 02-435

[4] Nielsen, M.G., J.M. Caldwell, C.W. Culbertson, and M. Handley, 2002, *Hydrologic Data Collected in Small Watersheds on Mount Desert Island, Maine, 1999-2000.* U.S. Geological Survey Open-File Report 02-416

probably also have a high range of variability and eventually a transient model should be constructed to simulate seasonal patterns of recharge within the model area.

To summarize and put this latest model development in perspective:

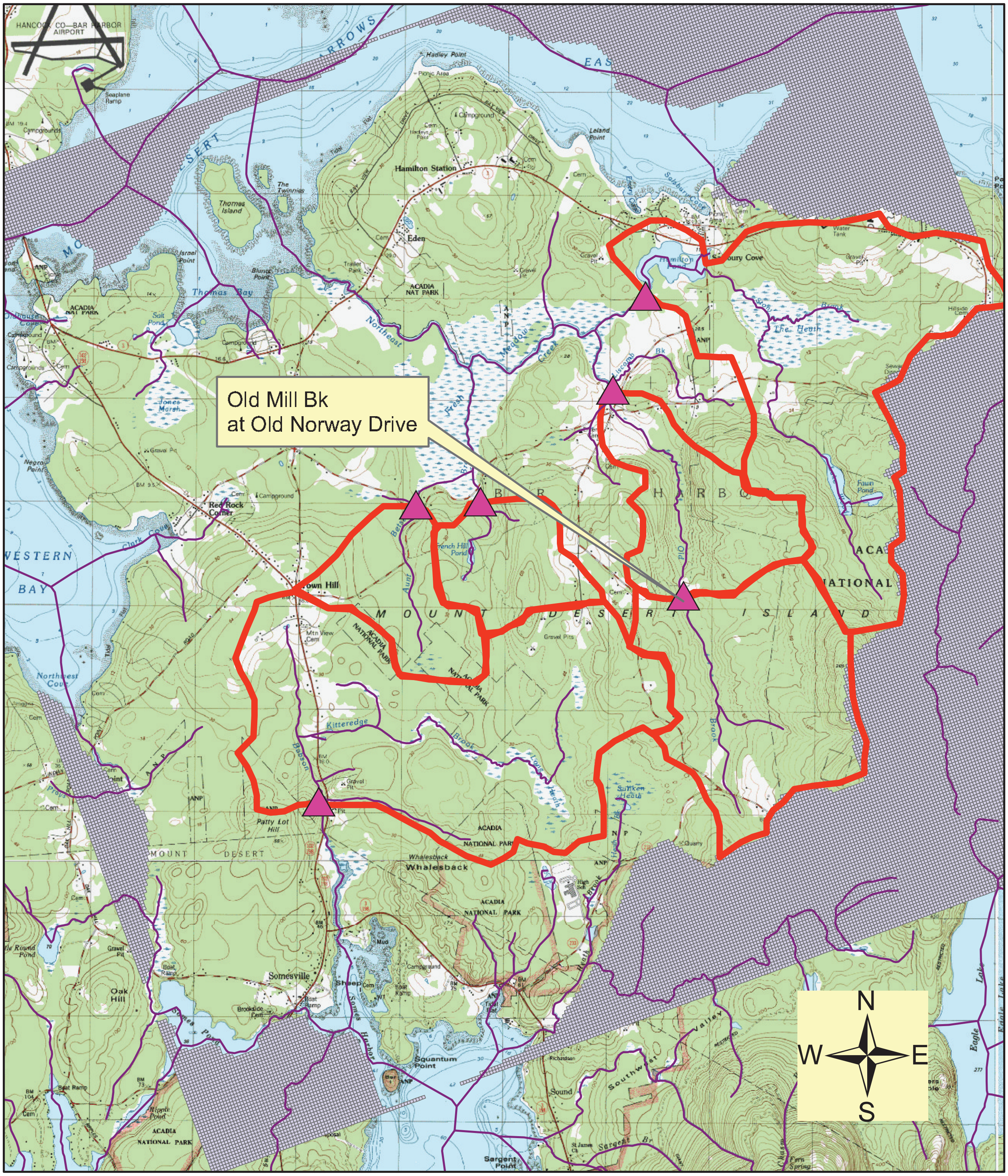
1) A detailed 3-dimensional groundwater model has now been developed for a large area of western Bar Harbor covering all of Northeast Creek watershed and the Town Hill area.
2) The model can be used to establish boundary conditions for more localized detailed models that have specific data available for calibration such as well water levels, pumping tests, field mapping, and geophysical surveys.
3) The model can be used to evaluate future development impact within Northeast Creek or other smaller watersheds encompassed by the model.
4) Future improvements to the model should include the development of seasonally variable recharge inputs with calibration to multi-year well water level data sets and multi-year gauged stream flow data.

