Impact on Groundwater of Future Development in the Hadley Point Area of Bar Harbor

Bar Harbor, Maine

for
Town of Bar Harbor

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1.0 Introduction

At a workshop in November 2000, citizens voiced concern about the impact of residential development on groundwater resources. In the interest of citizen concerns, the Town of Bar Harbor participated in a cooperative study with the United States Geological Survey (U.S.G.S.), and the National Park Service. Study results published in 2002 provided information on groundwater use, recharge and nutrient loading from residential wastewater disposal in eleven watersheds located within the municipal boundary of Bar Harbor.

Steady demand for new residential development and continued citizen concern prompted Bar Harbor to extend the findings from the U.S.G.S. study. The Town retained Stratex to perform a hydrogeologic study in 2004. The Stratex study investigated water resource vulnerability and analyzed threats from current and predicted residential development. The study outlined a process for protecting water resources through the development of resource policy goals and an ordinance implementation strategy.

The Stratex study concluded that, in general, there will be sufficient quantity of water for development predictions to 2034 but that the Town is justified in implementing protection goals in light of citizen concerns, the value of resource, and the vulnerability of certain areas. Of particular concern for water quality is the impact to areas of thin soils and exposed bedrock, soils with low recharge rates, and the upper reaches of watersheds. To evaluate the vulnerability from residential development and salt water intrusion, Bar Harbor requested a more detailed investigation.

Stratex has developed a groundwater model for a section of Bar Harbor to analyze the impact of predicted future development on groundwater. With assistance from Stratex, the Town has selected the area of Hadley Point for its analysis (**Figure 1**). The selection of this watershed is based on observations of growth trends, the physical setting, existing land use, and the fact that this area has neither public water supply nor public sewer.

Stratex has developed a three-dimensional groundwater model to simulate groundwater flow and contaminant transport in the area of interest. With the use of groundwater modeling, the impact of future development under existing zoning can be predicted and allow the Town to see whether this would create any unacceptable impacts to the groundwater resource. Stratex has developed the model to simulate groundwater impacts from existing development. The model also simulates the groundwater impacts under the future build-out scenario based on the maximum permitted development of this area under current zoning (40,000 square feet per lot). The model allows an evaluation of groundwater levels, flow paths, travel times, the dilution of contaminants (e.g., nitrate nitrogen) from their source locations in the model (i.e., septic systems). The model also evaluates the potential extent of saltwater intrusion.

2.0 Modeling Objectives

The groundwater model and resulting tables and graphical representations were created to develop an understanding of groundwater flow in the soil and rock within the Hadley Point area. The portion of Bar Harbor that has been included in this model is shown in **Figure 1**. The modeling objectives include:

A) Develop a conceptual model based on the geological literature and topographic maps;
B) Determine a model area that would include the site and all relevant nearby topographic and boundary condition controls;
C) Incorporate the ocean boundary condition on the top layer of the portion of the model in the subtidal area as either saltwater in a density-dependent model or as equivalent freshwater heads in a standard non-density-dependent model;
D) Use available well data to develop a set of observed groundwater levels (called "heads") to use to compare with model-predicted heads at the same locations and approximate depth of the existing wells;
E) Use existing mapped NRCS soil data to correlate to average annual recharge rates;
F) Perform a number of different simulations with different hydraulic conductivity values and assumptions about transmissivity anisotropy to see which combinations produce the best matches of predicted heads with observed heads;
G) Place septic systems and wells on each existing lot and simulate their long term effect on nitrate nitrogen distribution emanating from each septic system under average annual recharge conditions;
H) Simulate septic systems and wells in developable areas at the maximum lot density permitted under the current zoning ordinance, under both average annual and drought recharge conditions.
I) Simulate the incremental drawdowns within the model area comparing the existing density with the maximum developable density;
J) Simulate the incremental saltwater intrusion that may occur on and near the proposed development due to both the existing development and the maximum developable density;
K) Evaluate the effects of a typical dry summer on groundwater levels and on saltwater intrusion potential.

2.1 Modeling Software

The flow model was constructed using the "original" 1996 version of MODFLOW (Harbaugh and McDonald, 1996) as developed by the US Geological Survey (USGS). Solute transport was implemented using MTD3MS (Zheng, 1999) developed by the US Army Corps of Engineers (COE). Seawater intrusion analysis was performed using SEAWAT2000 (Langevin, et al., 2003), which is a special version of the USGS MODFLOW2000 program incorporating MTD3MS in a density-dependent formulation. Groundwater Vistas (GWV), GW4, Version 4.25, has been used as the pre- and post-processor, with additional post-processing performed by Surfer.

ArcGIS 9.1 was used to prepare data sets and present model results. Map bases were obtained from the Maine Office of Geographic Information Systems.

3.0 Site Geology

3.1 Surficial Geology

The surficial geology is an important factor in the recharge potential of the underlying aquifers and relating to the acceptance of waste disposal at the land surface such as from septic systems. The distribution and permeability of the soils in the recharge and discharge areas are quite important to a number of hydrologic characteristics such as the potential for saltwater intrusion.

The surficial geology of the model area includes primarily glacial till and glaciomarine soils. Borns and Smith (1980) have produced a regional-scale surficial geology map for Mt. Desert Island with little detail for the model area. The glaciomarine soils are interpreted to overlie glacial till as a thin veneer on land, which has a variable thickness over bedrock. Glacial till is a heterogeneous mixture of boulders, cobbles, gravel, sand, and silt that was produced by the grinding and mixing of soil and rock under and within the continental ice sheet that spread over the area from about 22,000 to 13,000 years ago. It has a moderately low permeability and can be up to 40 feet thick in the model area based on well drillers' records. The soil deposits under Northeast Creek and Fresh Meadow are interpreted to be primarily glacial till. The glaciomarine soils are primarily composed of silts and clays that were deposited on the ocean floor from 13,000 to 10,000 years ago from glacial meltwater flowing into an ocean with a level several hundred feet higher than today's level. Some of these glaciomarine soils are clayey ("blue clay") but some consist of uniform fine sand. The bay mud deposits below tide level in Eastern Bay are interpreted to be soft blue clay with a very low vertical permeability.

There are some forested wetland areas in the upland areas that probably support "perched" water tables during high groundwater periods of the year, but the water tables in these wetlands are probably not continuous downward everywhere into the bedrock aquifer. Review of aerial photos suggests there may be sand and gravel deposits in moraines or kames in the eastern part of the model area, but no site confirmation is available.

Figure 2 shows the total soil thickness based on interpolation and extrapolation of "overburden thickness" or depth to bedrock data provided from the State of Maine drilled well database (Maine Geological Survey, 2006, unpublished well data), using best professional judgment. Although the higher elevations have relatively thin soils as a general rule, there are soils with significant thickness around much of the edge of the model area. **Figure 3** shows the hydraulic conductivity of soils designated in the model as layer 2. As described below, the groundwater model has 6 layers, including two soil layers. The top soil layer is treated as having a thickness of 10 feet or less and having a uniform hydraulic conductivity (same meaning as permeability for our purposes) of 0.5 feet per day in the horizontal direction. Model layer 2 is between the top soil layer 1 and the bedrock and accounts for the variable thickness of the soil. The thin soils and fine sandy glaciomarine soils have a hydraulic conductivity of 0.5 feet per day (zone 1); the silty glacial till soils have a hydraulic conductivity of 0.1 feet per day (zone 2); and the bay mud is assumed to have a hydraulic conductivity of 0.0062 feet per day (zone 3).

3.2 Bedrock Geology

The bedrock geology is very important to the area covered by this model because nearly all, if not all, of the current and probable future residents obtain their water from wells drilled into bedrock. Although well yield and depth reports are somewhat helpful in understanding the overall permeability of the rock, they do not tell us whether the rock is more permeable in one direction than another or how susceptible the rock might be to future saltwater intrusion. Water travels within fractures within the bedrock and it is these fracture zones that we strive to understand as part of groundwater model construction.

The bedrock geology is interpreted from Reusch (1991). He defines two basic rock formations in the model area: 1) the Ellsworth schist which is a complexly-deformed laminated rock along the northern portion and southeast corner of the model area; and, 2) the Somesville granite and a smaller area of unnamed granite which make up the rest of the model area. The two granites should have similar fracture patterns and behavior from a groundwater perspective. There is almost no mapped fracture data within the granite rock bodies to confirm this assumption.

The main information we have on fracture patterns within the granite is in the form of photolineaments. Photolinears are interpreted from aerial photos as thin linear features crossing the landscape, even where bedrock is not close to the surface, with darker color tones indicating their location. The darker tones often indicate areas of bedrock fracture concentrations where groundwater can be more easily extracted from the rock. We have compiled the high-altitude photolineament interpretation of Caswell Eichler & Hill (1986), and have performed our own lineament interpretation from aerial photos dated 11/13/66 at a scale of 1"=1667'. Stratex borrowed aerial photographs from the Maine Geological Survey for lineament interpretation.

Stratex prepared a “rose diagram” based on the frequency of compass orientation of the ground expression of the photolinears. **Figure 4** shows the “rose diagram” of photolinear orientation. The rose diagram suggests that the direction with the highest concentration of linears is NW-SE with the second most frequent orientation being orthogonal to that at NE-SW. This type of orthogonal, almost equally weighted, result suggests that the bedrock aquifer could be treated as isotropic in the horizontal direction with the movement of groundwater almost equally likely in any direction, other hydrogeologic factors being equal.

Within interpreted photolinear zones vertical permeability is assumed to be equal to horizontal permeability. This assumption is based on evidence suggesting that most photolinears have a steep dip and from observations on most Maine coastal granite which show that most inclined joint sets have steep to near-vertical dip. Photolinears are usually concentrations of parallel fracture planes. We are assuming here that the groundwater will also move through single fractures with similar orientations to the photolinears but the local transmissivity or permeability of these single fractures is much less than the bulk permeability of a concentrated fracture zone interpreted from photolinears.

Figure 5 is generated by a special program in Rockworks software that contours the relative likelihood of encountering a high yield well among the photolinear zones. It weights frequency of orientation, length of linears and the number of intersections of the linears in a special way to produce this map. Those zones corresponding with the highest numerical value have the highest likelihood of producing a high-yield well.

The Ellsworth schist has both joints and foliations, although most academic geologists (such as Reusch) concentrate on mapping compass direction of the intersection of the *foliation* planes with the horizontal (called the “strike”) and the angle that the planes make in a downward direction from the horizontal, perpendicular to strike (called the “dip”). The mapped foliation strikes of the Ellsworth Formation within the model area are highly variable. It appears that joints that strike about N20W, as interpreted from terrain analysis, may be most important to internal water transport within the rock. Therefore, the groundwater model was oriented with the Y-axis aligned on a N20W orientation and the X-axis oriented on a N70E orientation.

Figure 6 shows the distribution of hydraulic conductivity in the deep bedrock layers of the model. Zone 5 of the model represents the Ellsworth Schist, Zone 8 represents the granite, and Zone 6 represents the photolinear zones which are assumed to represent fracture concentrations. The hydraulic conductivity values listed in the legend are those for the X-axis direction. Zones 6 and 8 are treated isotropically, meaning the X-, Y-, and Z-axes all have the same hydraulic conductivity. Zone 5, on the other hand, has a Y-axis hydraulic conductivity that is 5 times greater than the X-axis direction. Model layer 3 hydraulic conductivity values for the top bedrock layer (which is only 25 feet thick), is slightly higher than for layers 4 through 6 because the upper 25 feet of bedrock in Maine is typically more weathered, fractured, and open than the deeper rock.

3.3 Soils and Related Precipitation Recharge Rates

The USDA NRCS soil series map (medium intensity maps available through the Maine Office of GIS or “OGIS”) provides an excellent basis for assigning average annual precipitation recharge rates in the type of terrain within the modeled area. The soil series are broken down by soil genesis (e.g., types of parent material such as glacial till, glaciomarine soils, etc.), texture, depth to bedrock, and position of seasonally high groundwater table, all of which are important to recharge capability. **Figure 7** shows the soils within the model area (not broken down by slope designation). Each of these soils is translated into a recharge rate as shown in **Table 1** and **Figure 8**. The basis for assigning particular average annual recharge rates to specific soils is our long experience in modeling groundwater in New England using this approach and correlating the soil genesis, texture and thickness in the USDA descriptions with the soils discussed in Gerber and Hebson (1996). Zones 7 through 11 represent individual existing leachfields within the model area discharging 270 gallons per day per house. Zones 12 and 13 represent the leachfields for the Hadley Point Campground taken at 60 gallons per day (gpd) per campsite for 180 campsites and dividing by 4 to allow for only summer operation.

4.0 Model Discretization

The groundwater flow model is a 3-dimensional finite-difference model, using rectangular block-centered cells to discretize the spatial dimensions of the area that is modeled. The edges of the model must be defined far enough away from the land area of interest that normal wells or slight errors in choice of a groundwater divide position will not affect the heads and flux in the area of interest. We chose topographic divide locations on the east side of the model. We extended the northern boundaries into the middle of Eastern Bay, assuming that groundwater flow moving south from the north will flow upward at the approximate northern model boundary location. The discharge of groundwater to the ocean is affected by the depth of seawater and thickness and permeability of the mud that overlies it.

The model grid consists of cells that measure in plan view 50 feet by 50 feet. The area covered by the active portion of the model is shown on many of the figures, such as **Figure 8** where the active model is enclosed within the gray area. The model includes 228 rows, 225 columns, and 6 layers in the vertical or z-direction. There are 235,416 active cells in the model. The grid is aligned to N20W, to allow alignment with the strike of presumed joints in the Ellsworth Schist. The model layers are numbered from the top down. The vertical layering was established by first importing into Groundwater Vistas the USGS topographic contour lines from OGIS and ocean bottom contours that we digitized from NOAA charts and relating both to NGVD29 datum. This gave us the top of the solid earth surface. The thickness of bottom soils in the offshore areas was estimated using best professional judgment. The thickness of the land soils was determined by kriging (a particular contouring algorithm) the thickness of soils determined from the Maine Geologic Survey well data base. The top of bedrock was calculated by subtracting soil and mud thickness from top of model elevation. Below the soil layer, bedrock layers increase in thickness with depth: model layer 3 (top of rock) thickness = 25'; layer 4 thickness = 75'; layer 5 thickness = 150'; and model layer 6 (bottom of model) = 300' thick.

All of the model data were constructed within ArcGIS 9.1 to keep correct and consistent spatial relationships. Many of the regional databases were downloaded from the Maine Office of Geographic Information Systems (OGIS). We converted the OGIS UTM datum to Maine State Grid, East Zone, NAD83, within ArcGIS 9.1. Our vertical datum is NGVD29. We evaluated NOAA tide datums based on information from their websites and derived the information shown in **Table 2**. It appears that Mean Sea Level is approximately 0.4 foot above the NGVD29 datum. Sea level rise in Bar Harbor between the 1983-2001 Tidal Epoch and the 1960-1978 Epoch was 0.08 feet (NOAA website).

5.0 Boundary Condition, Recharge, and Discharge Specifications

Any type of mathematical model requires boundary conditions in order to calculate a unique solution to the series of equations that define groundwater pressure (or "head") and concentrations in each point or cell of the model. Here the ocean is one boundary for the purposes of long-term simulations of solute transport. Streams and wetlands that permit the discharge of groundwater into surface water are also very important controls on the distribution of groundwater heads in the model. Rainfall and snowmelt add water to the top layer of the model, as do septic systems. Wells take water out of various layers of the model, depending on the depth to which they are drilled.

5.1 Streams, Wetlands, and Ocean

Figure 9 (phreatic contours) shows the translation of streams, wetlands, and ocean areas into boundary conditions applied to the top layer of the model. The streams used in creating the boundary conditions were taken from USGS topographic maps and the "streams" layer from OGIS. Wetlands used in creating the boundary conditions were taken from the NWI wetlands map obtained from OGIS.

No-flow boundaries (a special case of constant flux boundaries--also called Neumann or Type 2 boundaries) are placed around the outside of the naturally-defined limits of the model, and under the bottom of the model. As calibration proceeded, certain areas of the uplands that were predicted by the model to become "dry" then become no-flow cells for purposes of calculating flux into and out of that layer and no solute transport would be allowed in dry cells or no flow areas. Normally model layers 1, 2, and 3 are allowed to be simulated as "unconfined" (i.e., the thickness of the saturated aquifer layer decreases as the computed phreatic surface decreases with the top active model layer) if the layers above were not predicted to be saturated. With SEAWAT2000, the model had to be run with all layers defined as "confined" layers because the time-step constraints were too severe when running in unconfined mode.

The ocean in Eastern Bay within the model area is treated as constant head cells (also called Dirichlet or Type 1 boundaries) with a defined elevation of 0.4 feet NGVD29 for average annual recharge-based simulations. There are 10,948 constant heads defined only in layer 1 of the model. Because the ocean is saline with a density of 1.025 times the freshwater density, the depth of seawater over the ocean bottom has to be multiplied by 1.025, then subtracted from the depth to get the equivalent head of freshwater at that point on the top of the ocean bottom. This calculation is performed automatically in SEAWAT2000, but in using MODFLOW and MT3DMS for the septic and drawdown simulations, we had to supply the equivalent freshwater head distribution.

Streams, upland rivers, and wetlands were defined as "drains" (also called Cauchy or Type 3 boundaries). There are 3,878 drains in the model. This is a condition that allows discharge from the model at the drain, but when the water table is predicted by the model to drop below the defined drain bottom elevation, there is no water simulated to be discharged to the stream. The resistance to discharge into the drain is controlled by the "conductance" value assigned to each drain cell. The drains were digitized in segments based on the USGS map elevations along streams defined on the OGIS shape file of "streams". Where some of the drain cells are located on steep slopes and soil thickness is thin, the linear interpolation routine caused some "drain" cells to be defined below the top layer of the model. However, the cells are active in the next layer down and perform in the same manner to permit water to discharge. The conductance of the drain cells was defined as 100 cubic feet per day per square foot per foot, with a one-foot thick stream bottom resistance layer assumed.

5.2 Recharge

Figure 8 shows the distribution of recharge in the model under average annual recharge conditions according to **Table 1** and **Figure 7**. The legend shows the precipitation recharge rate in feet per day. Recharge is applied to the top active layer of the model, so if the soil layer is predicted to be dry, the recharge is applied to the next active layer beneath it. See **Section 3.3** for a discussion of what some of the recharge zones represent. Bar Harbor has an average precipitation of 55 inches per year (Nielsen, 2002). The drought analysis for purposes of nitrate nitrogen simulations is taken as 60% of the average annual precipitation rate. The flux from a single residential 270 gallon per day (gpd) septic system is added to one 50'x50' model cell with the underlying precipitation recharge rate. For example, Zone 7 equates to Zone 2 (which is the recharge rate without a septic system input) and provides for the flux from a 270 gpd septic system. **Table 1** shows the computation of the flux for each septic system according to which recharge zone the septic system falls within.

5.3 Septic System Inputs and Well Withdrawals

Figure 10 shows the location of septic systems representing the future build-out scenario. Stratex modeled the addition from these additional septic system with the recharge from precipitation to the soil layers of the model. **Figure 11** shows the location of wells under the existing development pattern along with the predicted groundwater contours in model layer 4 simulated using the SEAWAT2000 model. **Figure 12** shows the hypothetical location of wells under the future build-out scenario in model layer 4 simulated again with SEAWAT2000. The concentration of nitrogen coming out of septic systems is assumed to be 40 mg/L. The total precipitation recharge in cubic feet per day entering a 50' by 50' model cell is treated as having a background concentration of 0.25 mg/L. The volume rate of precipitation recharge times 0.25 mg/L is added to the volume rate of septic discharge (270 gpd) times 40 mg/L, then divided by the total volume rate of flow to get the flow-weighted nitrate input for the model cell. All of these assumptions are in accordance with the nitrate modeling guidelines put out by the Maine Department of Environmental Protection for residential projects submitted under the Site Location of Development Guidelines.

6.0 Hydraulic Conductivity

The two most important aquifer property variables in groundwater flow modeling are recharge and hydraulic conductivity. They vary directly such that if you increase recharge, you must also increase hydraulic conductivity (although not necessarily in a linear fashion) to maintain model calibration. Recharge rates are generally constrained within a fairly small range of no more than plus or minus 50% of estimates based on soil conditions. However, aquifer layer hydraulic conductivity can range over 2 to 3 orders of magnitude, even as measured, for example, with insitu permeability testing. Therefore, we usually fix average recharge rates based on past experience and vary hydraulic conductivity to achieve model calibration.

The groundwater conceptual model is that precipitation recharge in the form of direct rainfall and snowmelt infiltrate the soil after large fractions are lost in either direct runoff or evaporation and transpiration. Once in the soil, if the soil is saturated, part may flow downhill and discharge to a local stream, wetland, or ocean and part may continue downward and become part of the bedrock aquifer flow. Infiltration occurring on hilltops and ridges tends to move downward more or less vertically to great distances in the bedrock aquifer before turning and moving toward a discharge zone. Once under a discharge zone, the bedrock aquifer water moves upward to discharge.

The bedrock in the site area has two primary features that control movement: 1) assumed anisotropy in the horizontal plane in the Ellsworth Formation (there is no direct evidence of this, but it is added for purposes of illustrating a typical treatment of foliated metamorphic rock) due to fracture density and orientation favoring movement N20W or S20E (the Y-axis orientation of the model); and 2) discrete, vertical or near-vertical fracture zones (inferred from photolinears) that extend to great depth and have much higher local hydraulic conductivity than the bulk rock. We chose an anisotropy ratio of hydraulic conductivity 5 times greater in the N20W direction than in the N70E direction (the X-axis direction of the model). The linear fracture zones have varying lengths and orientations. These zones are treated as discrete narrow zones one model cell wide with hydraulic conductivity usually much greater than the adjacent rock.

The top 25 feet or so of most Maine coastal rock are weathered and moderately fractured in three dimensions and therefore moderately permeable (see **Figure 13**). Beneath this weathered zone, the predominant rock fracture systems and linears as discussed in **Section 3.2** are most important.

The thin soil layer at the top of the model layer cake is predicted to be dry in many upland areas under average annual recharge, but it was assigned a hydraulic conductivity of 0.5 feet per day horizontally and 0.05 feet per day vertically. This is typical of stratified silty sand such as typical of many glaciomarine deposits and the weathered zone of glacial till. In model layer 2 subtidal sediments below the approximate Mean Low Water mark are assigned a lower hydraulic conductivity typical of marine mud. We used the value from the Maine Yankee study in Montsweag Bay (CH2M Hill et al., 2005) of 0.0062 feet per day horizontally and 0.00012 feet per day vertically.

Figure 3 shows the distribution of hydraulic conductivity (K) in layer 2 of the model (bottom soil layer of variable thickness). **Figure 6** shows the distribution of hydraulic conductivity in layers 4 through 6 of the model (the unweathered bedrock layers). The bulk rock K values in the unweathered rock layers are 15% of those in model layer 3 (the weathered rock), except for the linear zones, which are held constant with depth. All the linear zones are treated as having an isotropic hydraulic conductivity of 1.0 foot per day.

7.0 Transient and Solute Transport Parameters

Because transient simulations were performed (nitrate-nitrogen drought analysis) and because some of the model runs were performed with SEAWAT2000 (which also ran in a transient mode to develop heads for the saltwater intrusion analysis), it was necessary to estimate storativity (or storage coefficient) and specific yield (Sy). Specific storage (Ss) was specified rather than the storage coefficient (specific storage is equal to storage coefficient per foot of aquifer thickness). Specific storage works more accurately with unconfined model layers. We have used values based on our experience in working with similar Maine geologic units where we had pumping test values to evaluate these parameters. (For example, see Gerber, et al., 1991, for a discussion of storativity values and a general defense of using porous media models to model this type of fractured bedrock terrain.) **Table 3** gives the values used for the zonation of specific storage, specific yield, and porosity in the model. Notice that the values decrease with depth.