Sincerely,

SEBAGO TECHNICS, INC.

Robert G. Gerber, C.G. #110
Vice President, Environmental Engineering

RGG:rgg/kn
Attachments: Figures 1-9



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Groundwater Model Area and USGS Gaged Watersheds
Bar Harbor Groundwater Model
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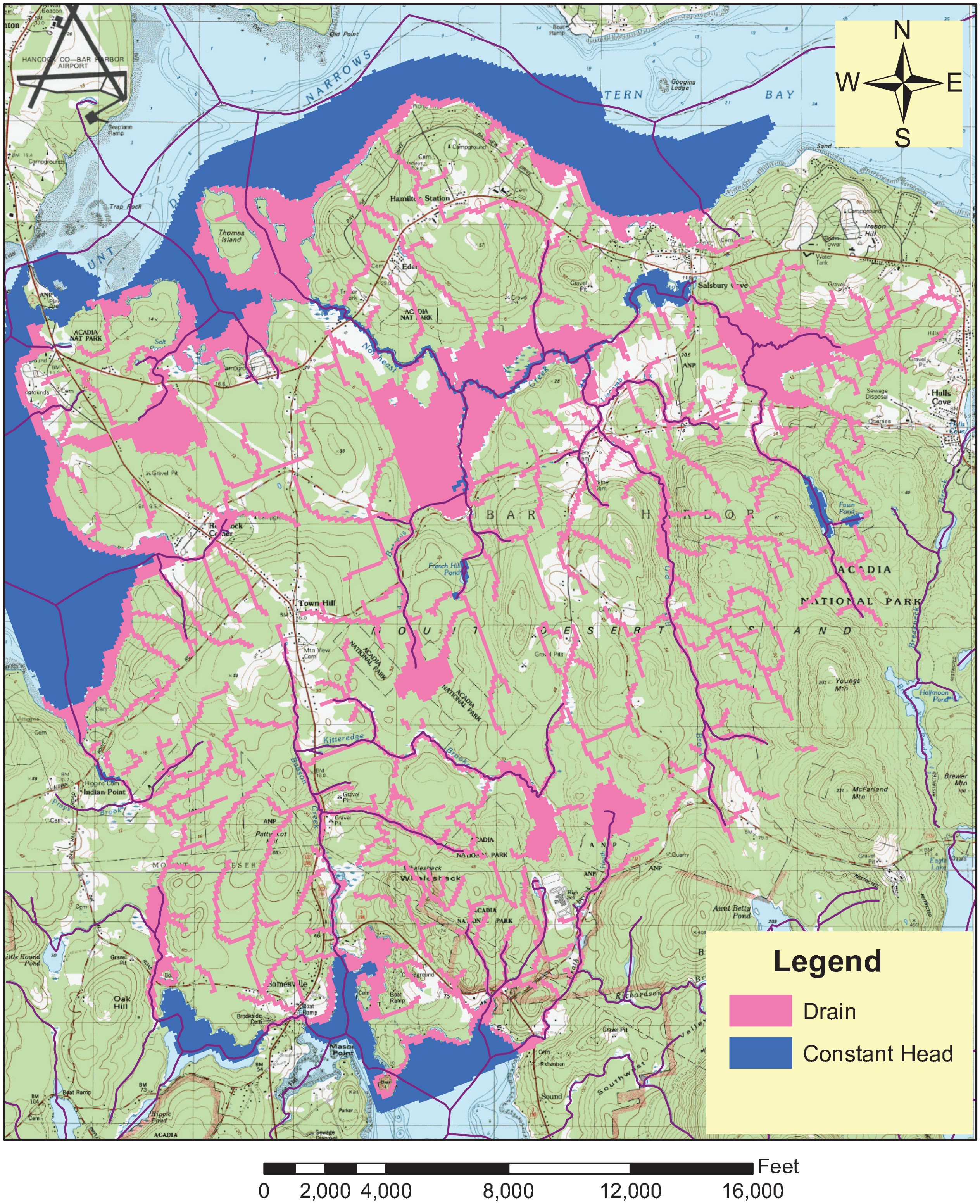
Figure 1



Boundary Conditions
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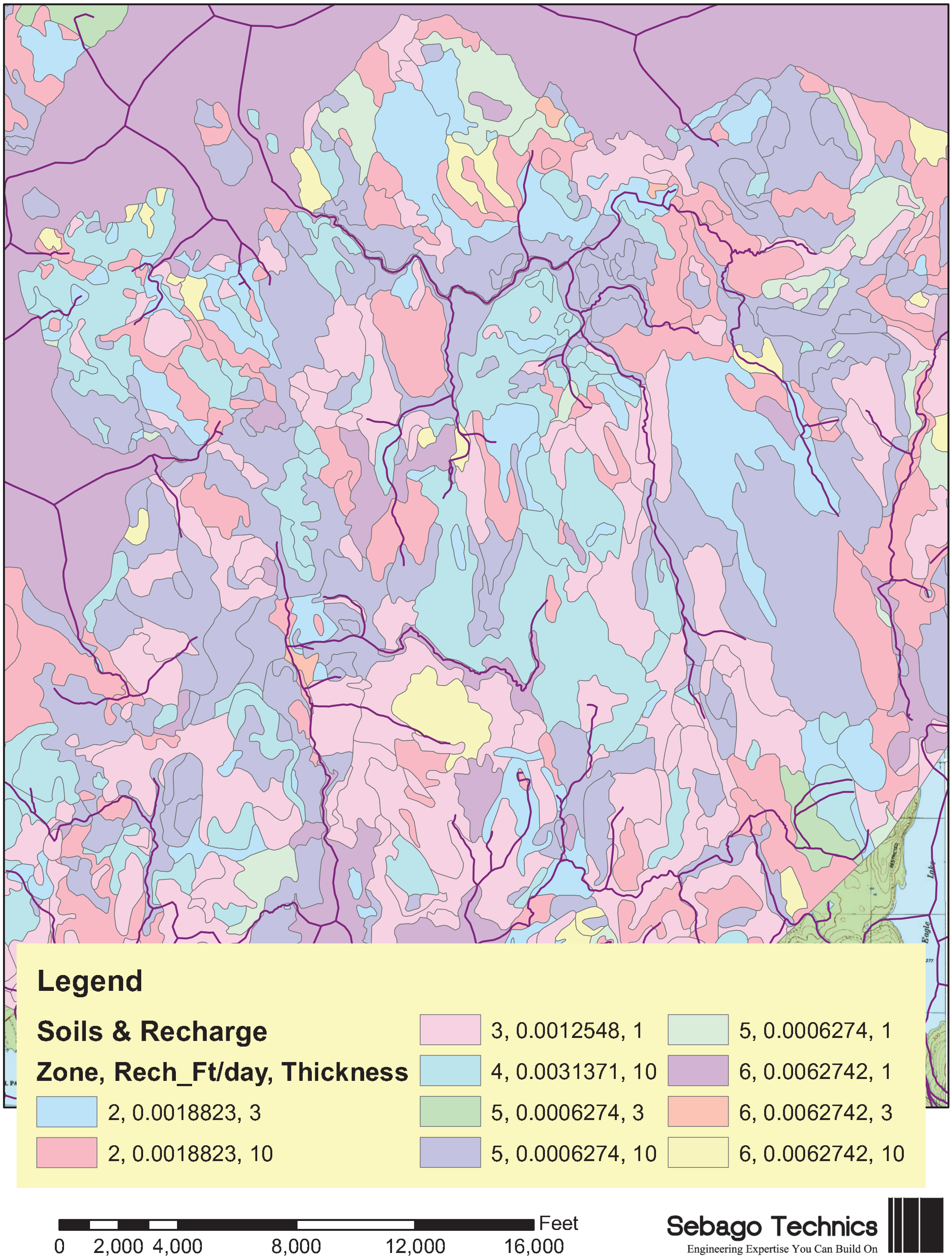
Figure 2