Dispersivity is a scale-dependent parameter that causes spreading of a contaminant plume in groundwater. Macro-scale dispersivity is a surrogate for lack of complete understanding of the exact distribution of hydraulic conductivity. The larger the dispersivity, the more a plume will spread. We have used a rather small set of dispersivity values here, for lack of any data to support larger ones: longitudinal dispersivity (D_L) = 25 feet; transverse dispersivity (D_T) = 2.5 feet; and vertical dispersivity (D_V) = 0.25 foot throughout the entire model domain.

Since nitrate-nitrogen and chloride are the only two chemicals for which we have evaluated the transport, and since both are conservative tracers (nitrate only transforms in the presence of organic carbon, which is low in concentration below the zone of water table fluctuation), we have not employed any biodegradation decay rates or sorption (Kd) factors.

8.0 Model Calibration

Groundwater flow models can be calibrated in a variety of ways. The ability to reproduce the measured base flow in a stream and to reproduce the drawdown with time from a pumping test are two excellent ways. More commonly the only available data are groundwater level fluctuations in wells at different levels in the model. Called the "inverse problem," we adjust parameters in the model (primarily hydraulic conductivity, in this case) until model-predicted levels come into good statistical agreement with measured water levels.

Unfortunately, the well database for the Hadley Point area includes only one water level measurement in each of two bedrock wells. This is not adequate for realistic model calibration, so we have not performed the usual rigorous model calibration and sensitivity analyses that we would normally do for a groundwater model. Therefore, one of the greatest weaknesses of the model is the lack of water level data in existing bedrock wells. Several other communities we have worked with have used volunteers to measure water levels bi-weekly or monthly for a period of a year or more in order to establish a legitimate water level database for future modeling efforts. For the two wells for which we have one data point each, one is in the southwest area of the model in layer 5 and has a predicted groundwater elevation of 100.8' versus a measured groundwater level of 98'. The other well is in the north-central portion of the model and has a predicted groundwater elevation of 73.8' versus a measured groundwater level of 88'. We do not know how representative the water level measurements are compared to what the long-term average static levels would be in those wells.

We have no information on salinity or nitrate concentrations in groundwater at this time for calibration of those models, either. Again, long-term water quality monitoring at representative well locations would be important to establishing a database for model calibration and to evaluate water quality changes with time.

Part of model calibration is to check the overall mass balance of the computer model. The model keeps track of the flux of fluid and contaminant mass moving into and out of each cell and the boundary conditions. **Table 4** summarizes the mass balance for the groundwater flow models at the end of 20 years of simulation. Two different models were used and one can see that the MODFLOW model has a much lower mass balance error. The SEAWAT2000 model, used to model the density-dependent saltwater intrusion potential, uses a coupled flow and solute transport model. Solute transport mass balance errors are usually much larger than flow model errors, so this discrepancy between the two model mass balance errors is not surprising.

One of the main differences between the models is in the amount of water discharged to the streams (a boundary condition called "drains" in modeling language). The SEAWAT2000 model has less flow into the upland streams and therefore more flow into the ocean. The reason for this is that, as discussed more below, the predicted heads in the SEAWAT2000 model are typically lower (some small areas are actually higher, however) in the upland area than those in the MODFLOW model by varying amounts up to about 30 feet at certain places. We have noticed this same difference in another saltwater intrusion model in a different location on the Maine coast. There are definite differences in the computer solution routines between SEAWAT2000 and MODFLOW and we are not sure how much of the head differences between the models may be due to different solution routines versus actual response to the seawater boundary which is handled much differently between the two models. All the model layers in the SEAWAT2000 model are treated as confined or fully saturated, whereas the MODFLOW model treats the top three layers as being potentially unconfined and this would probably account for some of the reason why heads in the SEAWAT2000 model might be predicted to be lower (more flux can be pushed through the model layer with less head). For really critical evaluations, the SEAWAT2000 model could be run with the layers unconfined, but model execution time goes up dramatically (days to make a 20-year run instead of a few hours with a 3 GHz machine).

Another difference between the mass balances of the two models is in the amount of water outflow from storage. Both models are run in the "transient" mode, meaning that the models are allowed to adjust over time to addition of new wells and septic systems, starting from the set of heads that are close to steady state heads under average annual recharge conditions for each model. The septic system impact evaluations are run for 20 years and although this will cause most of the changes in head and contaminant distribution to adjust in this aquifer to the new stresses in this time frame, not all of the adjustments have taken place. Using MODFLOW, the significant release of water from storage indicates that the heads are still decreasing at the end of 20 years in that simulation, whereas for the SEAWAT2000 simulations changes in head with time must be small at 20 years based on the small changes in storage going on. Again, the main reason for this difference is that the MODFLOW model is being run as unconfined, which will take longer to adjust to changes in stresses than for a confined aquifer condition.

9.0 Groundwater Elevations

9.1 Existing Conditions

The main output of a groundwater flow model is a prediction of the groundwater elevation (called "heads") at the mid-point of each layer of a model. This would be the elevation that water would rise to if a well were drilled into the earth to the elevation of the layer mid-point at the geographic coordinates of the model prediction. The Bar Harbor model has square 50'x50' finite difference cells and elevations at points between the center of each cell are linearly interpolated.

The maps of groundwater elevation by model layer are contour maps. Each contour is a line along which the groundwater elevation is the same in terms of elevation above NGVD29 (approximate mean sea level). In isotropic materials the direction of groundwater flow is perpendicular to the groundwater contour line. In anisotropic material--which is how we have modeled the Ellsworth Schist--the flow lines are not necessarily perpendicular, but would be skewed to favor the direction of higher permeability.

The top soil layer in the model is thin, so many parts of the upland area of the model are predicted to be dry. In other words, these soils are not predicted to be saturated on a year-round, average basis. There are also extensive upland areas where the second soil layer is also very thin because the whole soil thickness over rock is thin, so large parts of the second soil layer are also dry. And finally, the top soil layer is only 25 feet thick and in some upland areas there are predicted areas of dry cells in the top rock layer.

Figure 9 shows the predicted elevations of the phreatic heads in layer 1 of the SEAWAT2000 model under existing conditions (existing wells and septic systems) with average annual recharge. Where the top layer is predicted to be dry, the model uses the heads in the first layer beneath that is predicted to have flow in it. **Figure 14** shows model layer 2 predicted heads; **Figure 15** shows model layer 3 predicted heads; **Figure 11** shows model layer 4 predicted heads; **Figure 16** shows model layer 5 predicted heads; and **Figure 17** shows model layer 6 predicted heads all for existing development conditions.

Notice that the groundwater contours are more or less parallel to topographic contours. This parallel character is sharper in the upper model layer and becomes more generalized and smooth in the deeper model layers. Flow is approximately perpendicular to groundwater contours so one can see the radial flow pattern from the center of the model area outward to Eastern Bay to the north and east and Fresh Meadow to the south. Heads decrease in elevation at the same point on the map from top to bottom in the upland areas and increase in elevation from top to bottom in the discharge areas such as Eastern Bay and Fresh Meadow. There are slight indentations coincident with the interpreted high-permeability photolinear zones.

There were several steps involved in the location of existing wells for the existing model scenario. Stratex contacted the Assessor in the Town of Bar Harbor to obtain information on lots with existing wells and septic systems. The data from the Assessor's office containing information on lots with wells was correlated with well data from the Maine Geological Survey. Existing wells with GIS locations identified by Maine Geological Survey were preserved. Wells in the data from the Assessor's office but not located by Maine Geological Survey were placed in the center of the parcel. Total well depths from the Maine Geological Survey records were used when available. Wells without depth data were assumed to be 275 feet deep from ground surface.

The wells in the records from the Maine Geological Survey (MGS) were located by visiting the Bar Harbor town office and matching the well owner in the state records with the town property tax records. For lots with successful matches, MGS located the well located on a topographic quadrangle from the drawing in the tax map files. MGS then digitized the location in GIS.

The well symbols are shown in the model layers in which the bottom of the well is located and all other layers above that layer up to and including model layer 4. Most wells are shown in model layers 4 and 5, within which the vast majority of the reported wells have been drilled. A few well symbols can be seen in layer 6 where a few deeper wells have been drilled. A few well symbols can be seen in Eastern Bay with the description "OBS_". These are not actual wells drilled in the Bay, but were placed as dummy observation points at those locations so we could evaluate the change of head and concentration with time as a guide to determining how long it took for the saltwater distribution to reach equilibrium in the aquifer under Eastern Bay.

The difference between the head predictions for SEAWAT2000 and MODFLOW for the existing development condition in model layer 4 is shown in **Figure 18**. In addition to the differences along the shoreline, which we would expect to be due at least in part to the different treatment of the seawater boundary condition, the main differences are in the north-central upland area.

9.2 Future Conditions

The future development scenario showing residential development to the full build-out limits of the current zoning ordinance increases both the number of septic systems and the number of wells in the study area from 169 to 845.

As wells and septic systems were added to existing wells and septic systems for the full build-out scenario, there were several considerations involved. First, the allowable lot size was assumed to be 40,000 square feet to be consistent with the current zoning ordinance in this area of Bar Harbor. Second, an efficiency factor of 75% was applied to the previously undeveloped land areas to represent, for example, non-dwelling infrastructure such as roads, and to take into account inefficiencies in siting building envelopes such as odd lot shapes, difficulty locating septic systems, and sloping land. This efficiency factor is based on recommendations by Terrence J. DeWan & Associates during the residential master planning process conducted for Falmouth, Maine, in 2002. Septic systems were placed 110 feet from wells to reflect the State Plumbing Code minimum setback requirement of 100 feet. After adding wells and septic systems in the full build-out scenario, wells and septic systems that landed in wetland areas, as shown on the National Wetland Inventory maps, were removed.

Since water taken out of the rock is put back into the top soil layer of the model as septic effluent, the net flux for this model is the same (we could have put less water back in than taken out as some is lost to, for example, human consumption and evapotranspiration, although the percentage difference per home has a large standard deviation). There is not much change in water discharged to local streams in either the SEAWAT2000 or MODFLOW model.

Compare **Figure 11** with **Figure 12** to see that the differences in pattern of head contours are hardly discernible. But when we subtract the future heads from the existing heads and contour the results, the differences in head become clear, although still not large. We have shown the differences between existing conditions and hypothetical full build-out in **Figures 19**, **20**, and **21** for model layers 4, 5, and 6, which cover the zones in which normal water wells are drilled. These maps were produced by comparing the MODFLOW results for existing and full build-out, because the MODFLOW model was run in unconfined mode, which gives a more accurate determination of actual drawdown. Notice that the incremental drawdown decreases with depth and that no drawdown exceeded 10 feet, which is the maximum amount of offsite drawdown that we normally recommend as acceptable for incremental impact from new development.

Therefore, in terms of groundwater *quantity* impact, the existing minimum lot size of 40,000 square feet, as identified in the current zoning ordinance for this area, is adequate to prevent over-pumping of the model area, based on its soil types, hydraulics, and percentage of developable land. There may be, however, some local situations where one well may adversely impact the availability of water in another well, particularly if the interfering well is pumped at much higher than average residential rates.

10.0 Saltwater Intrusion

The saltwater intrusion analysis has been performed using SEAWAT2000. This permits us to use chloride as a surrogate for seawater and using the density properties of seawater, the chloride will develop an equilibrium condition in the long-term average steady state. We simulated over 200 years to try to approximate equilibrium for the existing condition. Although slight changes in concentration were still occurring at the end of this time (on the order of a few percent over 20 years), the model was reasonably stable for the purposes of our analyses. The concentration of chloride in open ocean seawater is about 19,000 mg/L. We start our model with it defined as a concentration of 1.0 in the top layer of the model below Mean Sea Level in Eastern Bay, so results in groundwater can be contoured as the fraction of the pure seawater.

Having used SEAWAT2000 in another Maine coastal bedrock aquifer evaluation on a small peninsula surrounded by open ocean, we were surprised to find significant differences between that simulation and the Hadley Point simulation and we describe these differences. Great Head, Otter Point and the offshore islands would behave differently than Hadley Point.

10.1 Existing Conditions

Figure 22 shows the distribution of saltwater (by fraction of the full concentration of chloride in seawater) within the top bedrock layer (layer 3) of the model. Also shown on the figure are velocity vectors that show direction of flow in the aquifer and, by color coding, whether the flow in that model layer is up or down. **Figure 23** shows the saltwater distribution in layer 5 of the model (3rd bedrock layer and lower level of most drilled wells). The important comparison here is that in this model the degree of saltwater intrusion actually decreases with depth except in the area of the highest degree of saltwater intrusion, which is in the area of “The Twinnies”, islands in the northwestern corner of the model area.

The classic cross section through the land of saltwater intrusion shows a wedge of saltwater intrusion angling under the land area, such that a well drilled in the coastal zone would encounter increasing salinity with depth. In fact this was what was simulated by SEAWAT2000 in the other coastal peninsula problem. **Figure 24** shows the plan view of the peninsula in another town with the salinity distribution at depth in the bedrock. Notice that saltwater has moved inward from the coast along a high-yield linear toward a well. **Figure 25** shows a north-south cross section, looking west, through this saltwater intrusion. The same color scale from **Figure 24** applies to **Figure 25**. Notice how the denser seawater extends at depth farther under the peninsula than at the higher elevations. Also notice how the flow vectors define closed circulation cells in both the freshwater lens under the peninsula and out in the ocean. The vectors in the freshwater side flow upward next to the vectors in the saltwater side that flow upward. Notice the single blue cell extending above the main body of saltwater on the left (south) side of the peninsula represents an upconing of the seawater near the well shown in plan view on **Figure 24**. The blue groundwater contour shows an upward inflection in this area, too.

The saltwater intrusion pattern around Hadley Point is not the typical pattern for the following reasons:

1) The distance to the center of Eastern Bay is generally small relative to the distance from the shoreline to the groundwater divide to the south. This means there is a lot of groundwater trying to get to the surface in a relatively narrow strip of discharge area compared with the large recharge area.
2) Most of the Bay bottom below Mean Low Water is simulated as thick, low permeability mud except near The Twinnies. This makes it difficult for groundwater from the land side to get up through the mud to discharge. Most of the head loss occurs in the mud, not in the rock, so the strength of the upward discharge vectors overcomes the extra downward force of the heavier saltwater. The groundwater at depth in the rock turns to flow horizontally back toward the intertidal zone where most of the discharge occurs as shown in **Figure 26** near Leland Point. Notice in **Figure 26** that groundwater is pushing outward through the high-yield linear in the upper left corner of the figure. There is not enough well demand, even in this future full build-out scenario, to reverse the intrusion and pull it inland along the linear. **Figure 27** shows a cross section through Leland Point, looking north that shows a different pattern of intrusion than shown in **Figure 25** at the peninsula location. In **Figure 27**, the intrusion does not angle downward and inward under the land, but rather the seawater sits as a lens on top of the upward-discharging freshwater.

10.2 Future Conditions

Saltwater intrusion is not a strong threat in the Hadley Point area with existing development and it also is not a strong threat in the future build-out scenario. The change in seawater intrusion between existing development and future build-out is shown for model layer 5 in **Figure 28**. Notice that the main increases in seawater intrusion take place offshore in the northwestern corner of the model where soil cover is thin and the density effect of the seawater is strong enough to overcome upward-discharging groundwater from the uplands. The only land area that would be significantly affected is the southwestern shoreline of Hadley Point.

In a typical summer, there is often no recharge for about 3 months (typically July, August, and September). The effect of a typical summer period of no recharge is shown for model layer 5 in **Figure 29**. There is no significant effect of the summer dry period on increasing seawater intrusion in Hadley Point. Even in the peninsula example described above, increases in salinity in response to drought are slow.

11.0 Septic System Impacts

The limiting factor in groundwater with most dense development away from central sewer and water is due to septic system impact, not due to lack of well water. Residential septic impacts come from several main sources: 1) nitrate-nitrogen and 2) bacteria and viruses. Nitrate-nitrogen, as described earlier, is decreased in concentration through dispersion and dilution in the aquifer. Bacteria and virus impacts are controlled by providing enough separation distance between a septic system and the nearest downgradient well such that the bacteria and viruses stay in the ground long enough so most (99.9%) of the pathogens die off before entering the well. This is usually accomplished in a 200-day travel time. Our analysis here, however, focuses on how nitrate-nitrogen concentration changes with housing density. It is obvious that if houses are closer together, then wells and septic systems are closer together, too, thereby decreasing the distance between septic systems and wells.

11.1 Existing Conditions

Septic system impact is greatest in the soil immediately under and downhill from a leachfield (layer 1 of the model). **Figure 30** shows the nitrate-nitrogen concentration contours from existing development just below the phreatic surface. Where the color fill is not coincident with the contour lines, this means that model layer 1 was not saturated. There are a number of small plume areas with greater than 10 mg/L nitrate-nitrogen in groundwater (the EPA and State of Maine Maximum Contaminant Level, beyond which water is considered unsafe to drink). Plume concentrations decrease with depth. **Figure 31** shows the plume in model layer 4. Plumes in recharge areas travel straight down to the aquifer bottom, then move horizontally to the outer reaches of the discharge area. Plumes near discharge areas (such as the shoreline) stay shallow and move primarily laterally. This is shown in **Figure 32** which is a cross section through model column 139, looking west, through the Hadley Pt. campground leachfields. The south side of the model is on the left.

11.2 Future Conditions

The best way to show the incremental impact of future development is to subtract the existing nitrate-nitrogen concentration from the concentration at full build-out. This is shown for model layer 4 in **Figure 33**. Large areas add over 10 mg/L, but only a few small areas add over 20 mg/L in incremental nitrate-nitrogen. Therefore, the incremental effect of the full build-out would <u>theoretically</u> have a large impact on groundwater quality and put much the groundwater over the Safe Drinking Water Limit. We say "theoretically" because with silty tills and clayey glaciomarine deposits the assumptions on nitrate input into the ground from septic systems usually overstate the concentration by a significant amount compared with the same nitrate loading in a sandy aquifer. This occurs because the septic field is usually saturated and, with the organic carbon normally present, there is a fair amount of denitrification going on.

The impact of drought on groundwater heads and on nitrate concentration was explored with the MODFLOW model for heads and MT3DMS model for nitrate. **Figure 34** shows the typical change in heads during a drought at various places in the model domain in model layers 4 and 5. **Figure 35** shows typical changes in nitrate concentrations in the same wells. The total decrease in groundwater head can be as much as 20 feet, for example, in Well 1112. Notice that the low point in the heads is at the end of the drought period. For the nitrate concentration, **Figure 35** shows that the peak concentration occurs sometime after the end of the drought at 360 days (as late as 440 days from the start of the drought) and represents incremental increases as high as 4 mg/L (about 25% increase), for example, at Well 19. Therefore, drought can have a significant effect on increasing contaminant concentrations from leachfields.

12.0 Conclusions

The groundwater modeling for the Hadley Point area of Bar Harbor produced some results that should be considered in long term planning. These findings are summarized below along with recommendations to assist the Town of Bar Harbor in balancing future land development with groundwater resource protection.

12.1 Groundwater Elevations

Through groundwater modeling Stratex was able to evaluate groundwater levels in soil and bedrock under existing and future build-out conditions. The model was not calibrated accurately due to the lack of data needed for model calibration. Nonetheless, typical parameters were used that have been developed in other Maine coastal groundwater models that did have good calibration. The results of the modeling show a distinct though modest drop in the bedrock groundwater table when the number of wells in the Hadley Point area is increased from 169 existing wells to the full build-out estimate of 845 wells. As **Figures 19**, **20** and **21** show, the difference in groundwater levels (existing minus the future) ranges from 1 to 4 feet in the three bedrock layers of the model. In the model, all the water withdrawn from the bedrock at water supply wells is put back into the ground in the soil through subsurface disposal of septic effluent. This re-injection of water to the soil layers, rather than to the bedrock, changes the water distribution by reducing the water levels in bedrock on the order of 1 to 4 feet. Bedrock water table lowering suggests that some of the re-injected water may be discharging to surface water such as streams and the ocean from the soil layers rather than recharging the bedrock aquifer.

Stratex explored the impact of drought on water levels. The model simulates the total drop in groundwater levels to be as much as 20 feet during drought conditions. The lowest groundwater levels are likely to occur at the end of a drought period in topographically high areas.

While the future modeling scenario suggests a distinct though modest lowering of the groundwater table in the bedrock aquifer between the existing development condition and the future potential development condition, it is Stratex's opinion that the reduction in groundwater *quantity* is not unreasonable under the current minimum lot size of 40,000 square feet, as identified in the current zoning ordinance for this area. The current residential lot size appears to be adequate to prevent over-pumping from typical residential wells in the model area under average annual precipitation rates, based on soil types, hydraulics, and percentage of developable land. During a severe drought, the incremental drawdown will be as much as 20 feet in the water level at some wells. Adjustments in homeowner expectations and behavior are required during extreme events, so planners should be aware of the magnitude of these changes.

There may be some situations where well pumping may adversely impact the availability of water in other wells under average annual precipitation rates, particularly if the interfering well is pumped at much higher than usual residential rates. Open loop ground source heat pumps without re-injection, wells installed for industrial purposes, and/or large public water systems are examples of large groundwater withdrawals that might impact existing nearby well water levels. The impacts of these wells with large demand should be evaluated with Site Plan Review ordinances or as part of Subdivision Plan review.

Our findings from this modeling study support the guidelines recommended by Stratex for protection against water table lowering during the review of Bar Harbor ordinances in 2006. For example, Stratex recommended site-specific evaluation for development applications proposing to withdraw more than 300 gallons per day per well and/or 1,000 gallons per day for a development to verify no adverse impact. The matrix attached to this report as **Table 5** summarizes Stratex's guidance as presented during the ordinance review.

12.2 Saltwater Intrusion

Stratex evaluated the potential for saltwater intrusion in existing and future build-out wells along the shoreline in the Hadley Point area.

The saltwater intrusion model results suggest that the Hadley Point area does not have the typical salt water intrusion profile found in many other coastal areas of Maine. Stratex believes this is due to the difference in size between the land recharge area relative to the discharge area in Eastern Bay. The land recharge area is significantly larger than the discharge area, unlike what would occur on an open ocean site. The land recharge area includes the area from the shoreline to the groundwater divide at the topographic highs of the model area. The discharge area includes the area from the shoreline to the channel divide at the center of Eastern Bay. The potential for saltwater intrusion is further reduced in the Hadley Point area by the inferred presence of thick, low permeability mud that makes it difficult for fresh groundwater recharged on the land to discharge upward through this salty layer.

The model suggests that the highest potential for saltwater intrusion exists in the area of "The Twinnies" islands in the northwestern corner of the model area. In this area, the thickness of low permeability mud in the subaqueous sediments is simulated as thinner than other locations along the shoreline of the model area and the zone of discharge is wider than to the east.

High-yield bedrock linears (inferred fracture zones in the rock) that extend from the land into the ocean can increase the potential for saltwater intrusion potential in most open coastal settings. We have found that high pumping rates in wells located in linears can actually pull the saltwater interface landward. However, in this unique setting where the groundwater discharge offsets the saltwater intrusion, even the additional well pumping simulated by the model for the future build-out scenario appears unable to reverse the outward flow of fresh water through the inferred linears. As a result of unique hydraulics in this area, saltwater is not significantly pulled inland along the linears toward the pumping wells in the situation where just residential wells are involved at the density allowed by the zoning ordinance. Large demand wells near the shore would require a site-specific evaluation.

Despite the unique findings for saltwater intrusion potential in the Hadley Point area, Bar Harbor should still be vigilant about the possibility of saltwater intrusion impacts on islands and in more open ocean areas within its boundaries. Stratex provided guidelines (**Table 5**) in our review of the ordinance which suggested a hydrogeologic assessment for, "Wells proposed to be located within 200 feet of the shoreline or farther than 200 feet from the shore but located adjacent to existing lots where wells are within 600 feet of the shoreline and lots are less than 1 acre in size."