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Recharge Zone Numbers, Recharge Rates, Soil Thickness
Bar Harbor Groundwater Model
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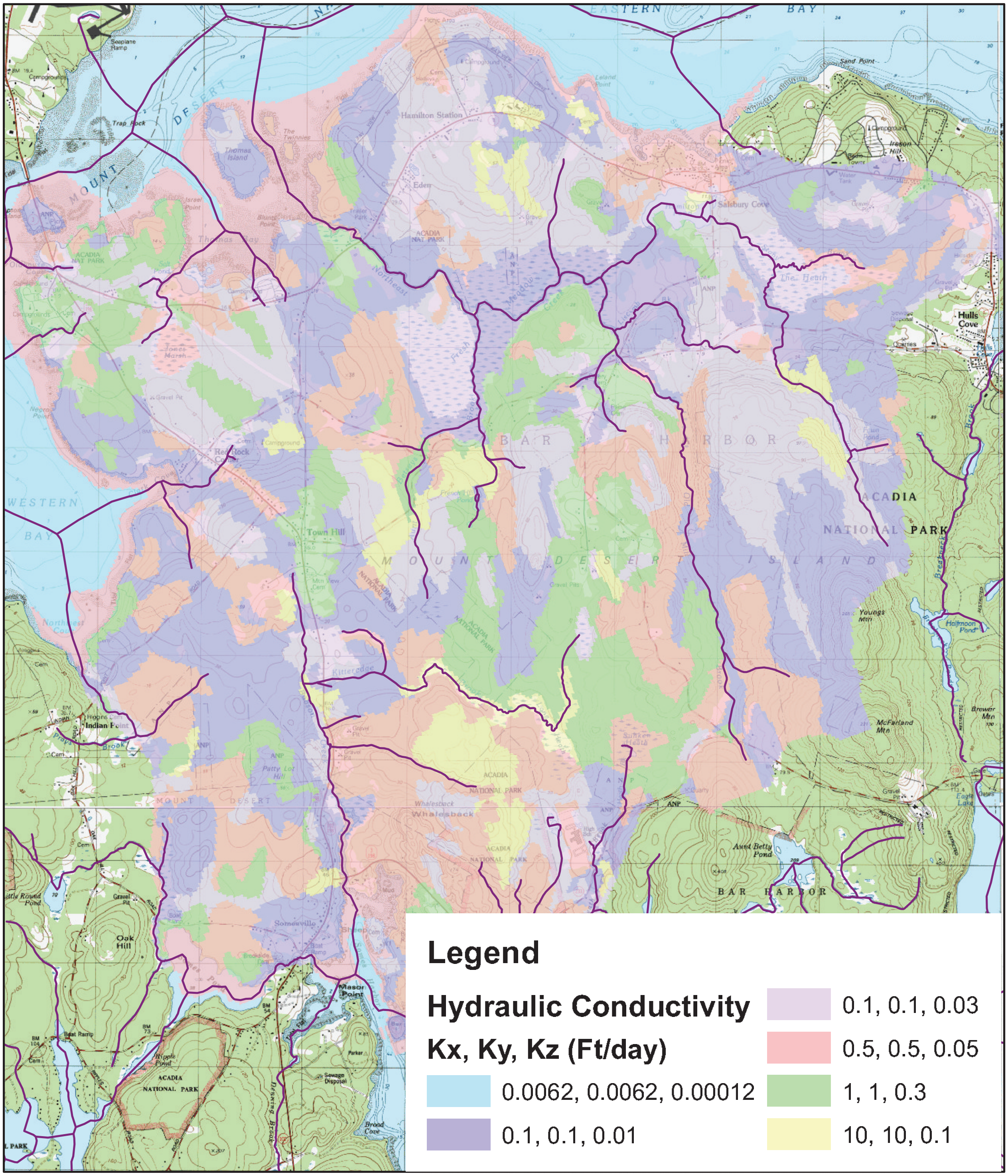
Figure 3



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Soil Hydraulic Conductivity, Layer 2
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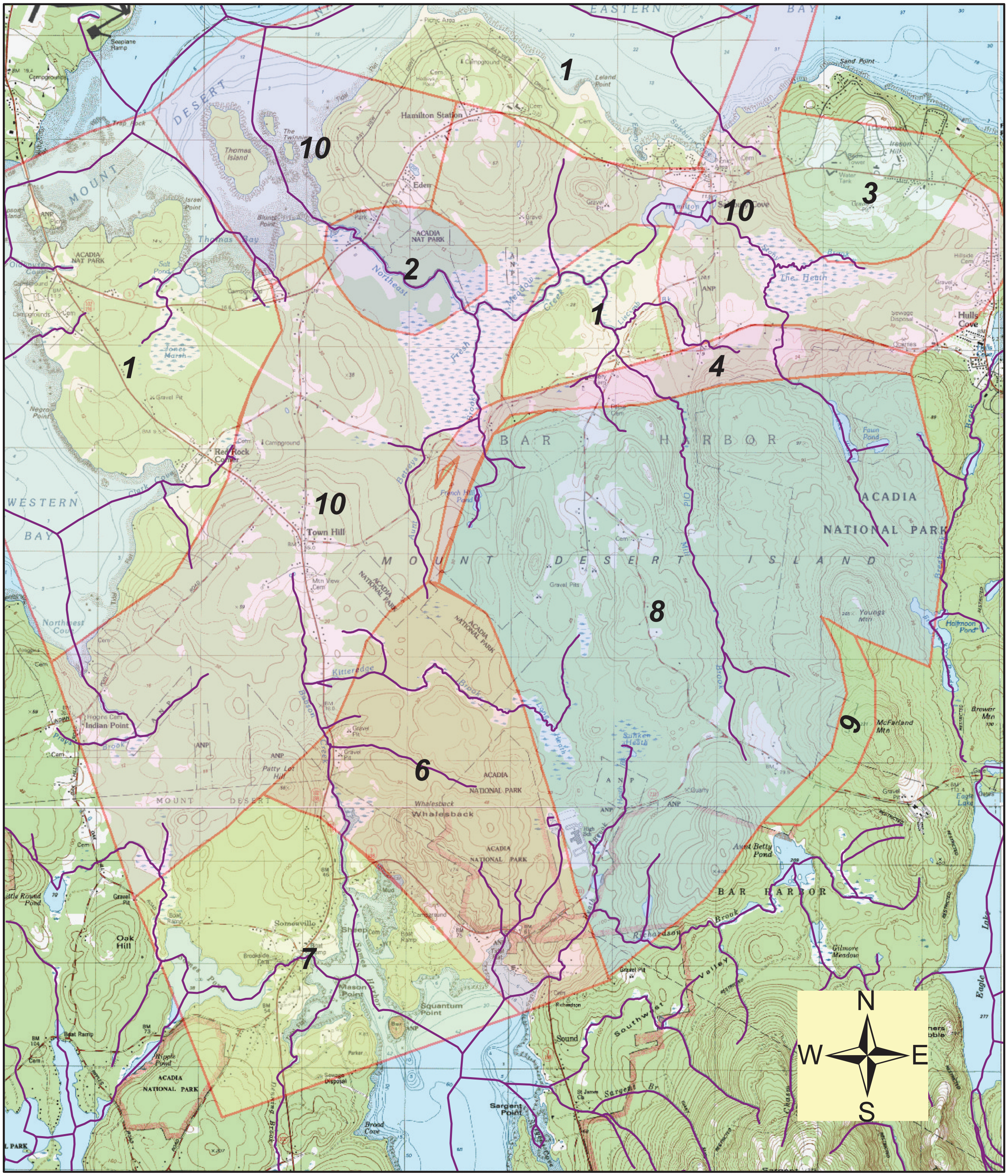
Figure 4



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Bedrock Types
Bar Harbor Groundwater Model
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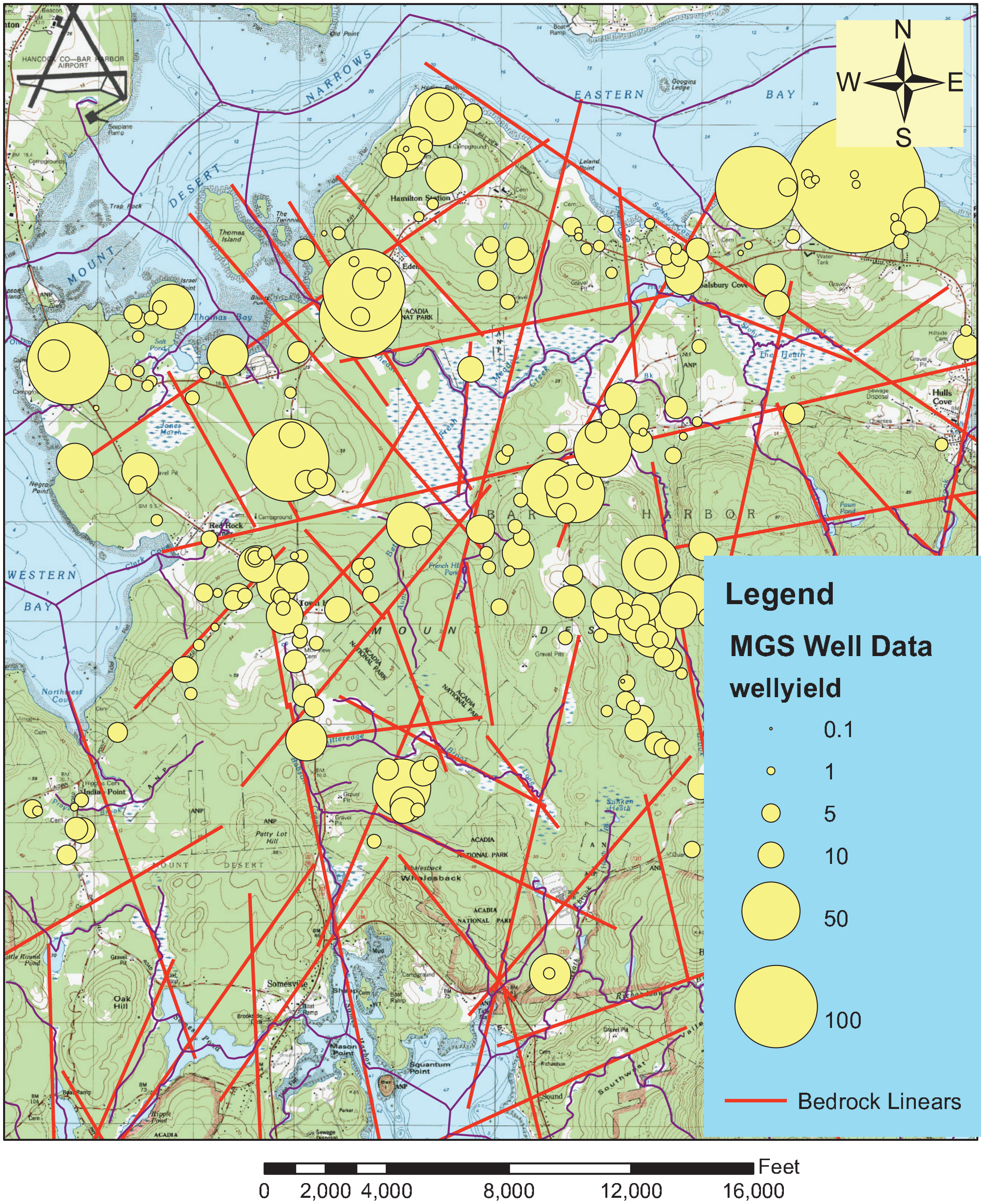
Figure 5