12.3 Septic System Impacts

Stratex modeled the impact of septic systems on soil and bedrock water quality for existing and future build-out wells and septic systems. We also applied drought conditions to the full build-out scenario to evaluate the impacts of both increased septic systems and reduced dilution from precipitation. Our evaluation used the methodology specified by the Maine Department of Environmental Protection for evaluation of septic system impacts for projects falling under the Site Location of Development Law. This focus is on the fate and transport of nitrate-nitrogen from septic systems. Although the methodology is fairly conservative for all but sandy, well-drained soils, use of this methodology will prevent future impairment of groundwater quality to wells in the area.

Under existing conditions there are very few areas where the impacts from septic systems would become unacceptable in a neighbor's well, although concentrations of nitrate-nitrogen could easily exceed recommended drinking water standards within 200 feet of a subsurface disposal area as shown in **Figure 31**. Subsurface disposal areas where large concentrated waste loads are discharged can have a more extensive effect. **Figure 32** shows the plume in cross section from the design load of the Hadley Point campground which could theoretically negatively affect groundwater quality for 1000 feet downhill. Actual conditions could be different if occupancy is less than design capacity, pre-treatment systems are used, or other assumptions prove to be incorrect.

The model results for the future build-out scenario indicate an increased concentration of nitrate-nitrogen of 10 to 20 mg/l in several large areas of Hadley Point as shown on **Figure 33**. A few small areas increase the concentration of nitrate-nitrogen by over 20 mg/l above the existing conditions. These results suggest that the incremental effect of the full build-out would theoretically have a large impact on groundwater quality and put much of the groundwater quality over the EPA Safe Drinking Water Limit.

Stratex explored the impact of drought on nitrate-nitrogen concentrations. The model results show that the peak concentration in nitrate-nitrogen occurs typically within 2 to 3 months after the end of the drought. The incremental increase in nitrate-nitrogen concentrations may be as high as 4 mg/L above the concentrations for the average annual recharge future build-out scenario, representing about a 25% increase. Drought can have a significant effect on increasing contaminant concentrations from leachfields and effects in small groundwater basins are more dramatic than in large groundwater basins.

Based on the results of the model simulations for nitrate-nitrogen, Stratex recommends adjusting the minimum lot size to ensure that groundwater quality is not adversely impacted by septic systems in areas not served by the public water supply. The current minimum lot size of 40,000 square feet, just less than an acre, is not sufficient to allow for dilution of septic system wastewater before it enters drinking water wells if an entire large area is developed to this density.

Although not evaluated in this study (but the model can be used for this purpose, however) is the separation of wells and septic systems to provide for adequate groundwater travel time to permit the die-off of harmful bacteria and viruses. Our evaluations in other studies shows that a typical rule of thumb is that a well located downhill of a septic system should be located about 200 feet away. As with nitrate impacts, it is difficult to site a well and septic system on each lot of a large development with lot sizes of 40,000 square feet in a manner that adequately protects all wells from from bacterial or viral contamination.

Using the modeling approach we describe in this report a planned development can site wells and septic systems in such a way that individual existing and new wells can be protected from the plumes from the new septic systems. This suggests that cluster housing can be developed with smaller lots when proper groundwater impact evaluation is completed. But if lots are developed incrementally, one lot at a time outside of Planning Board review, it appears that groundwater quality problems (bacteria, virus, or nitrate contamination) will eventually be inevitable under the existing zoning density.

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Table 1
Precipitation and Septic System Recharge Rates
Bar Harbor Hadley Point Groundwater Model

Present Condition	Ft/day added over 50'x50' area from septic system	Correlation to Recharge zone without Septic	Average annual precip recharge rate, ft/day	Average annual combined recharge rate, ft/day over 50'x50' cell	Weighted nitrate-N conc, average annual condition, house produces 40 mg/L
Zone 1	N/A	N/A	0	0	N/A
Zone 2	0.01440	N/A	0.0019	N/A	N/A
Zone 3	0.01440	N/A	0.001237	N/A	N/A
Zone 4	0.01440	N/A	0.003138	N/A	N/A
Zone 5	0.01440	N/A	0.000619	N/A	N/A
Zone 6	0.01440	N/A	0.006276	N/A	N/A
Zone 7	0.01440	2	0.0019	0.01630	35.4
Zone 8	0.01440	3	0.001237	0.01564	36.9
Zone 9	0.01440	4	0.003138	0.01754	32.9
Zone 10	0.01440	5	0.000619	0.01502	38.4
Zone 11	0.01440	6	0.006276	0.02068	27.9
Zone 12*	0.02410	2	0.0019	0.02600	37.1
Zone 13*	0.02410	3	0.001237	0.02534	38.1

* applies only to existing condition with campground

Future condition	Recharge zone	Average Annual precip recharge rate, ft/day	Drought Precip recharge rates, ft/day	Drought recharge rate on septic system cell, ft/day	Weighted nitrate-N conc in drought condition
Drought Rates	1	0	0.00000	0.00000	N/A
Drought Rates	2	0.0019	0.00114	0.00114	N/A
Drought Rates	3	0.001237	0.00074	0.00074	N/A
Drought Rates	4	0.003138	0.00188	0.00188	N/A
Drought Rates	5	0.000619	0.00037	0.00037	N/A
Drought Rates	6	0.006276	0.00377	0.00377	N/A
Drought Rates	7	0.0019	0.00114	0.01554	37.1
Drought Rates	8	0.001237	0.00074	0.01514	38.1
Drought Rates	9	0.003138	0.00188	0.01628	35.4
Drought Rates	10	0.000619	0.00037	0.01477	39.0
Drought Rates	11	0.006276	0.00377	0.01817	31.8

well pumping rates, gpd	270	
well pumping rates, ft3/day	36.099	

gpd added from septic system	270	

Table 2
Tidal Datums Bar Harbor, Maine

	Bar Harbor MLLW (m)	Bar Harbor MLLW (ft)	Bar Harbor MSL (ft)	Bar Harbor NGVD29 (ft)
Highest Observed Water Level (2/7/78)	4.94	16.21	10.54	10.94
Mean Higher High Water (MHHW)	3.47	11.37	5.70	6.10
Mean High Water (MHW)	3.34	10.95	5.28	5.68
NAVD88	1.82	5.97	0.30	0.70
Mean Sea Level (MSL)	1.73	5.67	0.00	0.40
Mean Tide Level (MTL)	1.73	5.66	-0.01	0.39
NGVD29	1.61	5.27	-0.40	0.00
Mean Low Water (MLW)	0.12	0.38	-5.29	-4.89
Mean Lower Low Water (MLLW)	0.00	0.00	-5.67	-5.27
Lowest Observed Water Level (1/20/84)	-0.78	-2.54	-8.21	-7.81

Notes: Data above based on Tidal Epoch 1983-2001

Table 3
Model Values of Specific Storage, Specific Yield, and Effective Porosity

Zone	Model Layer	Ss, Specific Storage	Sy, Specific Yield	n, Effective Porosity
1	1,2	0.010000	0.300000	0.300000
2	3	0.000400	0.010000	0.010000
3	4,5	0.000001	0.001000	0.001000
4	6	0.000001	0.000100	0.000100

Table 4
Model Mass Balances

SEAWAT2000 Flow Model (Current Condition) Mass Balance

	Inflow, ft3/day	Outflow, ft3/day
Storage	0.0542	5.303
Wells		6100.8
Constant Heads	204.345	49659.25
Streams		54576.89
Recharge	110622.88	
Total	**110827.28**	**110342.24**

% error = 0.4386

MODFLOW Flow Model (Current Condition) Mass Balance

	Inflow, ft3/day	Outflow, ft3/day
Storage	53.487	5614.15
Wells		6100.8
Constant Heads		30253.05
Streams		71410.7
Recharge	113325.54	
Total	**113379.03**	**113378.73**

% error = 0.00027

SEAWAT2000 Flow Model (Future Condition) Mass Balance

	Inflow, ft3/day	Outflow, ft3/day
Storage	0.053	5.062
Wells		30504.5
Constant Heads	212.68	49666.97
Streams		51765.27
Recharge	132212.81	
Total	**132425.55**	**131941.8**

% error = 0.366

MODFLOW Flow Model (Future Condition) Mass Balance

	Inflow, ft3/day	Outflow, ft3/day
Storage	18.43	5503.69
Wells		30504.5
Constant Heads		29899.23
Streams		71448.61
Recharge	137337.93	
Total	**137356.36**	**137356.03**

% error = 0.00024

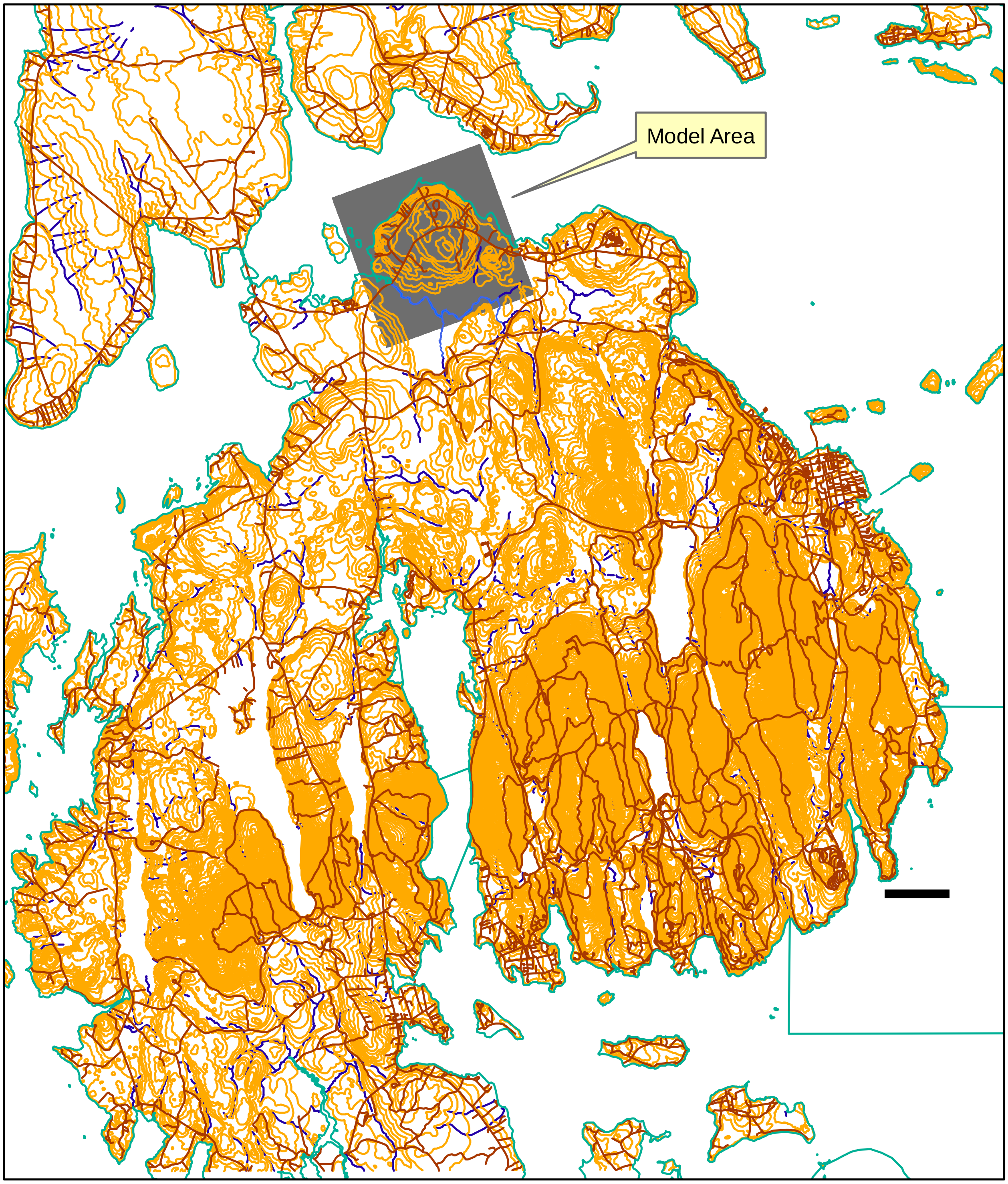
Table 5—Recommended Hydrogeologic Assessment Submission Requirements

	Submission Requirements:									
Proposed Activity:	NRCS soil map	High Intensity soil map	Nitrate and Ground water Travel Time[1] Analysis	Mounding Analysis	Background water quality testing	Average summer water level in surrounding existing wells or onsite wells	Public water supply locations within 300 feet of development	Existing private wells within 300 feet of development	Potential contamination sources within 300 feet of development	Wetlands and Surface water bodies within 100 feet of development
(a) Ground water withdrawal rate exceed 300 gpd per well and/or 1,000 gpd for the development §125-66N.2.a.	X	X					X	X	X	
(b) Housing Density greater than recommended by Nitrate Analysis §125-66N.2.b.	X	X	X		X		X	X	X	
(c) Public water supply proposed on site §125-66N.2.c.	X	X	X		X	X	X	X	X	X
(d) Wastewater flows >2,000 gpd §125-66N.2.d.	X	X	X	X	X		X	X		X
(e) Shoreline wells §125-66N.2.e.	X					X		X	X	X
(f) On or within 300 ft of Sand & gravel aquifer	X	X			X		X	X	X	X

[1] The purpose of groundwater travel time analysis is to estimate the time it would take for a dissolved, non-reactive, contaminant from a waste disposal system to reach the nearest sensitive receptor such as an existing or proposed well, wetland, or surface water body. Pathogens such as bacteria and viruses have approximate half-lives in groundwater. The effluent from in-ground wastewater disposal systems should remain in the ground 200 days before reaching a sensitive receptor to insure against pathogen contamination of the receptor.

§125-66N.2.f.										
(g) Within 300 ft of public water supply §125-66N.2.g.	X	X	X		X		X			
(h) Wastewater disposal less than 100’ from surface water §125-66N.2.h.	X		X							X
(i) Quarry / mining §125-66N.2.i.	X					X	X			X
(j) Commercial / Industrial Development §125-66N.2.j.	X	X	X	X	X	X	X			X

Notes:
1) Mounding analysis shall be performed in accordance with the Maine Department of Health and Human Services Wastewater Mounding Impact Analysis requirements.



Town of Bar Harbor, Hadley Point
Groundwater Model Location

Feet
0 5,000 10,000 20,000 30,000

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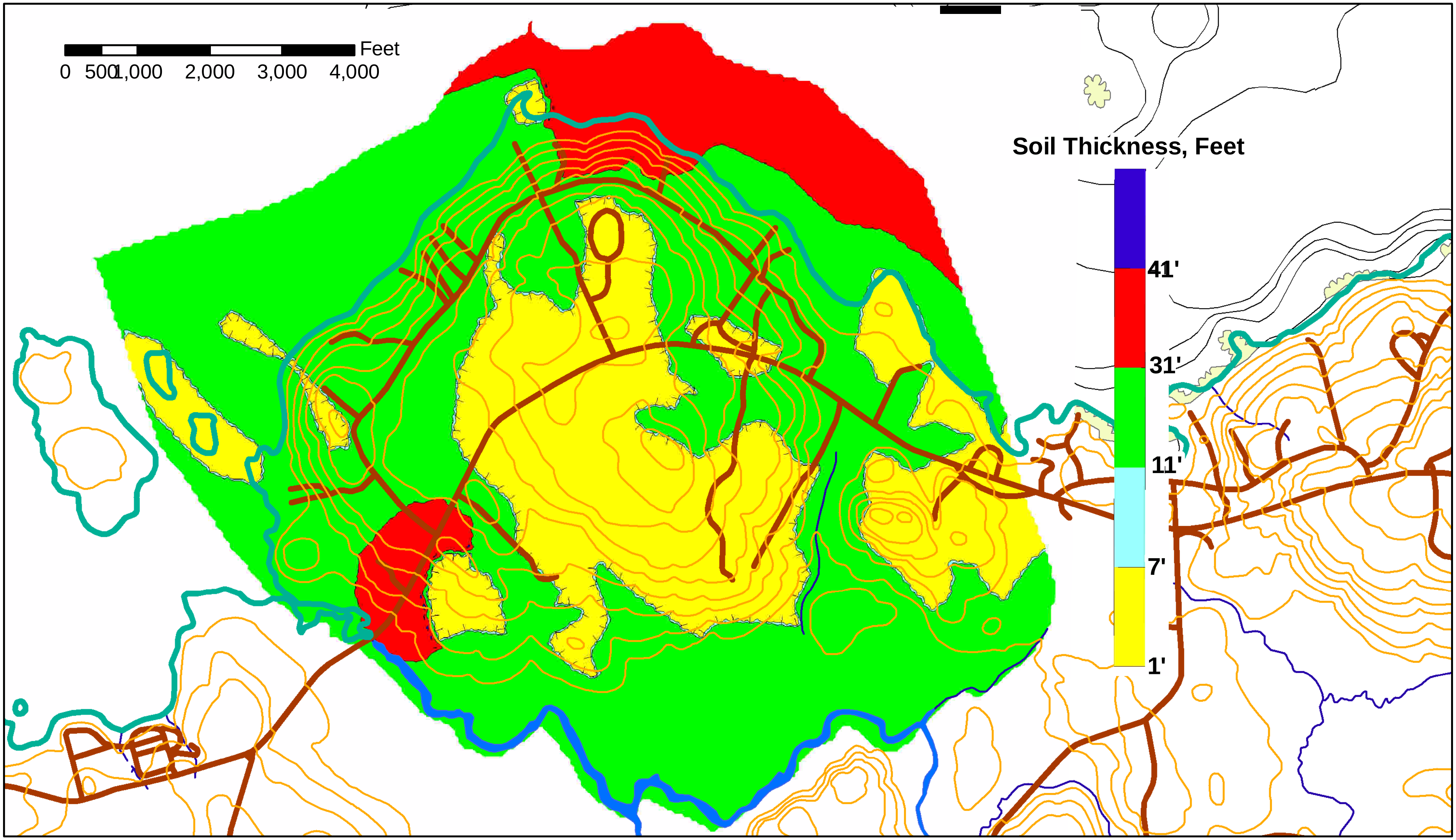
Figure 1



Bar Harbor Hadley Point Groundwater Model
Total Soil Thickness Used in Model

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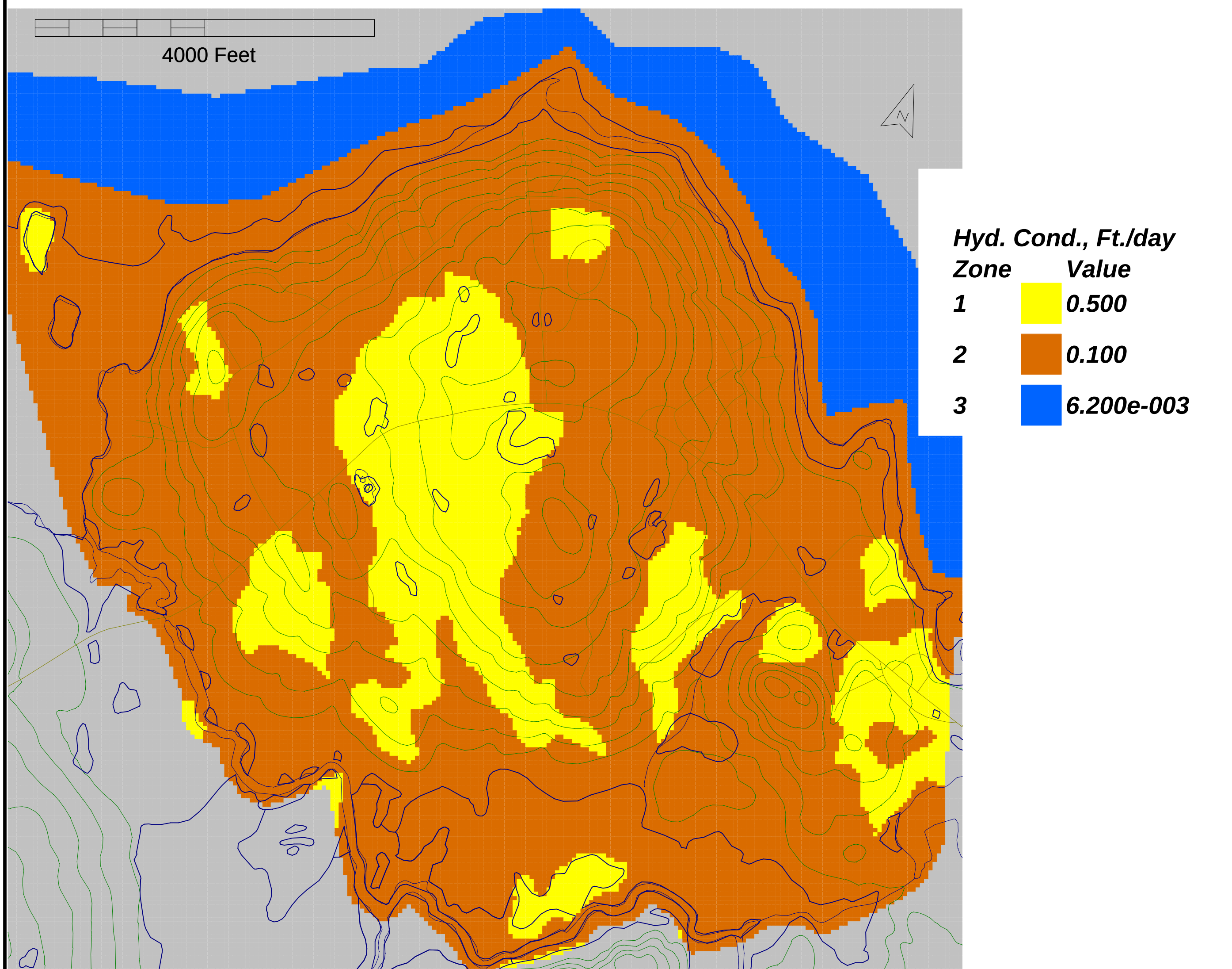
Figure 2



Bar Harbor Hadley Point Groundwater Model Properties

Hydraulic Conductivity Distribution, Model Layer 2

5/30/07

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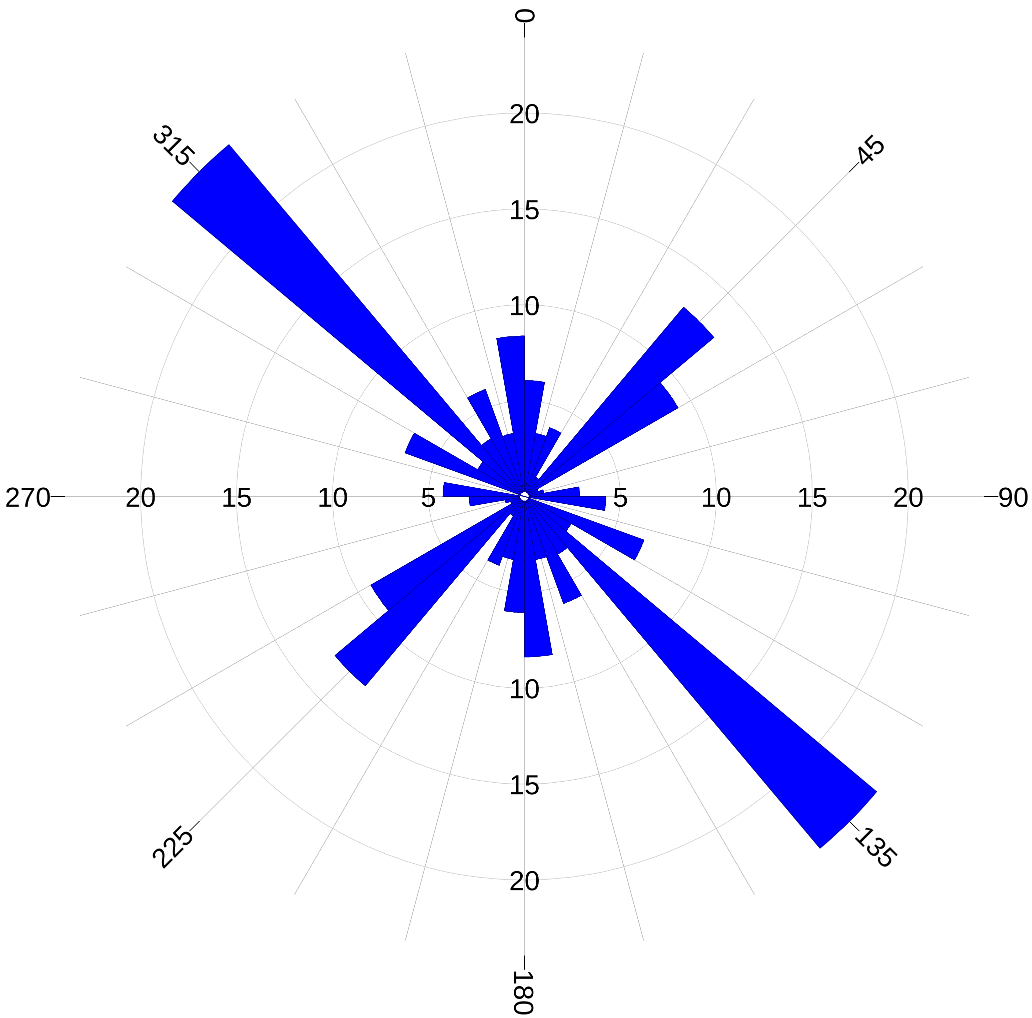
Figure 3