Bedrock Linears and Well Yields in GPM
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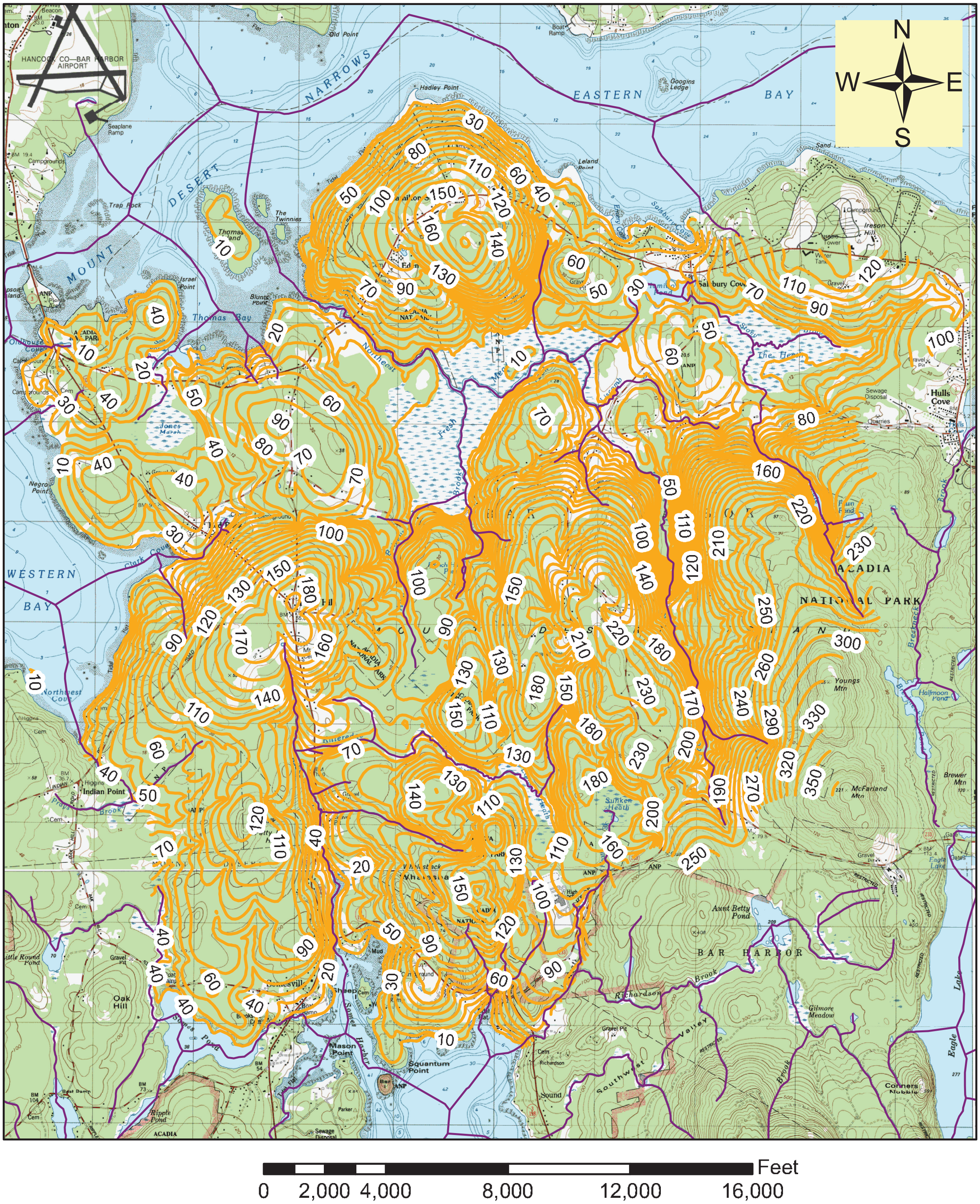
Figure 6