Statistical Summary	
Calculation Method:	Length
Class Interval:	10 Degrees
Min.Length Filtering:	Deactivated
Max.Length Filtering:	Deactivated
Azimuth Filtering:	Deactivated
Data Type:	Bidirectional
Population:	49
Maximum Percentage:	24.0 Percent
Mean Percentage:	5.9 Percent
Standard Deviation:	5.56 Percent
Vector Mean:	101.54 Degrees
Confidence Interval:	21.59 Degrees
R-mag:	0.61

Hadley Point Photolinear Rose Diagram

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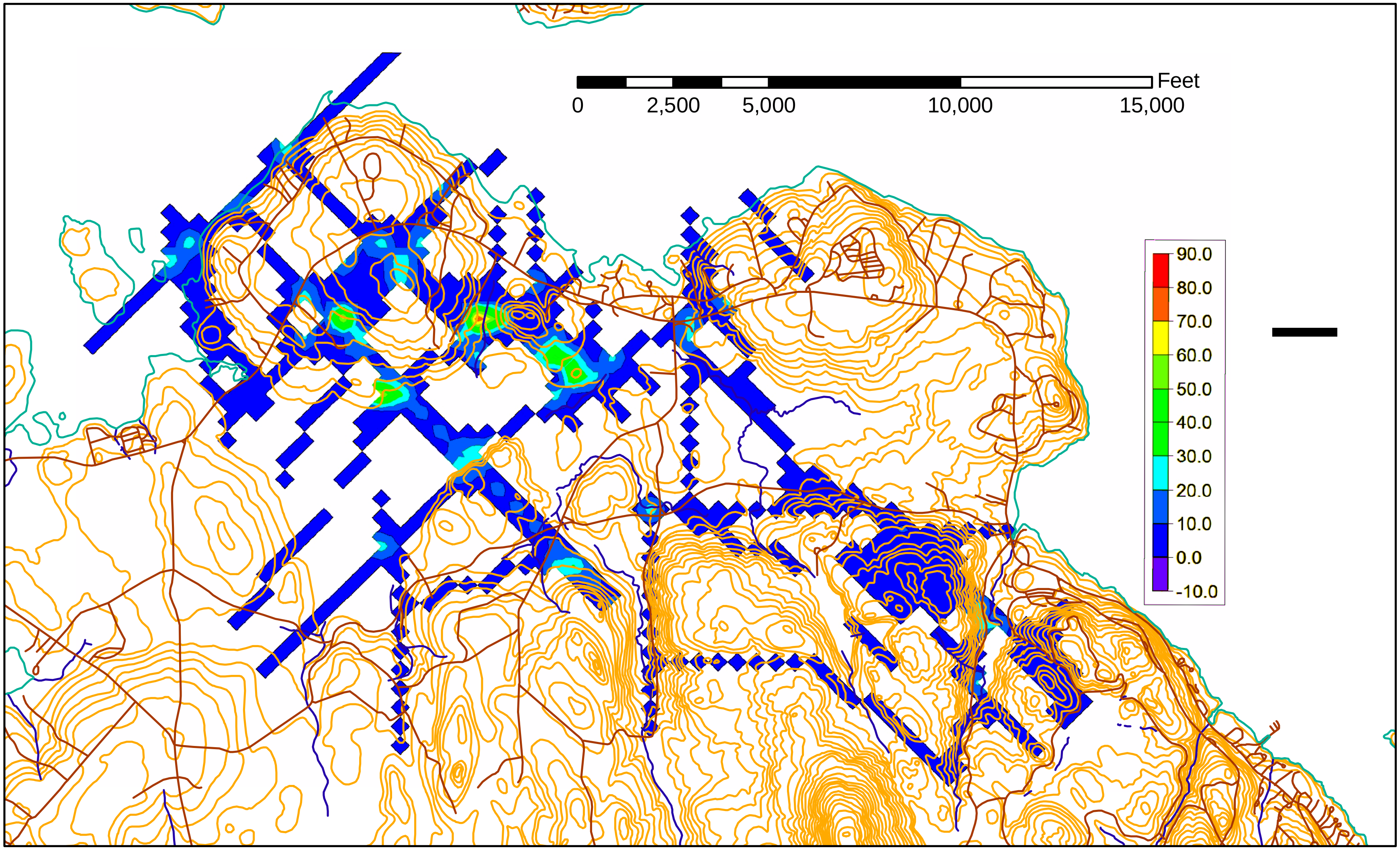
Figure 4



Town of Bar Harbor, Hadley Point Groundwater Model
Relative Probability of Finding High Yield Well Sites

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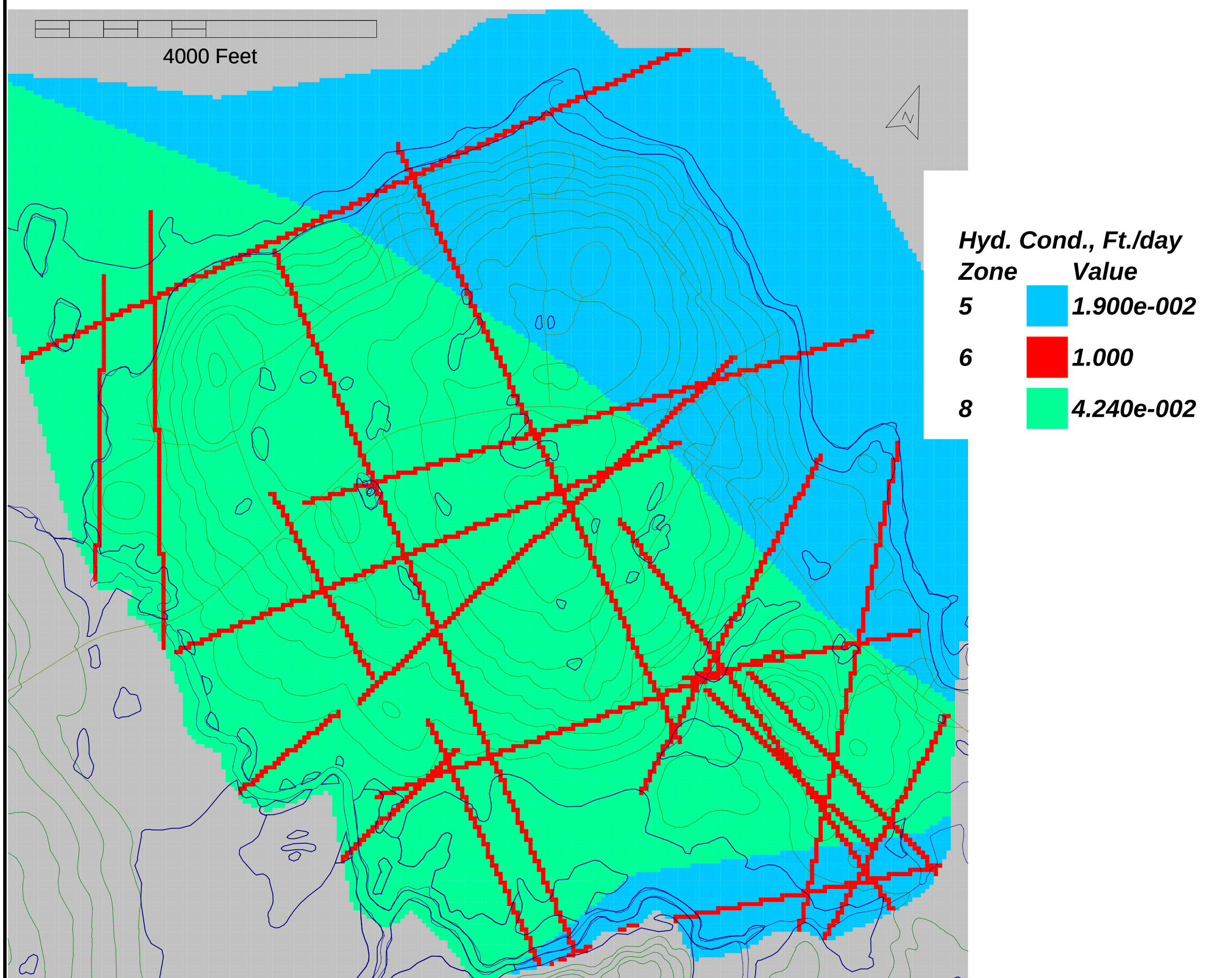
Figure 5



Bar Harbor Hadley Point Groundwater Model Properties

Hydraulic Conductivity Distribution, Model Layers 4 through 6

5/30/07

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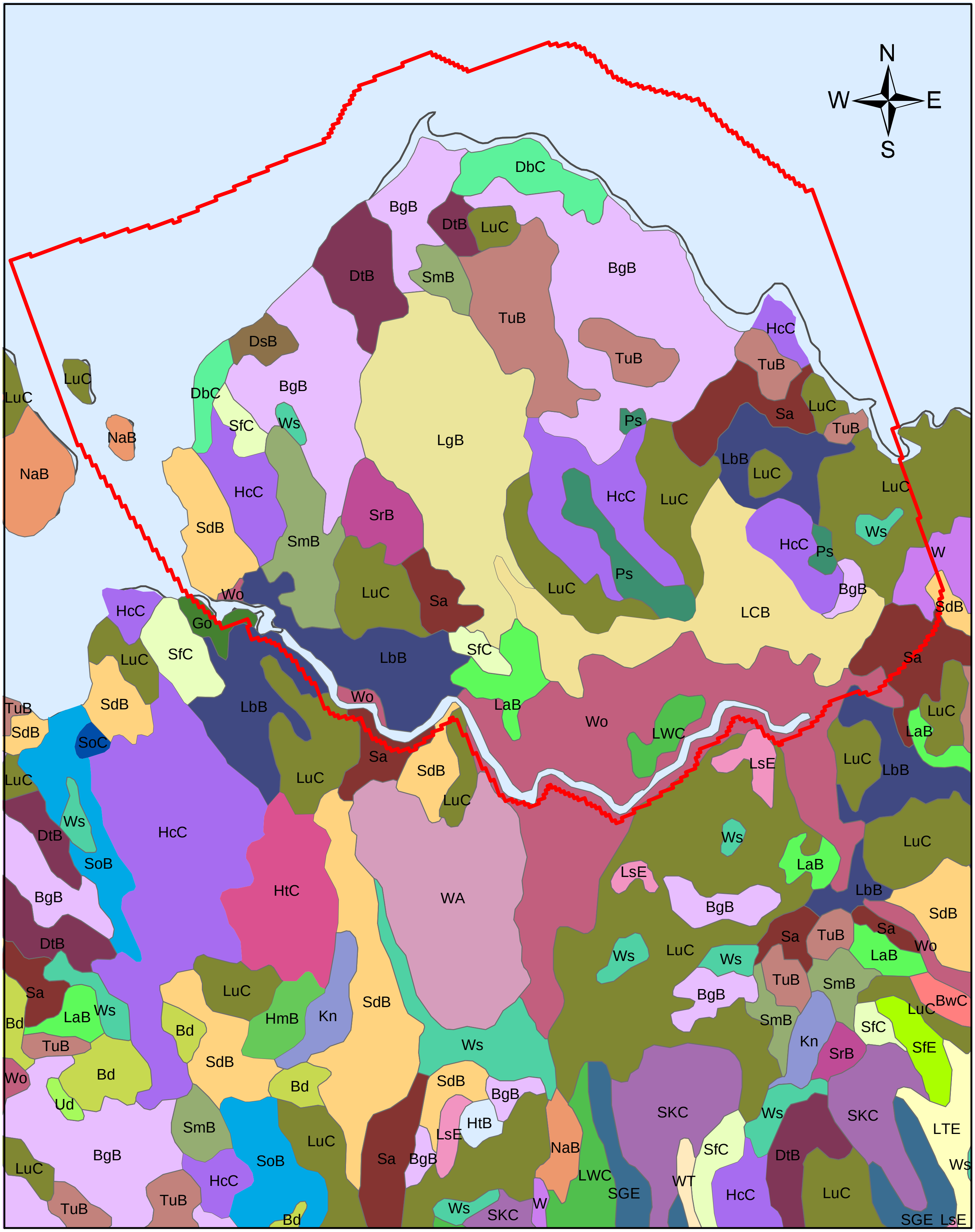
Figure 6



Legend

Soil Types

- Bd
- BgB
- BwC
- BwD
- DbC
- DsB
- DtB
- Go
- HcC
- HmB
- HtC
- Kn
- LCB
- LTE
- LWC
- LaB
- LbB
- LgB
- LsE
- LuC
- NaB
- Ps
- SGE
- SKC
- Sa
- SdB
- SfC
- SfE
- SmB
- SoB
- SoC
- SrB
- TuB
- Ud
- W
- WA
- WT
- Wo
- Ws
- model boundary

Town of Bar Harbor
Hadley Point Groundwater Model
NRCS Soils: The Basis of Assigning Recharge Rates

0 500 1,000 2,000 3,000 4,000 Feet

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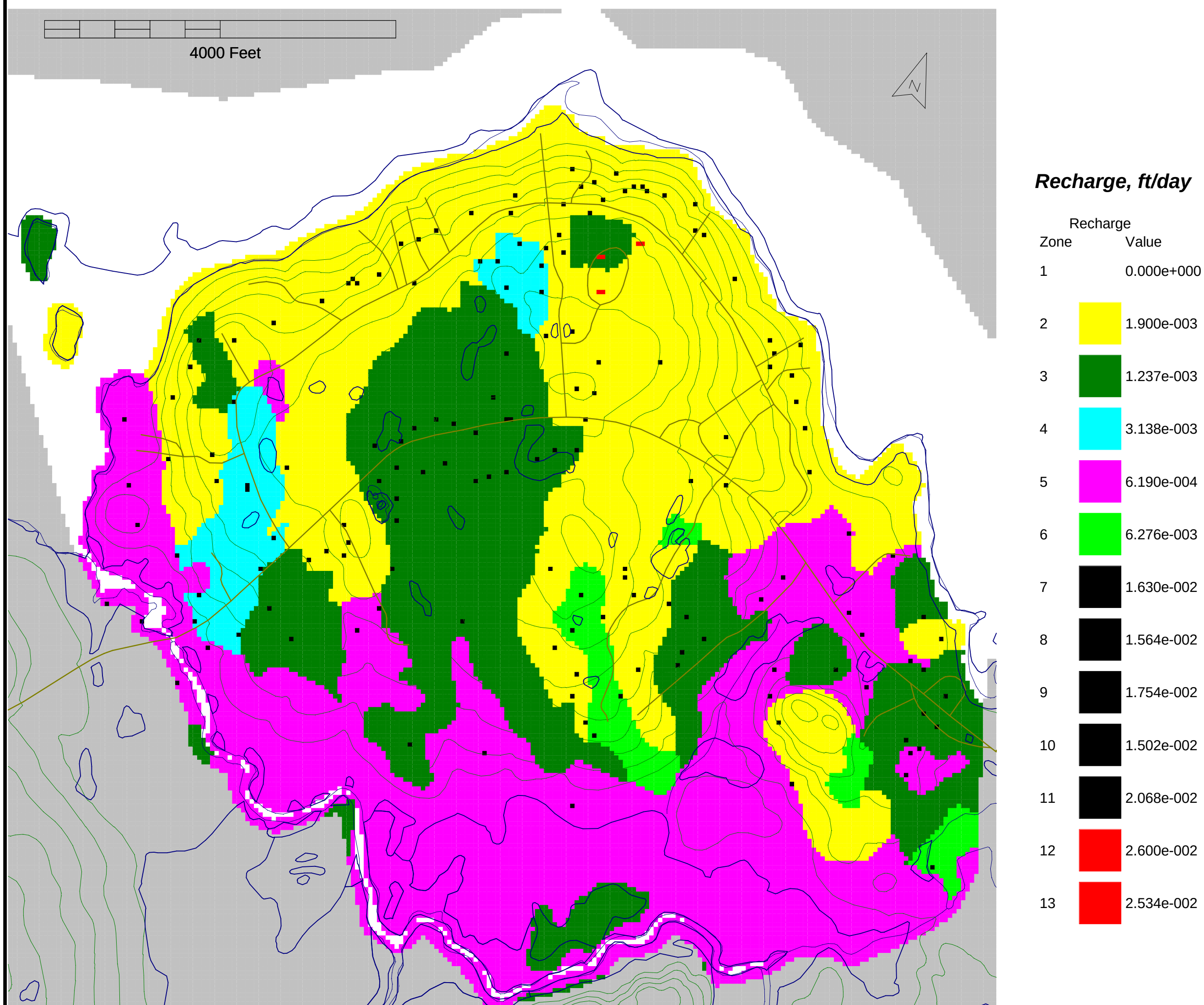
Figure 7



Bar Harbor Hadley Point Septic System Impact with Existing Development

Precipitation Recharge Rate Distribution, Average Annual Recharge

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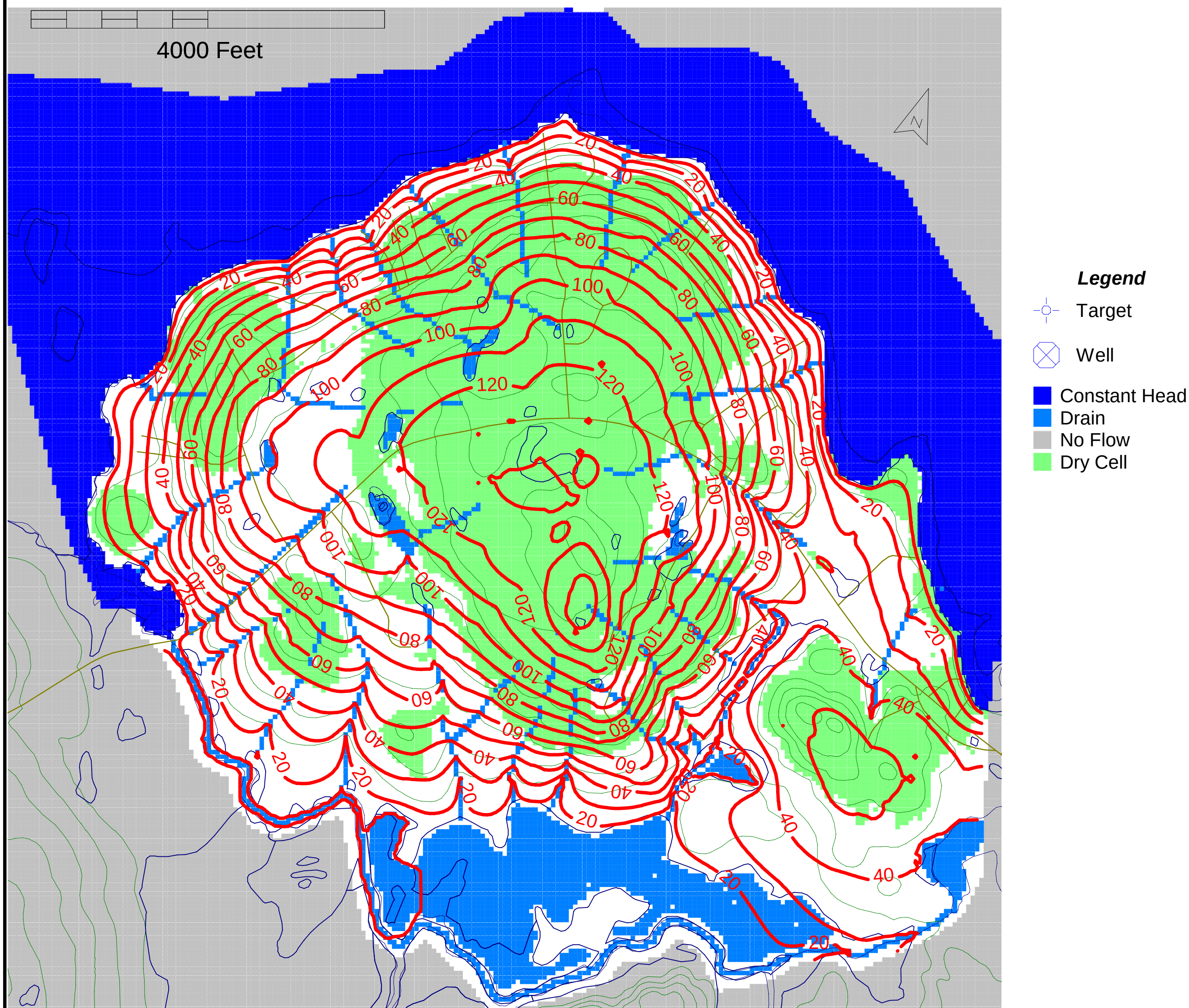
Figure 8