Simulated Phreatic Surface
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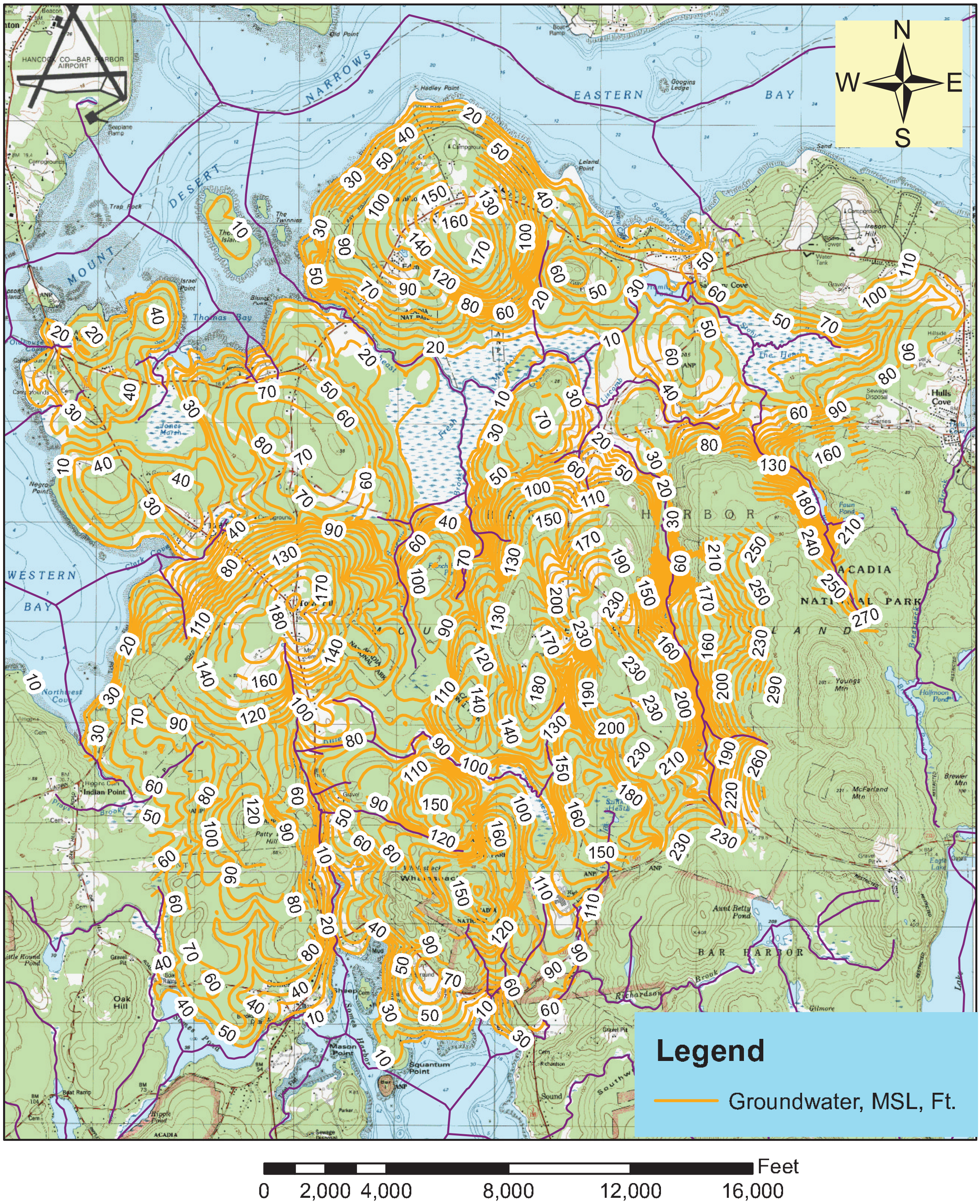
Figure 7