Bar Harbor Hadley Point Groundwater Contours with Existing Development

Phreatic Groundwater Contours in Feet, NGVD

Dry Cells are displayed for Model Layer 1

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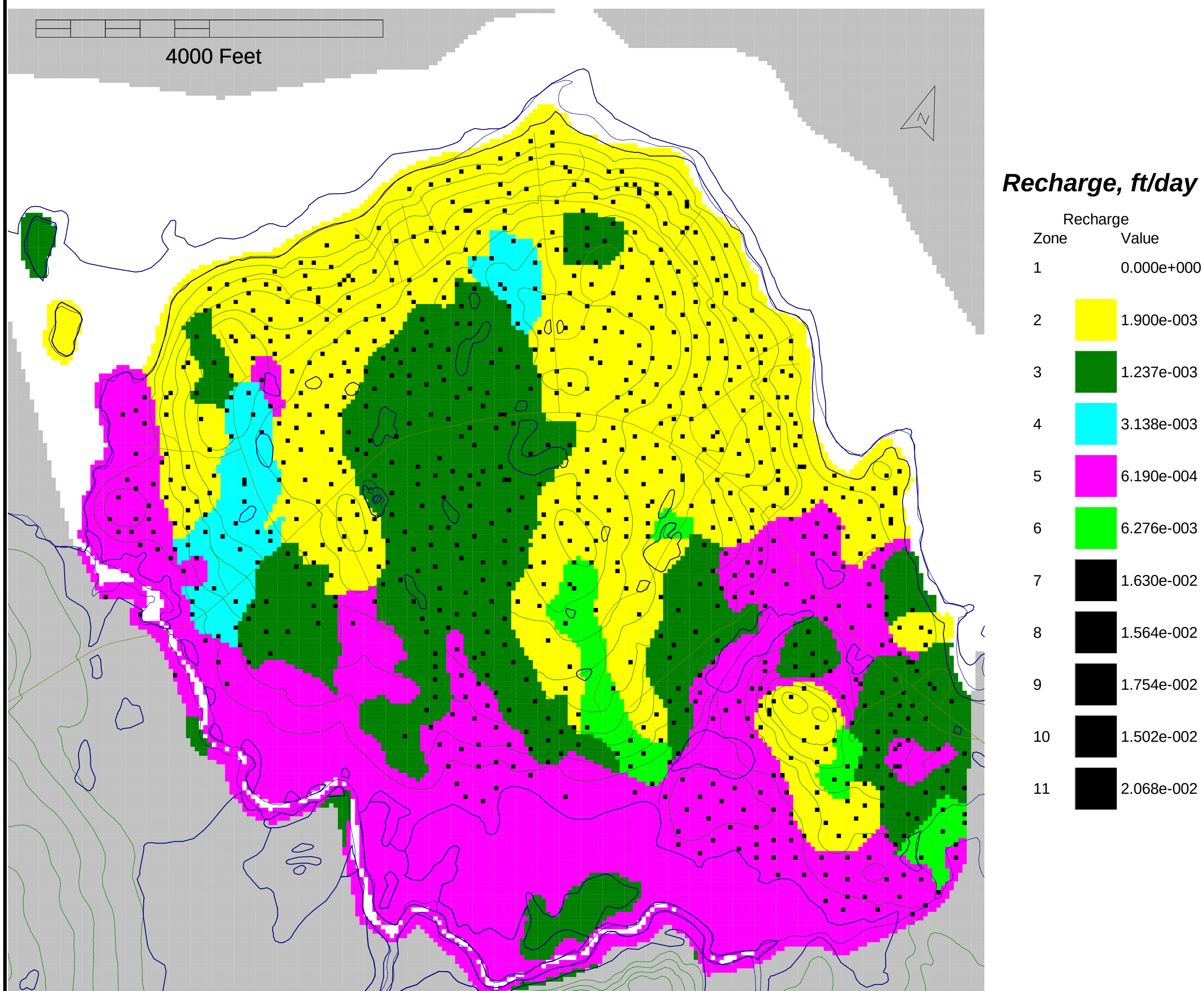
Figure 9



Bar Harbor Hadley Point Septic System Impact with Future Development

Recharge rate distribution, average annual recharge

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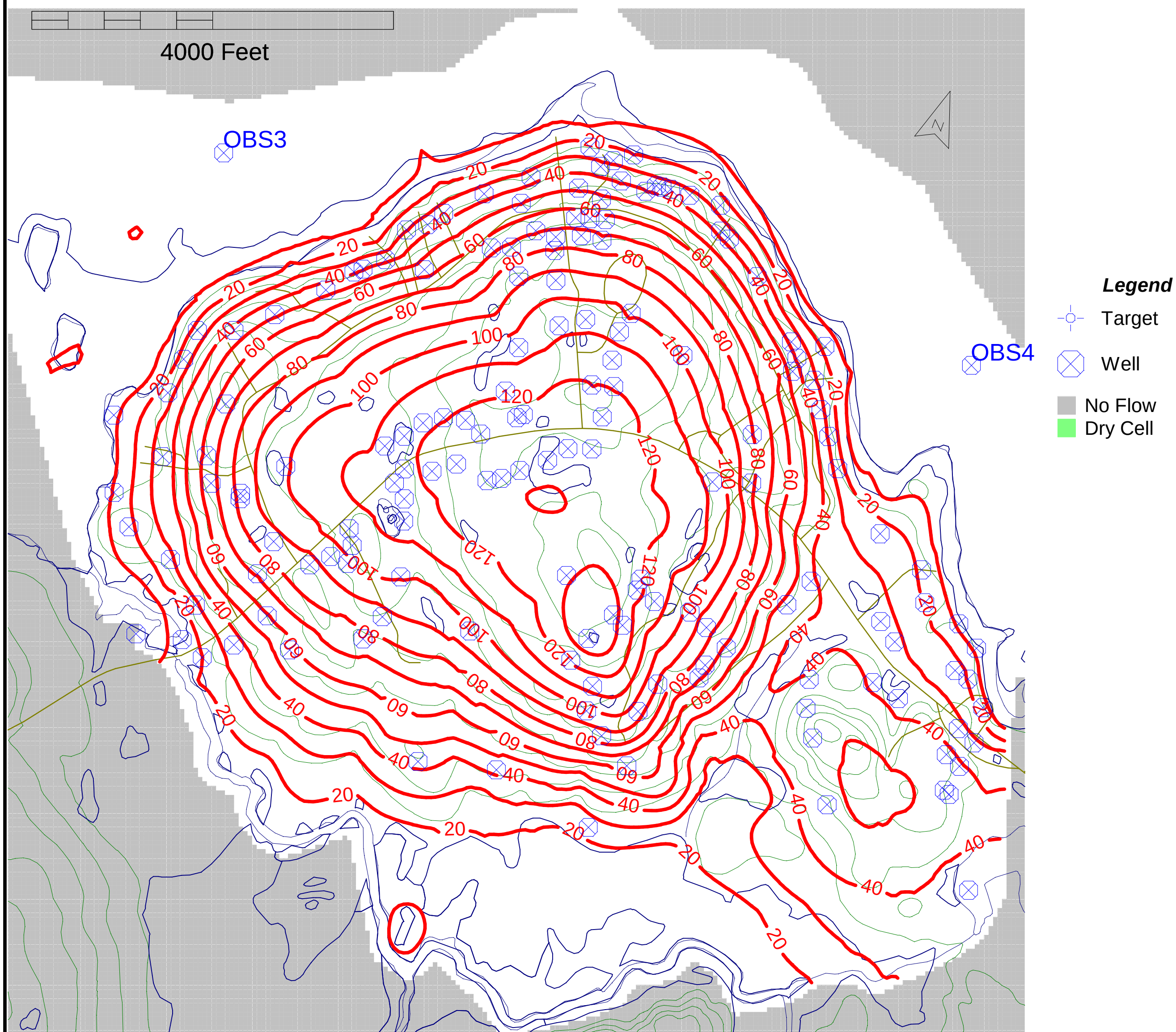
Figure 10



Bar Harbor Hadley Point Groundwater Contours with Existing Development

Groundwater Contours in Feet, NGVD, in Model Layer 4 (2nd rock layer)

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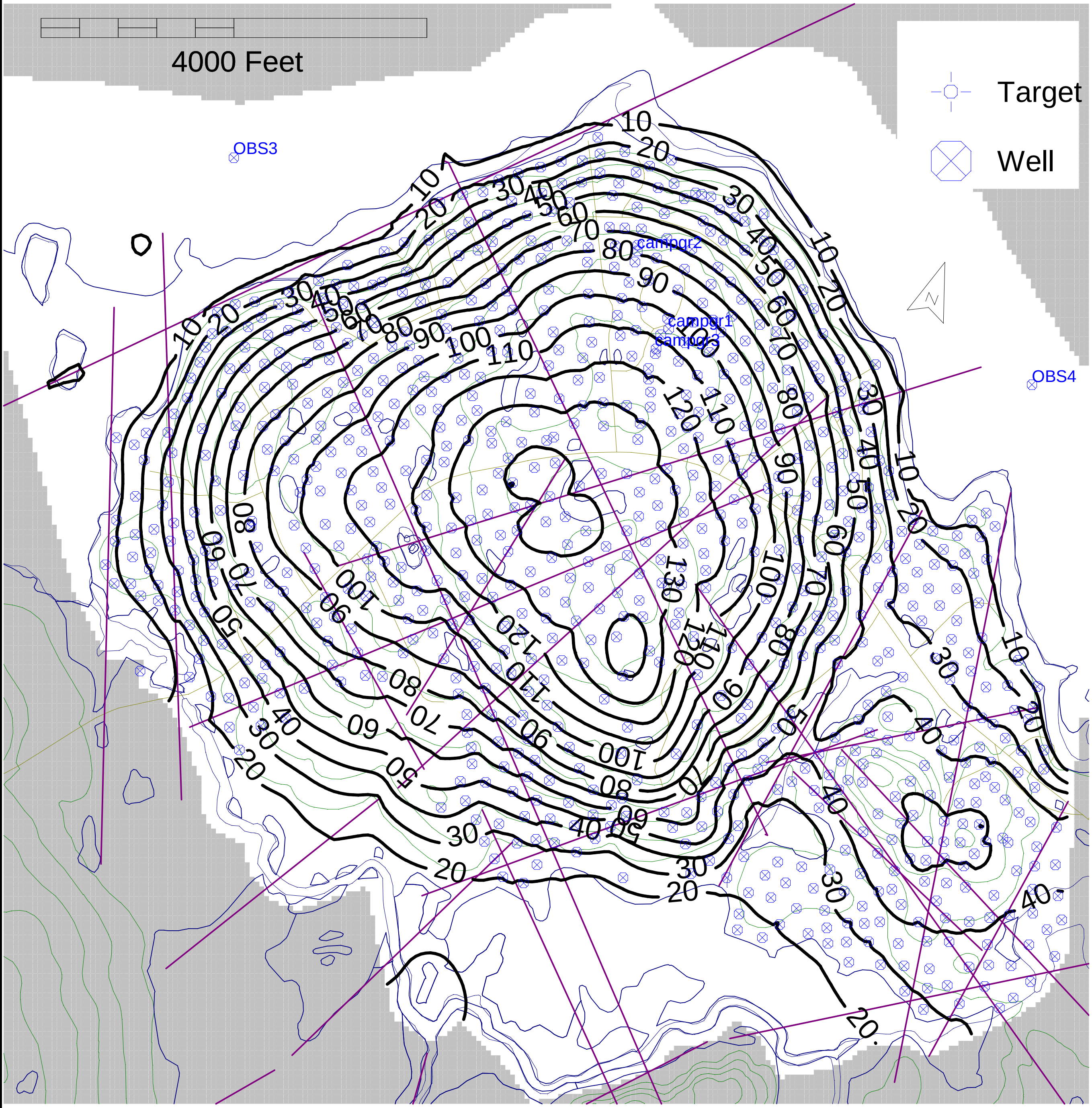
Figure 11



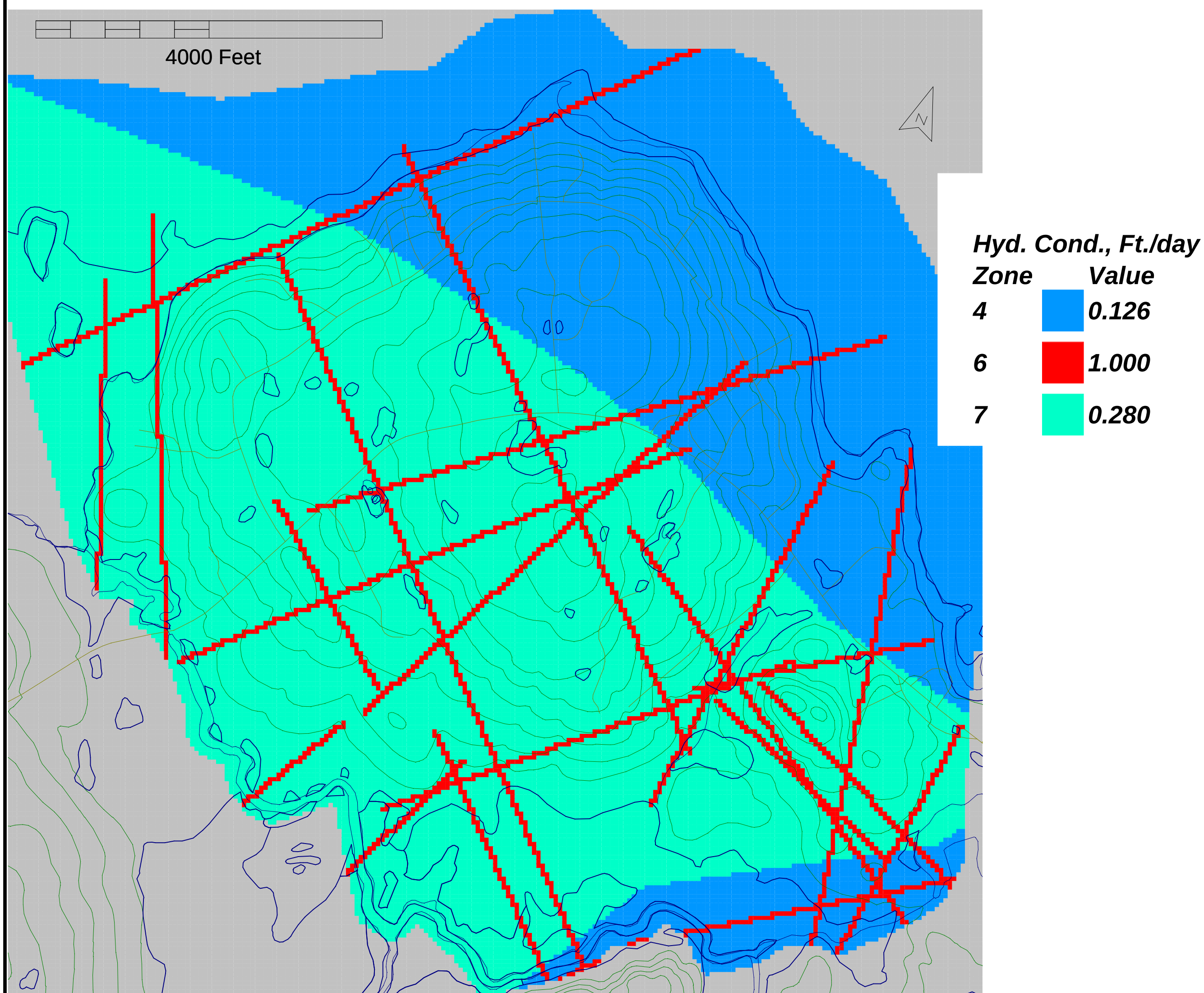
Bar Harbor Hadley Point Groundwater Contours with Future Development

Contour lines represent simulated groundwater elevations in Layer 4

Interpreted Photolinears are shown in purple

6/26/07

Figure 12



Bar Harbor Hadley Point Groundwater Model Properties

Hydraulic Conductivity Distribution, Model Layer 3

5/30/07

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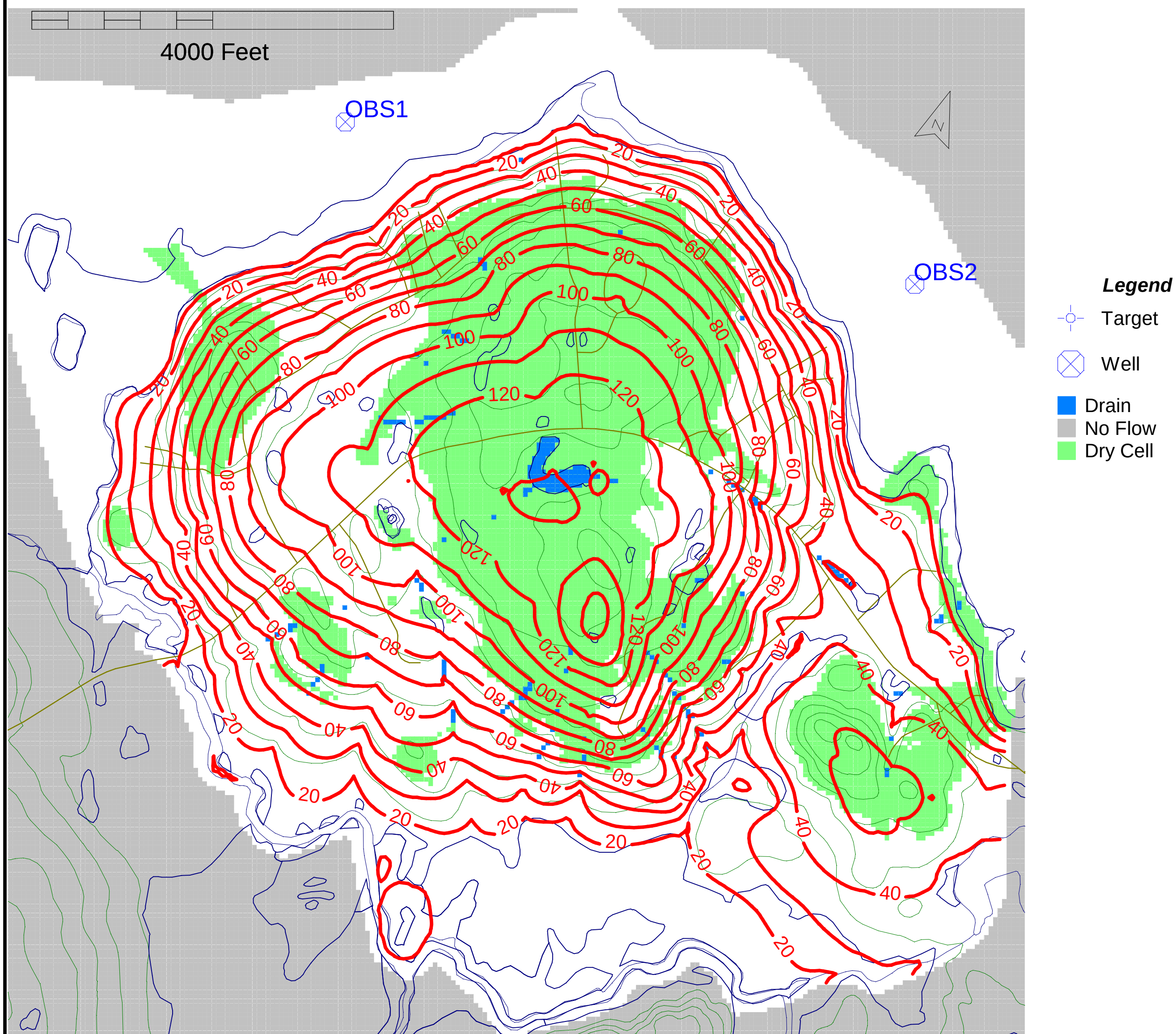
Figure 13



Bar Harbor Hadley Point Groundwater Contours with Existing Development

Groundwater Contours in Feet, NGVD, in Model Layer 2 (bottom soil)

Dry Cells are displayed for Model Layer 2

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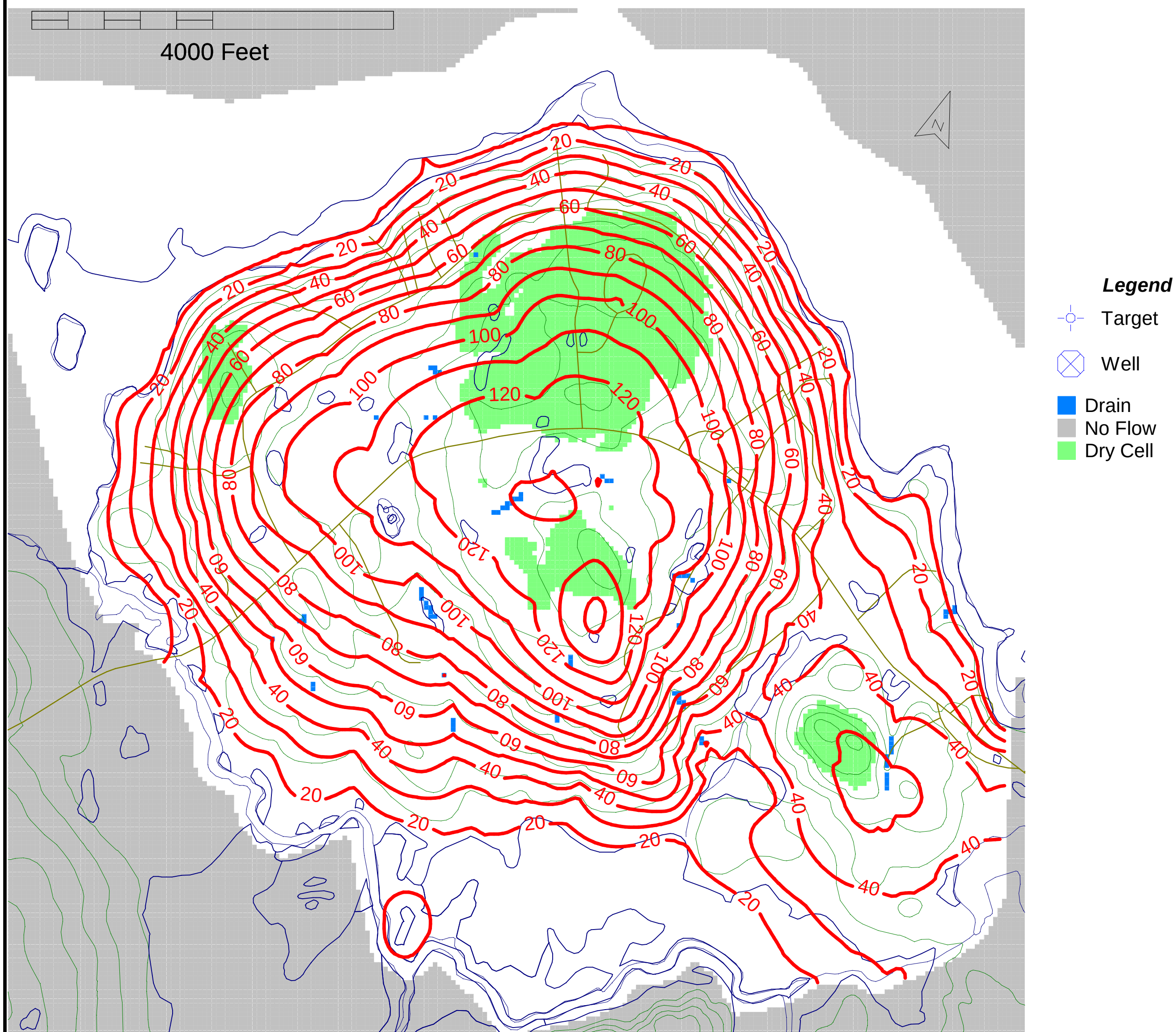
Figure 14



Bar Harbor Hadley Point Groundwater Contours with Existing Development

Groundwater Contours in Feet, NGVD, in Model Layer 3 (top rock layer)

Dry Cells are displayed for Model Layer 3

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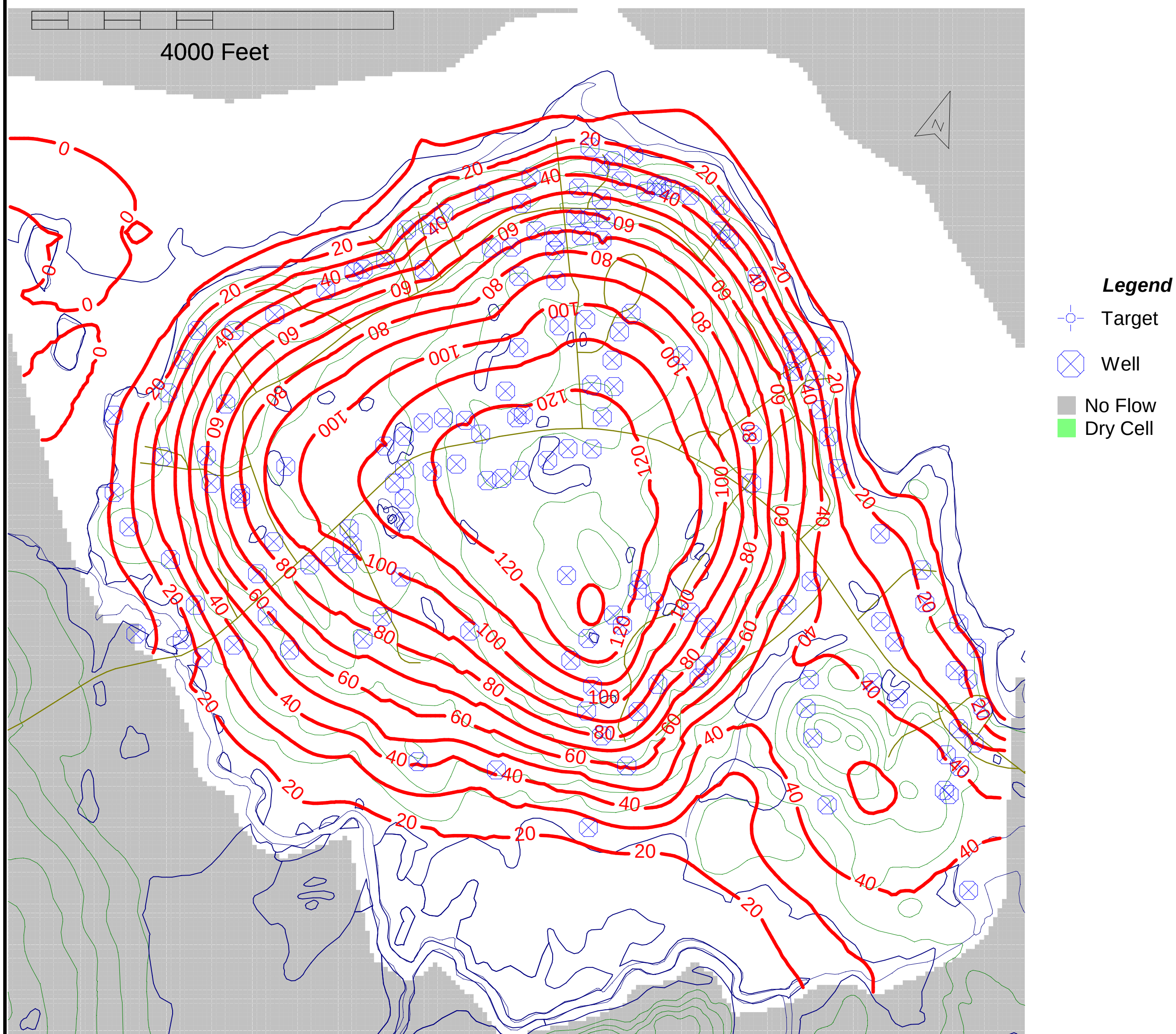
Figure 15



Bar Harbor Hadley Point Groundwater Contours with Existing Development

Groundwater Contours in Feet, NGVD, in Model Layer 5 (3rd rock layer)

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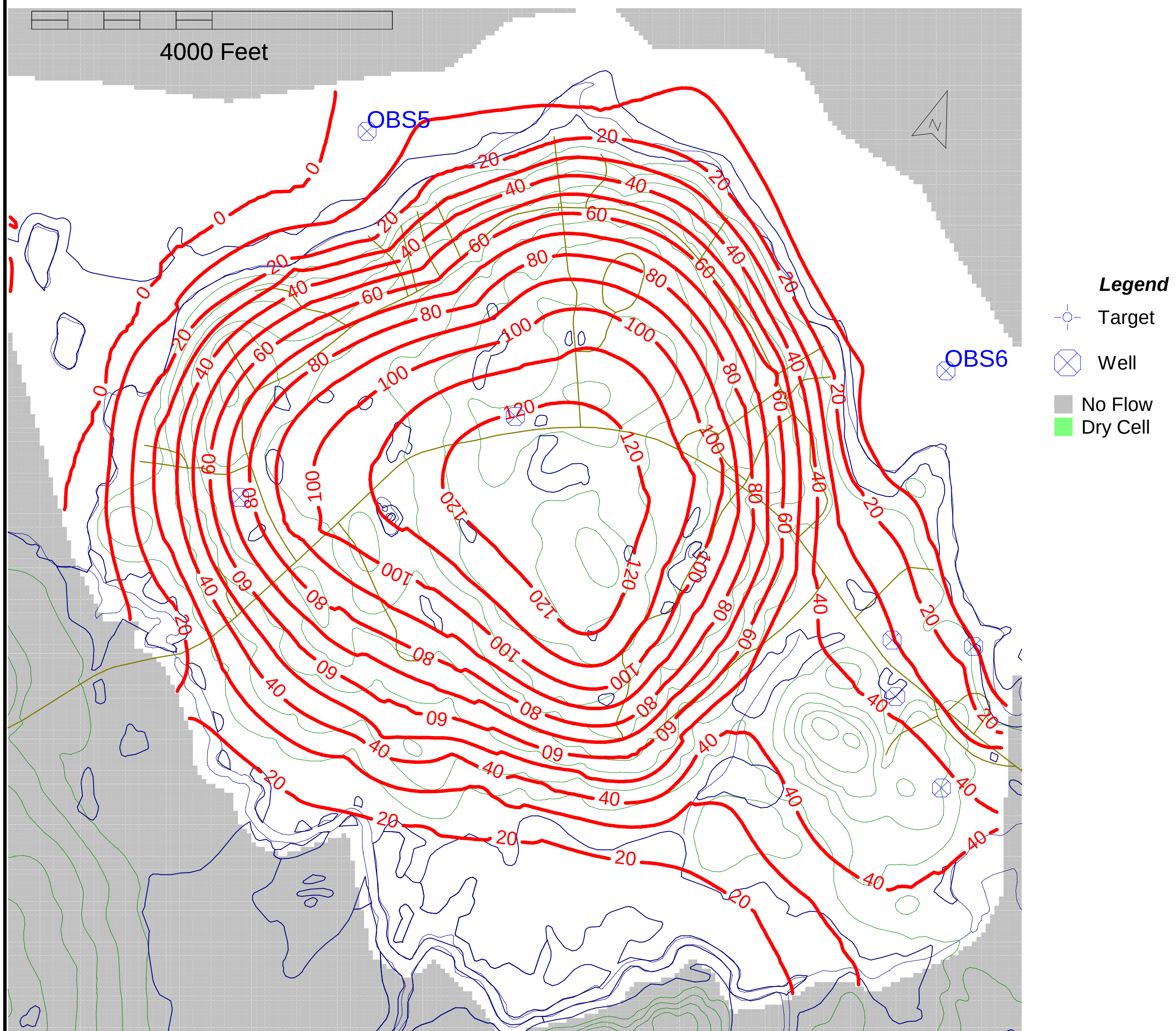
Figure 16



Bar Harbor Hadley Point Groundwater Contours with Existing Development

Groundwater Contours in Feet, NGVD, in Model Layer 6 (bottom rock layer)

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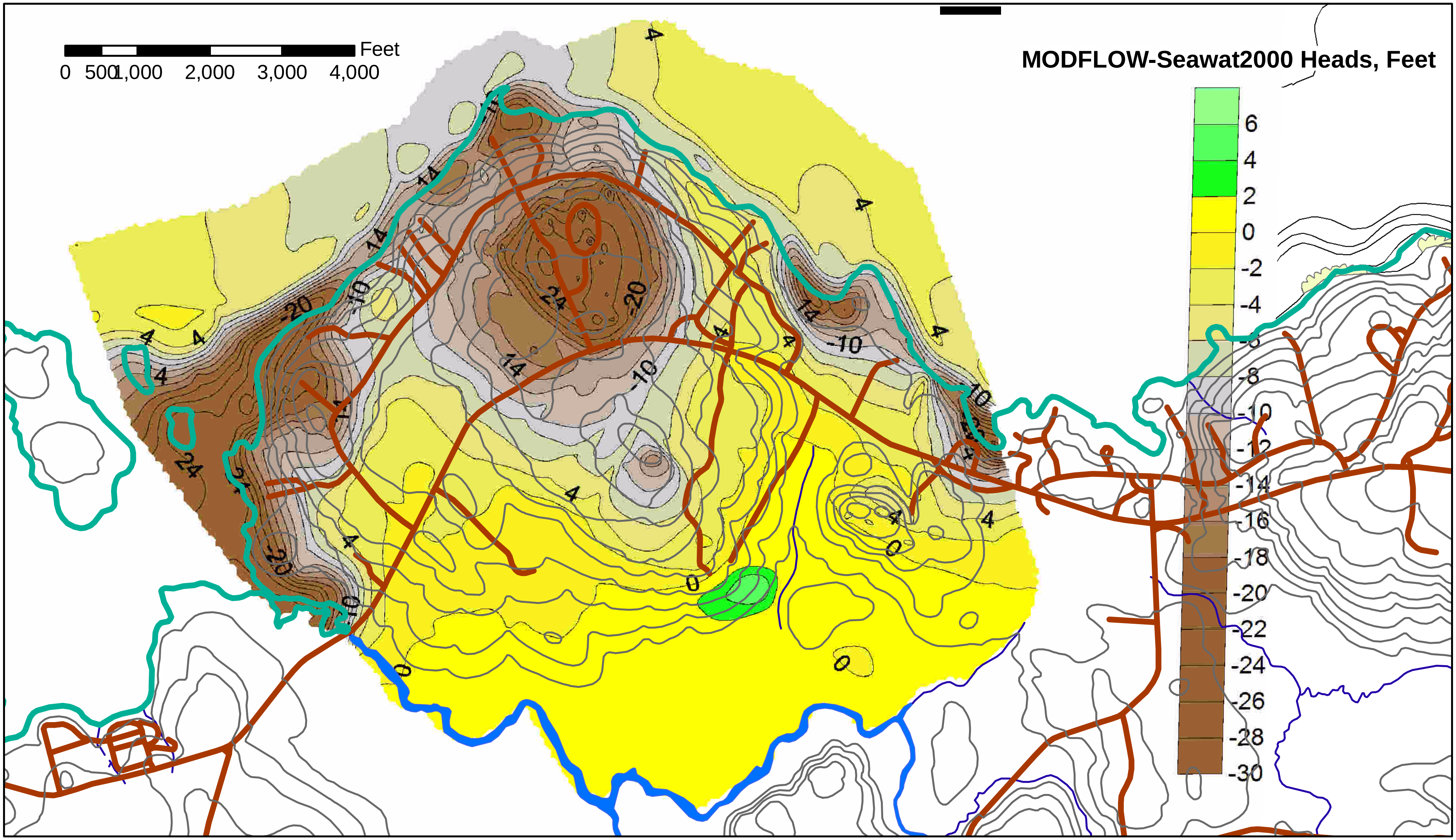
Figure 17



Bar Harbor Hadley Point Groundwater Model
Difference between MODFLOW and SEAWAT2000 Heads in Layer 4 under Existing Conditions

6/13/07

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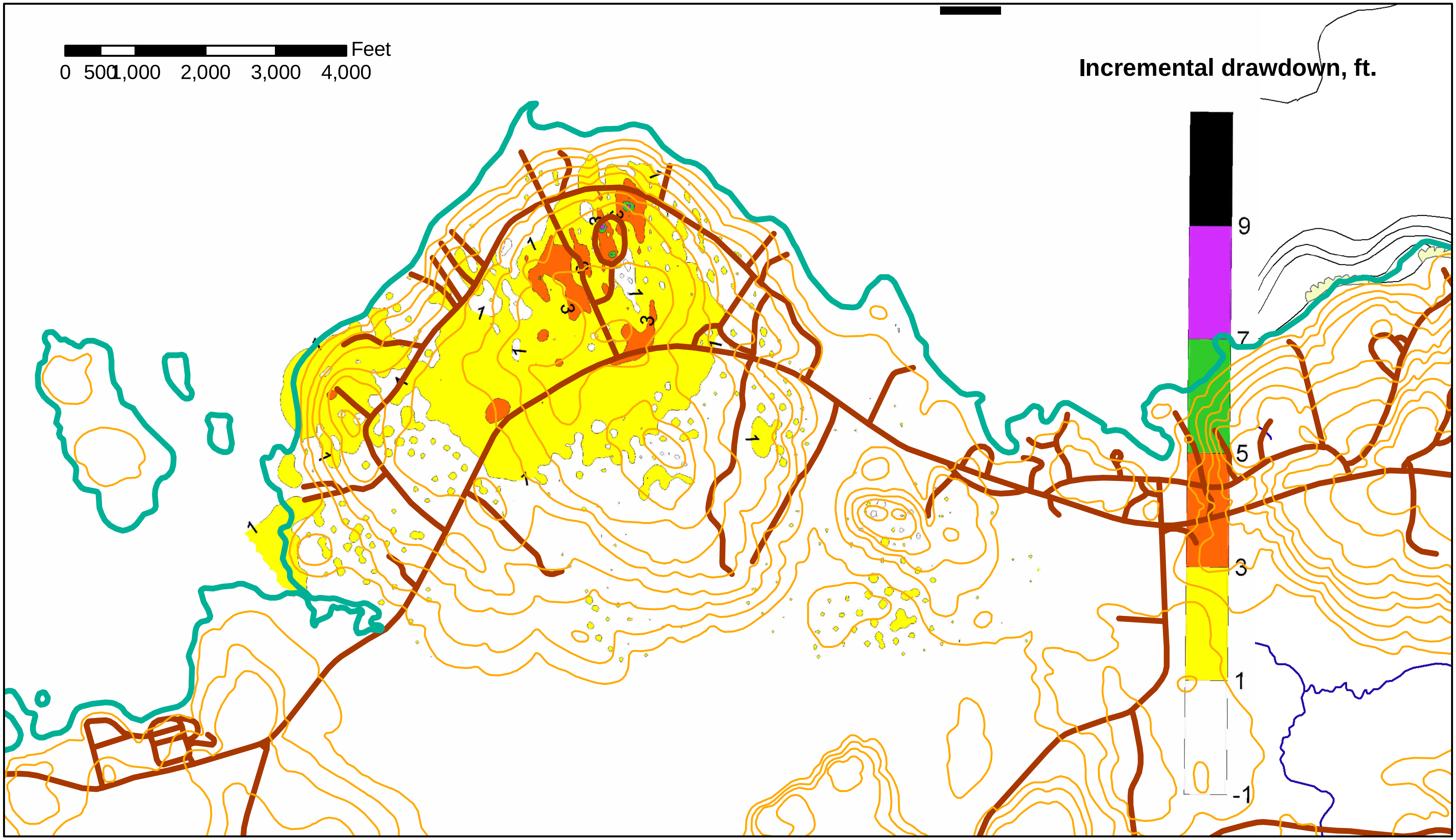
Figure 18



Bar Harbor Hadley Point Groundwater Model
Drawdown in Model Layer 4. Existing groundwater heads minus future heads.
6/13/07

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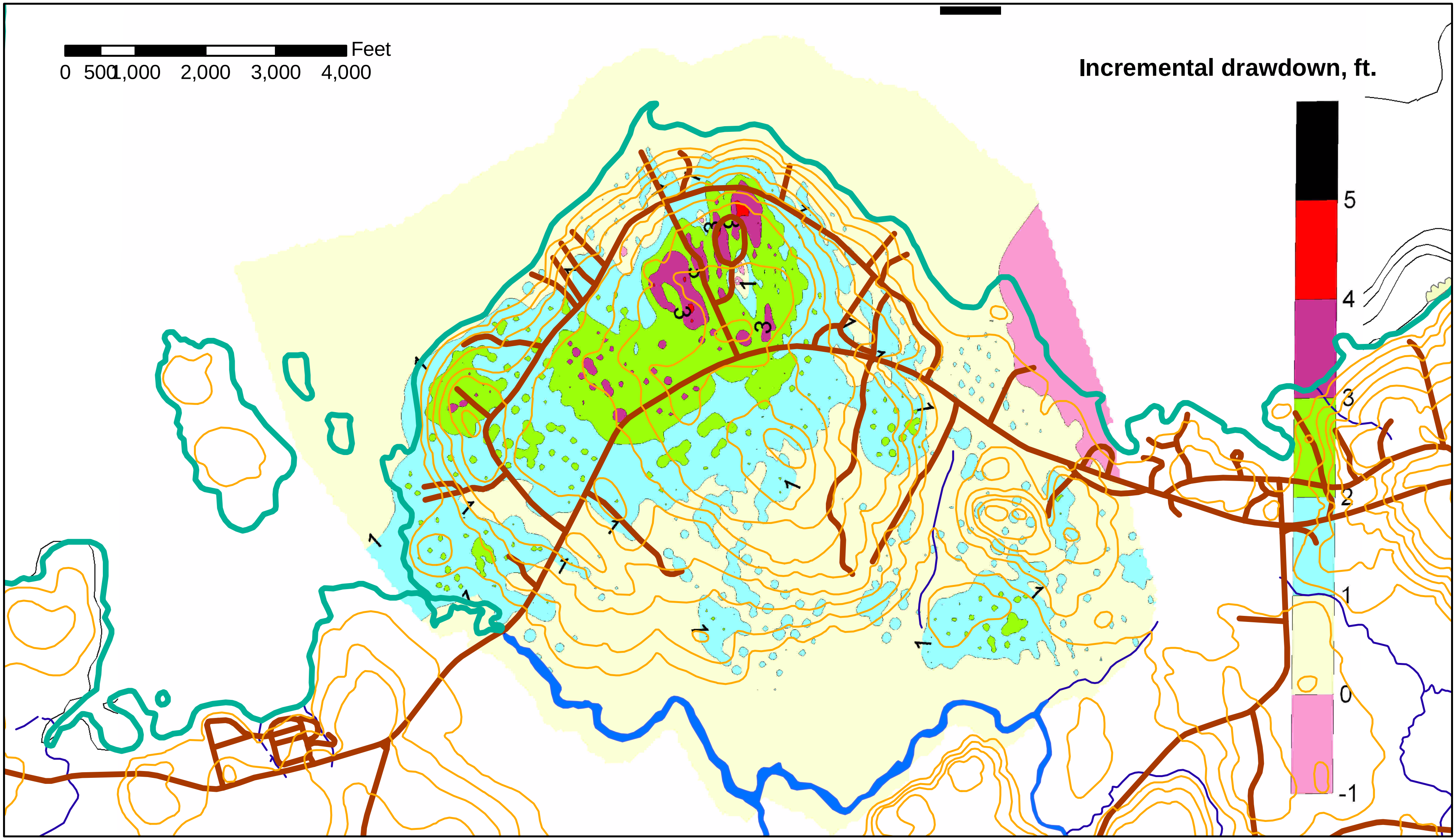
Figure 19



Bar Harbor Hadley Point Groundwater Model
Drawdown in Model Layer 5. Existing groundwater heads minus future heads.
6/14/07

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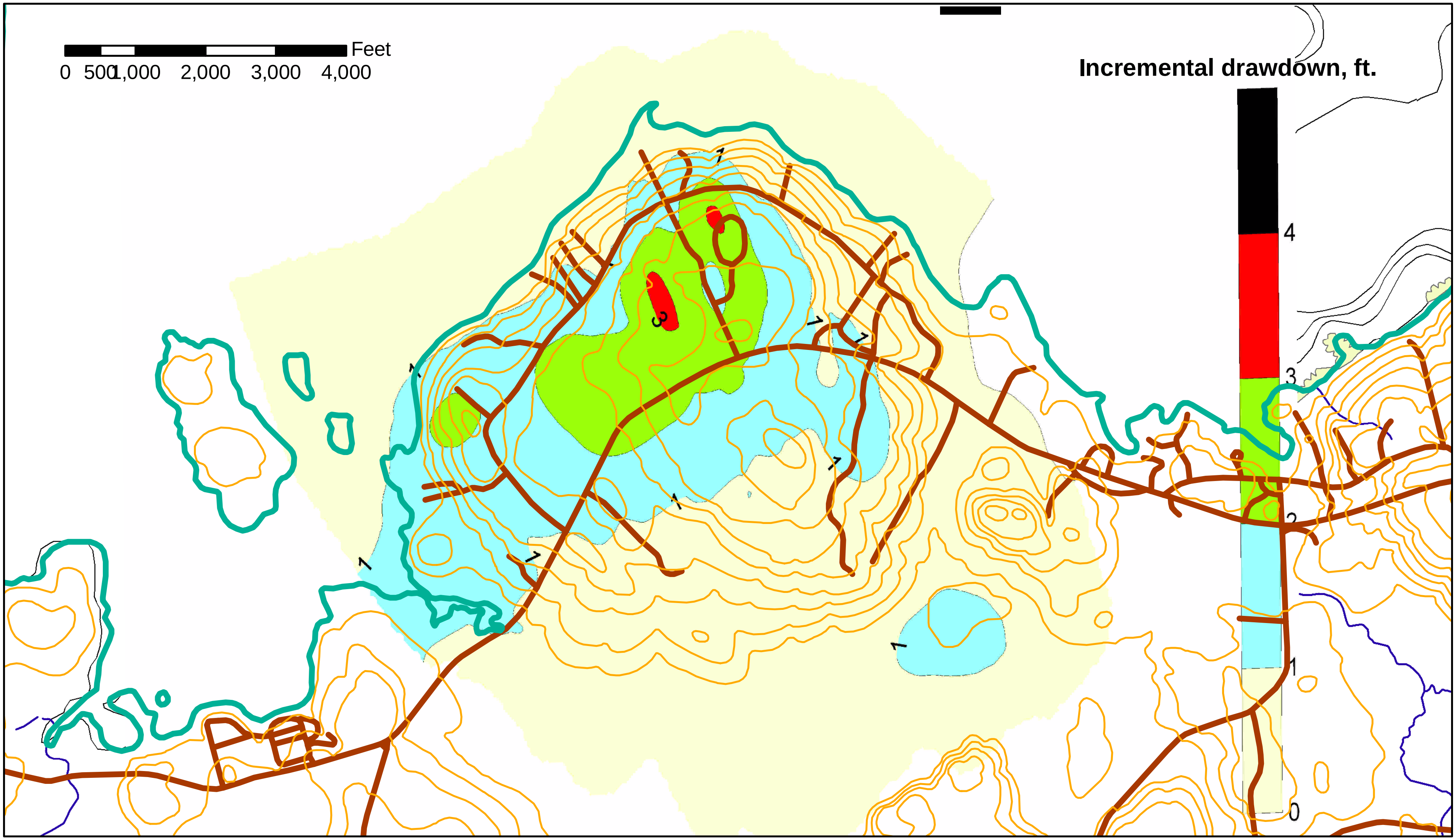
Figure 20



Bar Harbor Hadley Point Groundwater Model
Drawdown in Model Layer 6. Existing groundwater heads minus future heads.
6/14/07