Potentiometric Contours in Layer 3 (Top of Rock)
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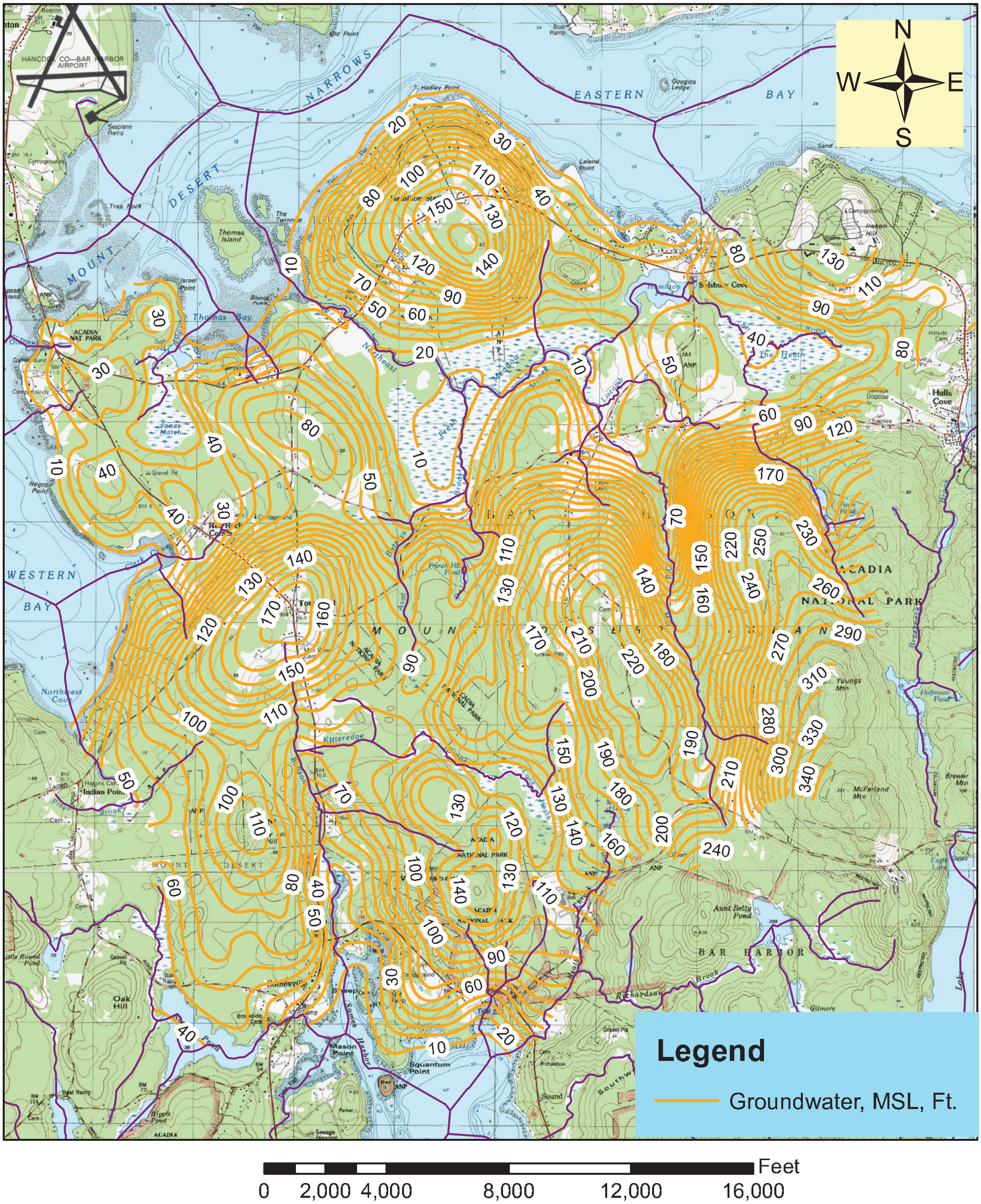
Figure 8



Potentiometric Contours in Layer 6 (Bottom of Rock)
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Figure 9