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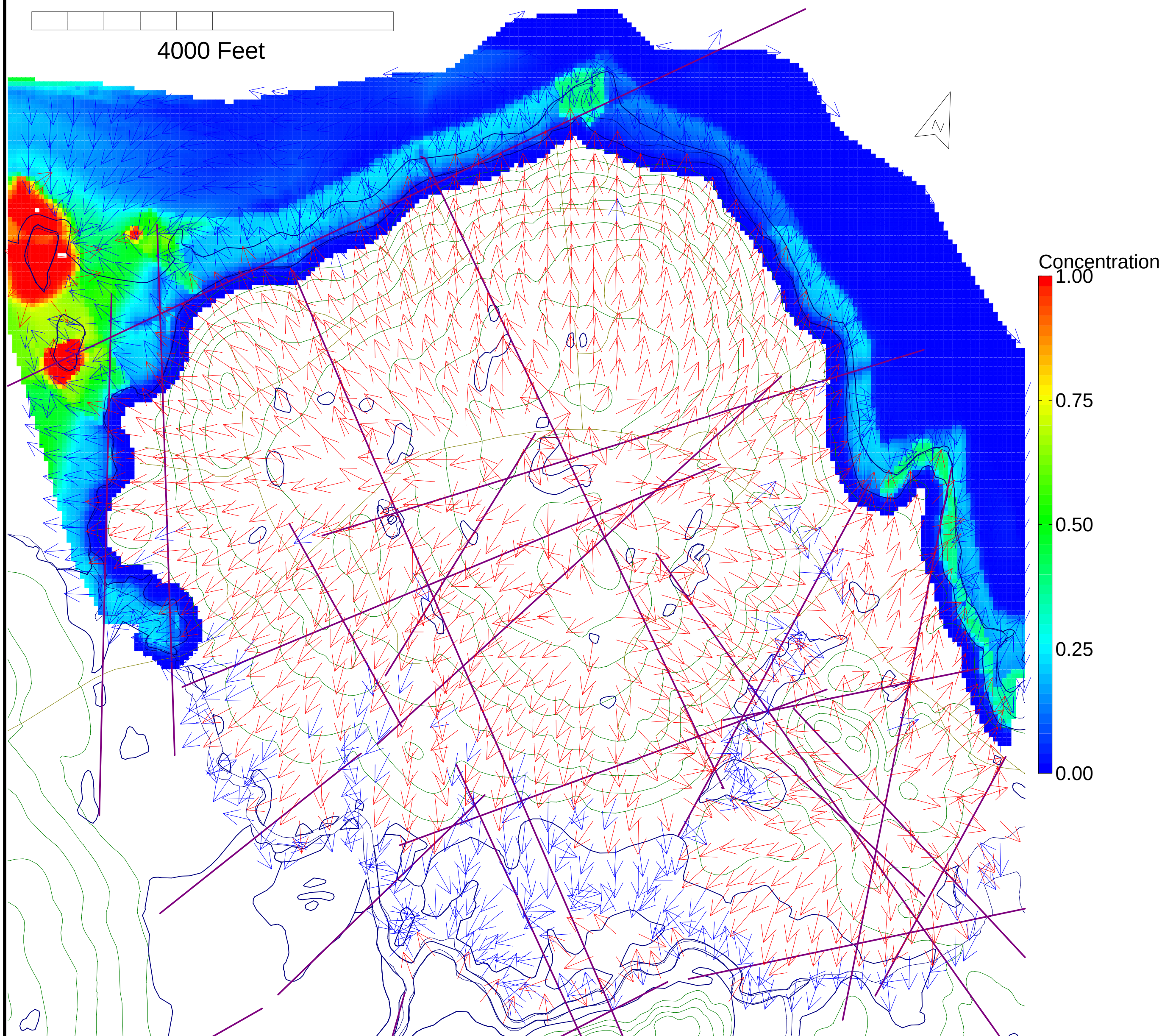
Figure 21



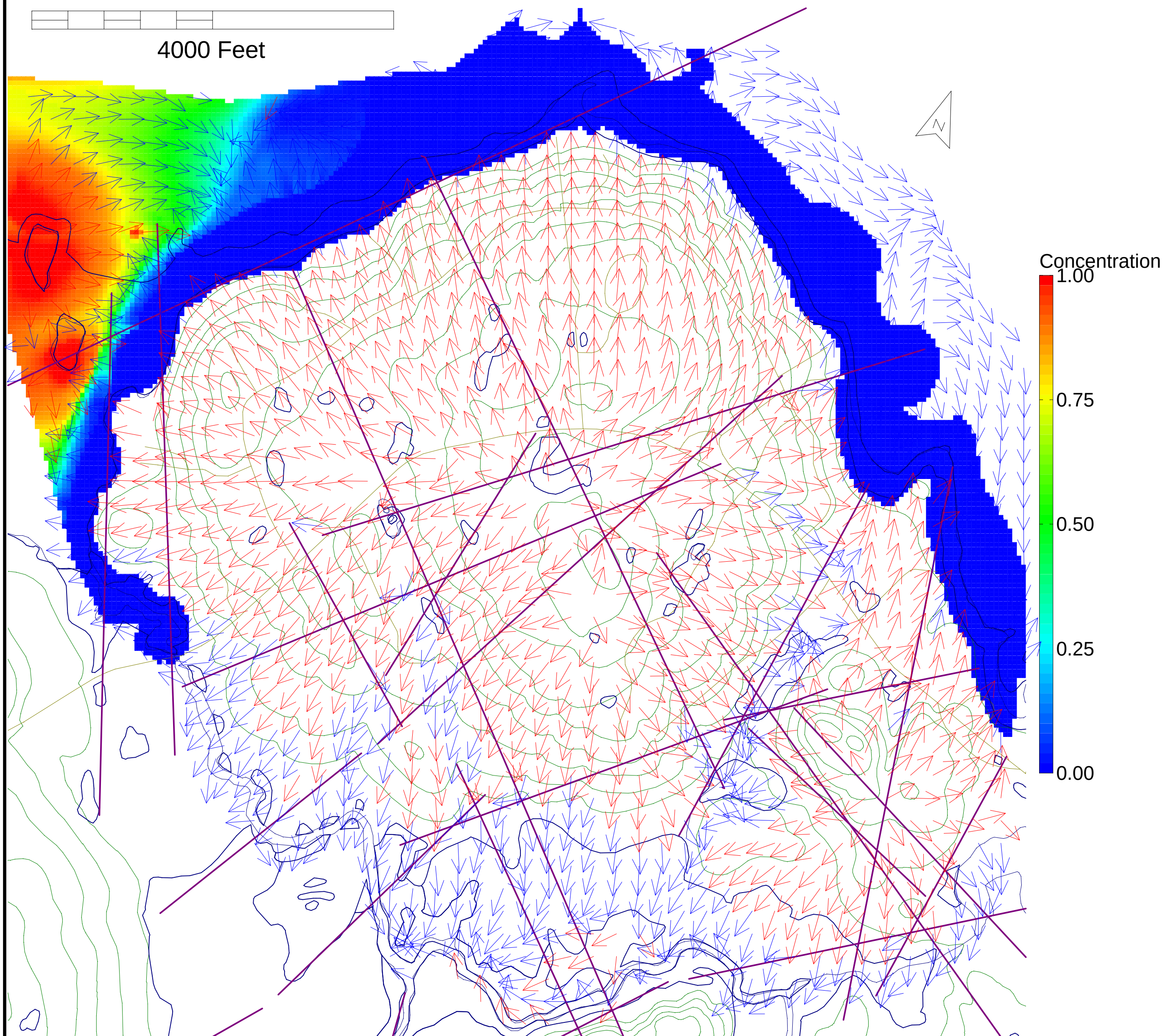
Bar Harbor Hadley Point Salt-water Intrusion Model with Existing Development

Top Bedrock Layer; colors represent percent pure seawater

Red velocity vectors down; blue vectors up

5/29/07

Figure 22



Bar Harbor Hadley Point Salt-water Intrusion Model with Existing Development

Third Bedrock Layer; colors represent percent pure seawater

Red velocity vectors down; blue vectors up

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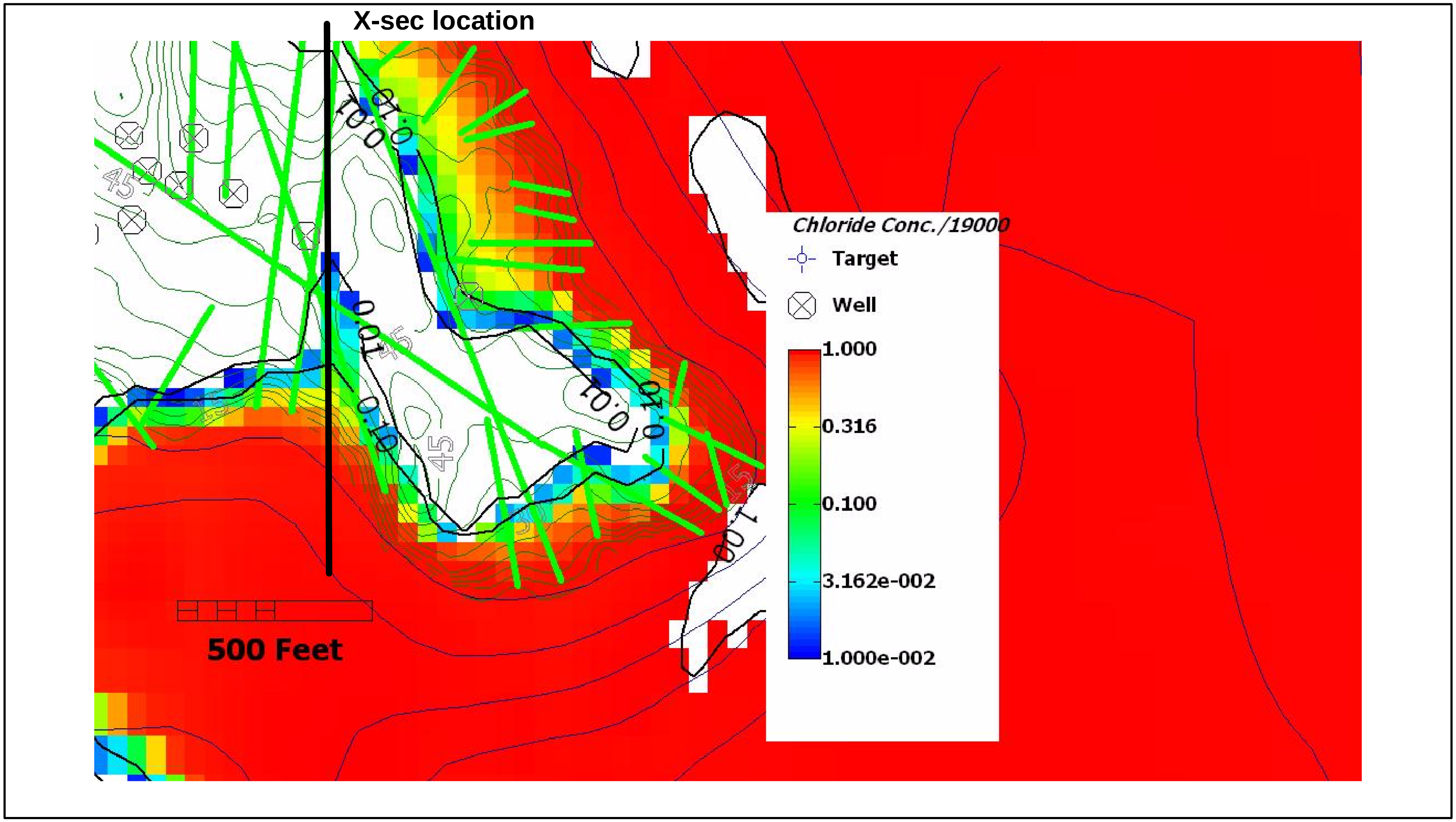
Figure 23



Saltwater intrusion in a bedrock aquifer on a peninsula on the Maine Coast
Notice saltwater migration along a fracture zone inland toward a well

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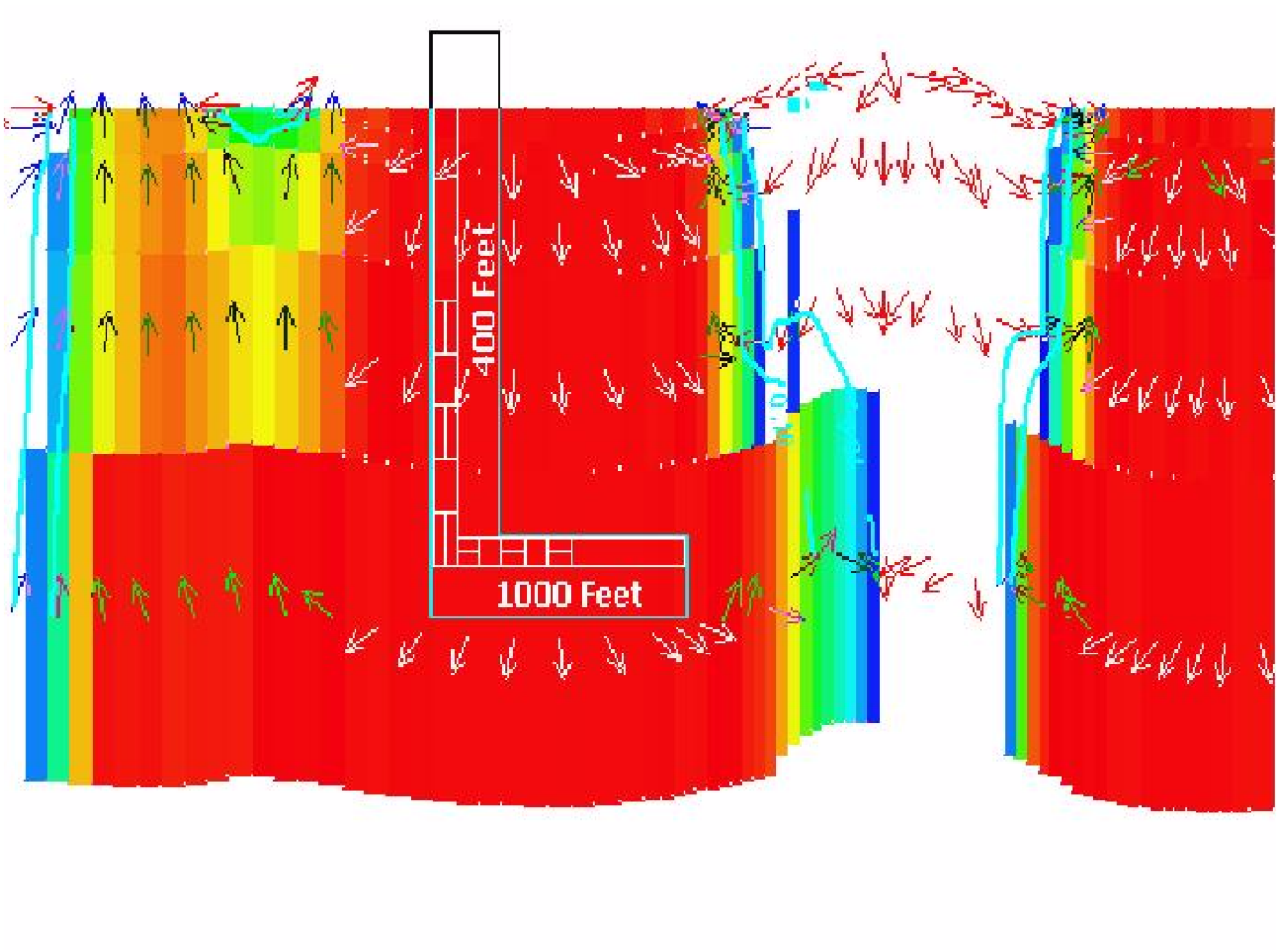
Figure 24



Vertical Cross Section north-south through peninsula shown on Figure 24
Notice how the saltwater intrusion extends downward and inward under the peninsula

See Color Fill Scale on Figure 24

6/15/07

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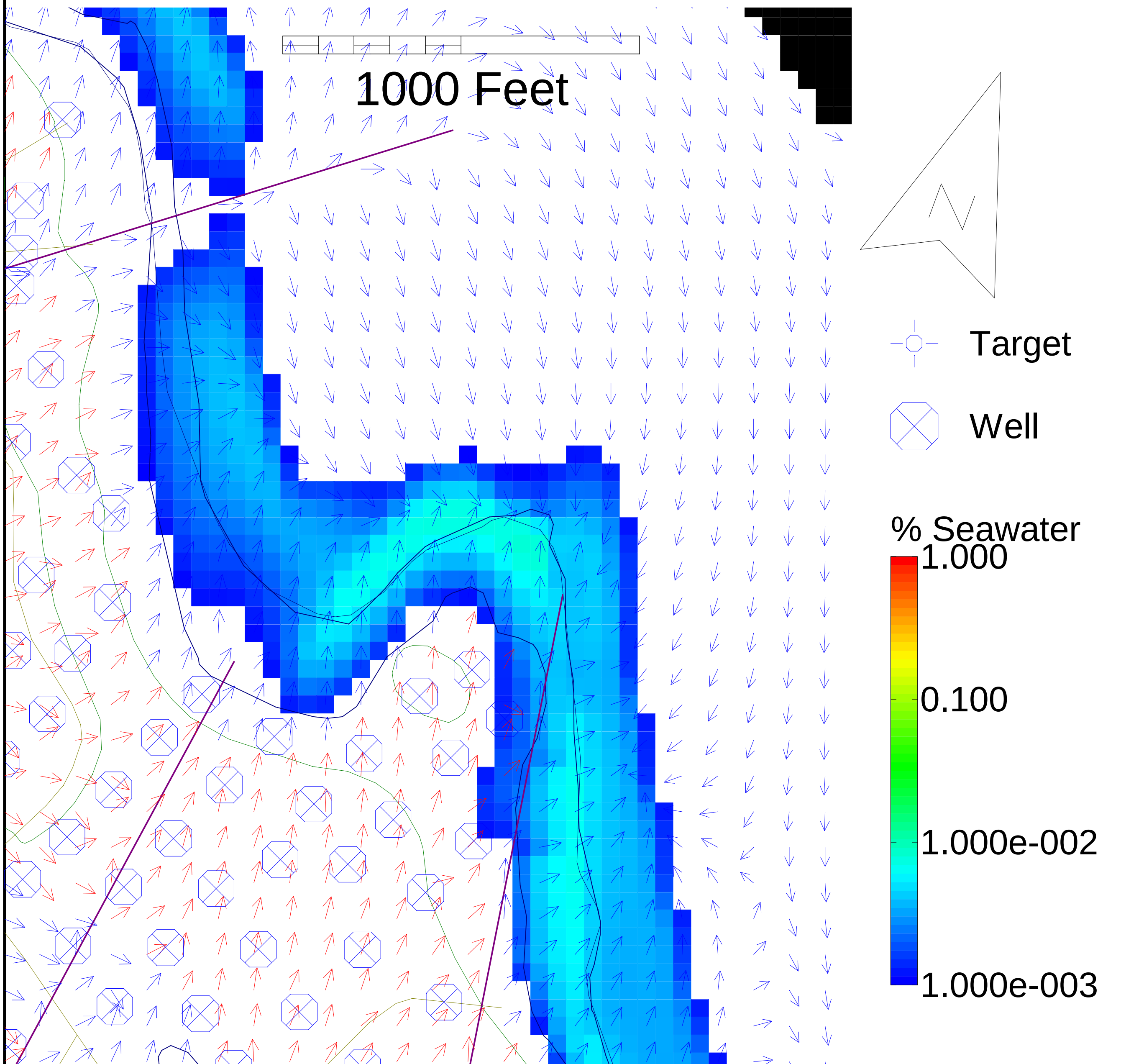
Figure 25



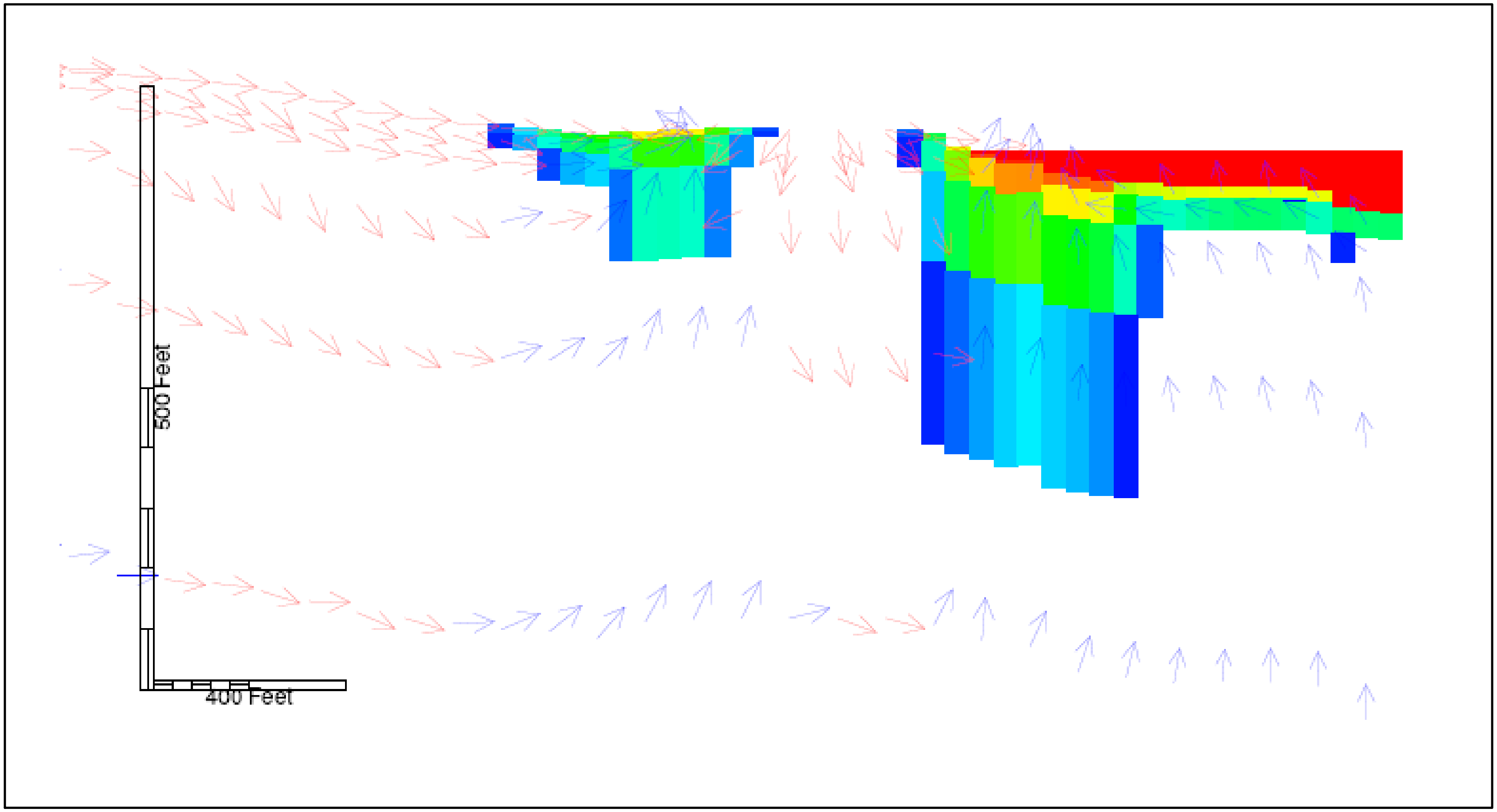
Bar Harbor--Leland Point Salt-water Intrusion Model with Future Development

Third Bedrock Layer; colors represent percent pure seawater

Red velocity vectors down; blue vectors up

5/29/07

Figure 26



Leland Point Geologic Cross Section on Model Row 109, Looking North
Future Development Scenario
Colors Display Concentration of Seawater. See Color Scale on Figure 26.
6/18/07

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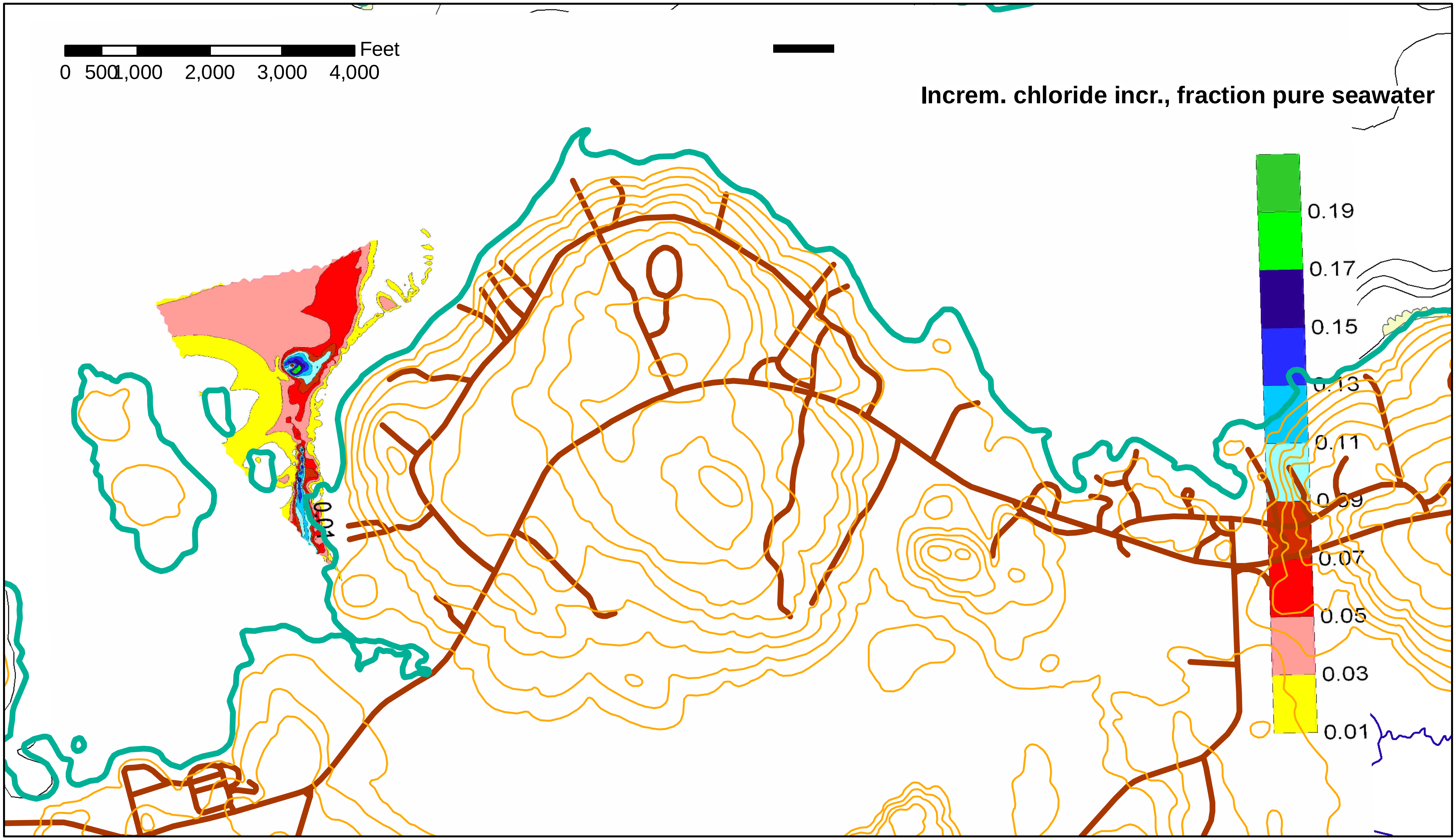
Figure 27



Bar Harbor Hadley Point Groundwater Model
Incremental fractional increase in seawater intrusion in Model Layer 5
Future Build-out minus Existing Concentrations
6/18/07

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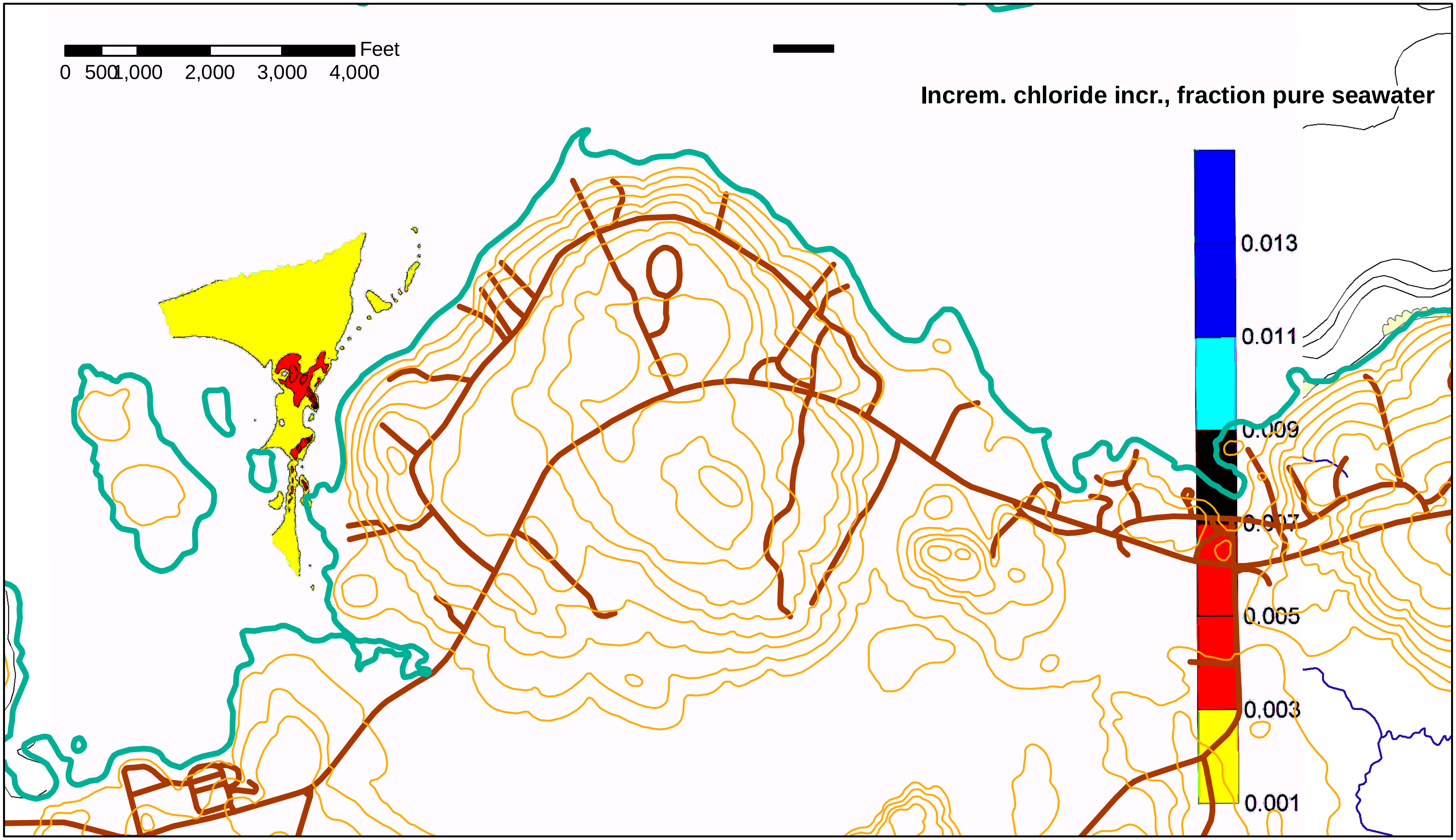
Figure 28



Bar Harbor Hadley Point Groundwater Model
Incremental fractional increase in seawater intrusion in Model Layer 5
Future Build-out; 3 months of no recharge
6/18/07

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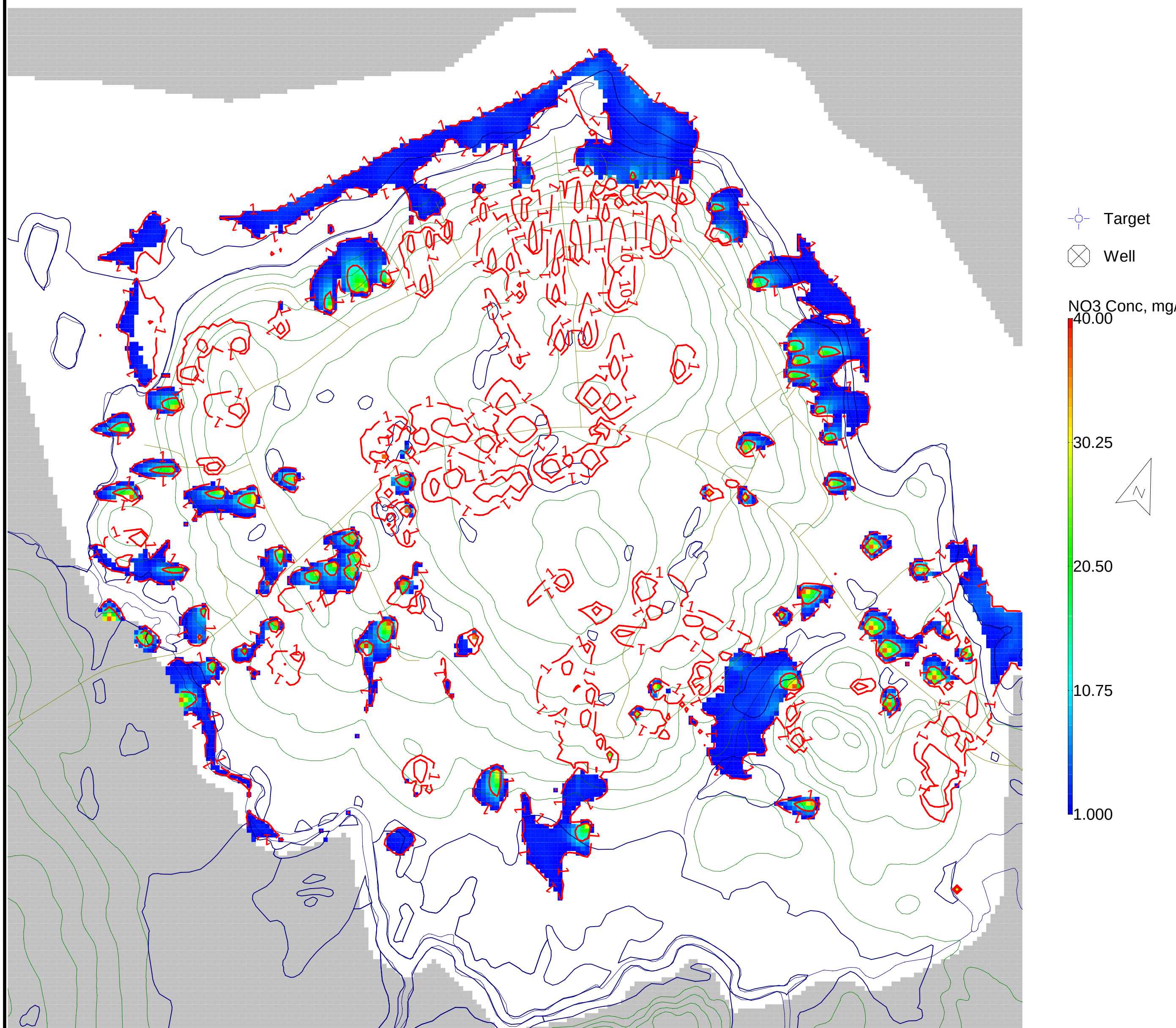
Figure 29



Bar Harbor Hadley Point Septic System Impact with Existing Development

Contours of Nitrate-Nitrogen on Phreatic Surface

5/29/07

1"=1740'

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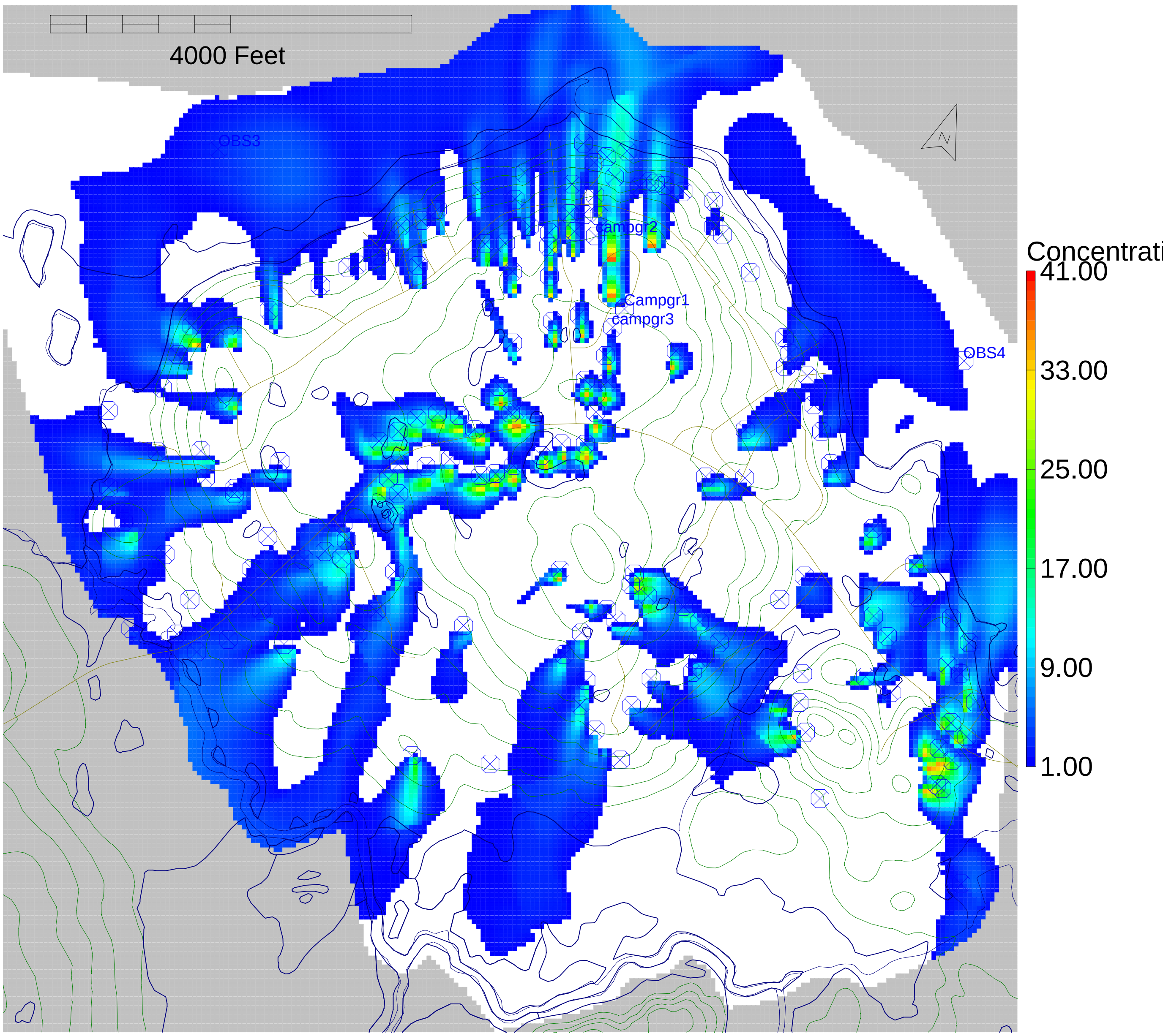
Figure 30



Bar Harbor Hadley Point Nitrate Impact from Existing Septic Systems

Model Layer 4 (second bedrock layer)

Concentrations as Nitrate-nitrogen in mg/L

6/18/07

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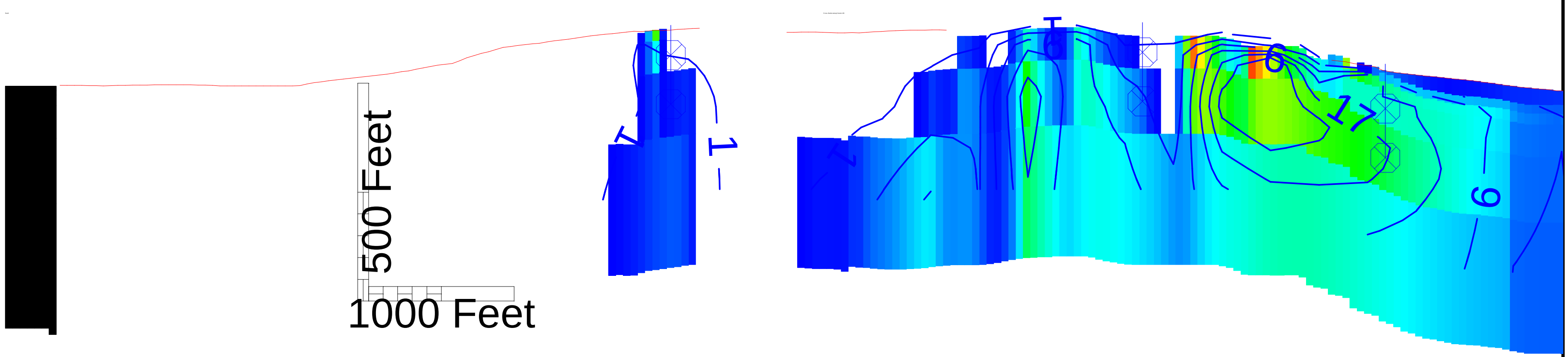
Figure 31



Bar Harbor, Hadley Point Groundwater Model

Existing Septic System Simulation; Contours are Nitrate-nitrogen in mg/L

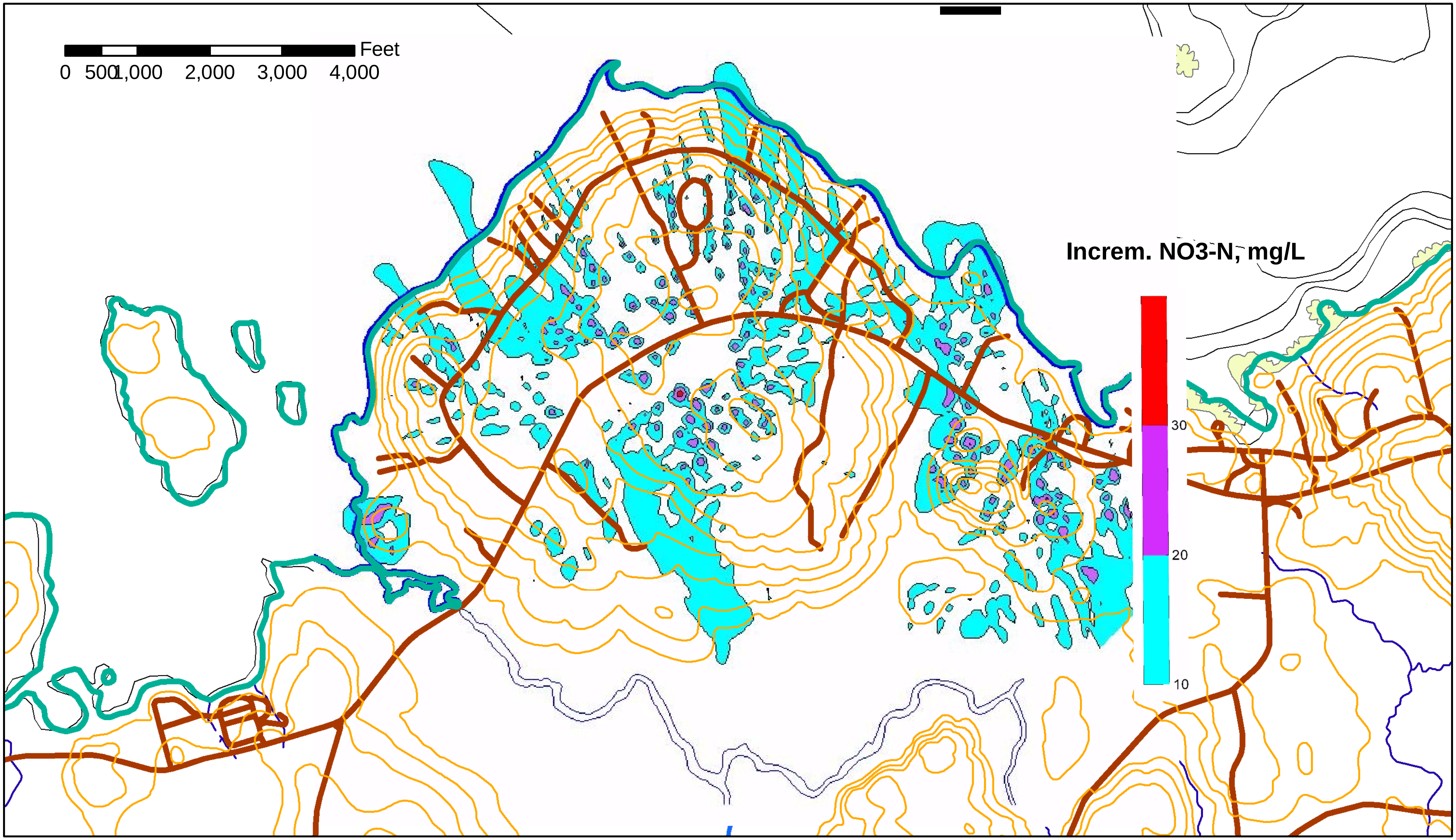
Cross Section on Model Column 136

6/15/07

See Color Fill Scale on Figure 31

STRATEX

Figure 32



Bar Harbor Hadley Point Groundwater Model, Layer 4
Incremental Nitrate-N from Septic Systems: Future Build-out minus Existing Concentrations
6/15/07

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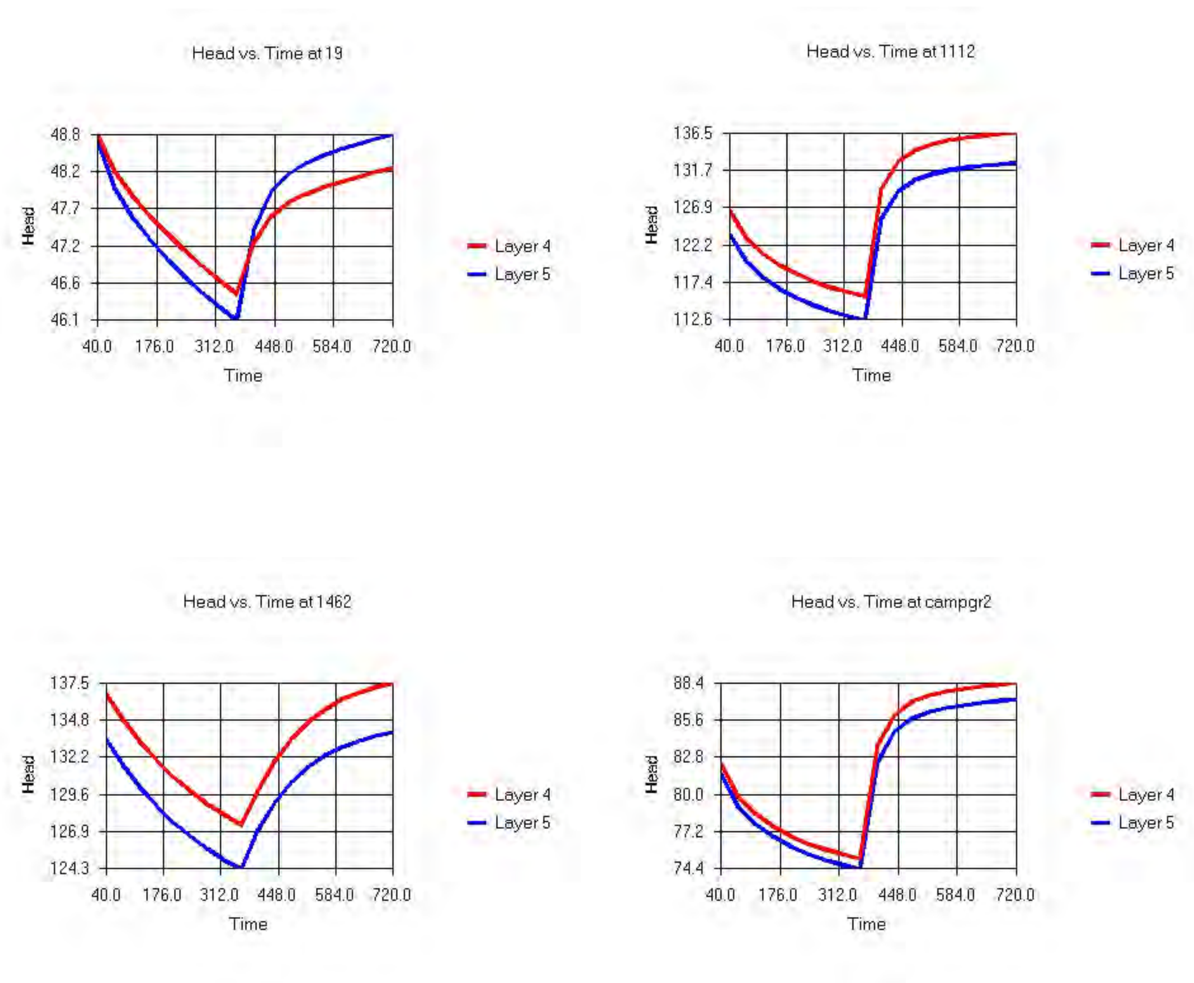
Figure 33

Figure 34

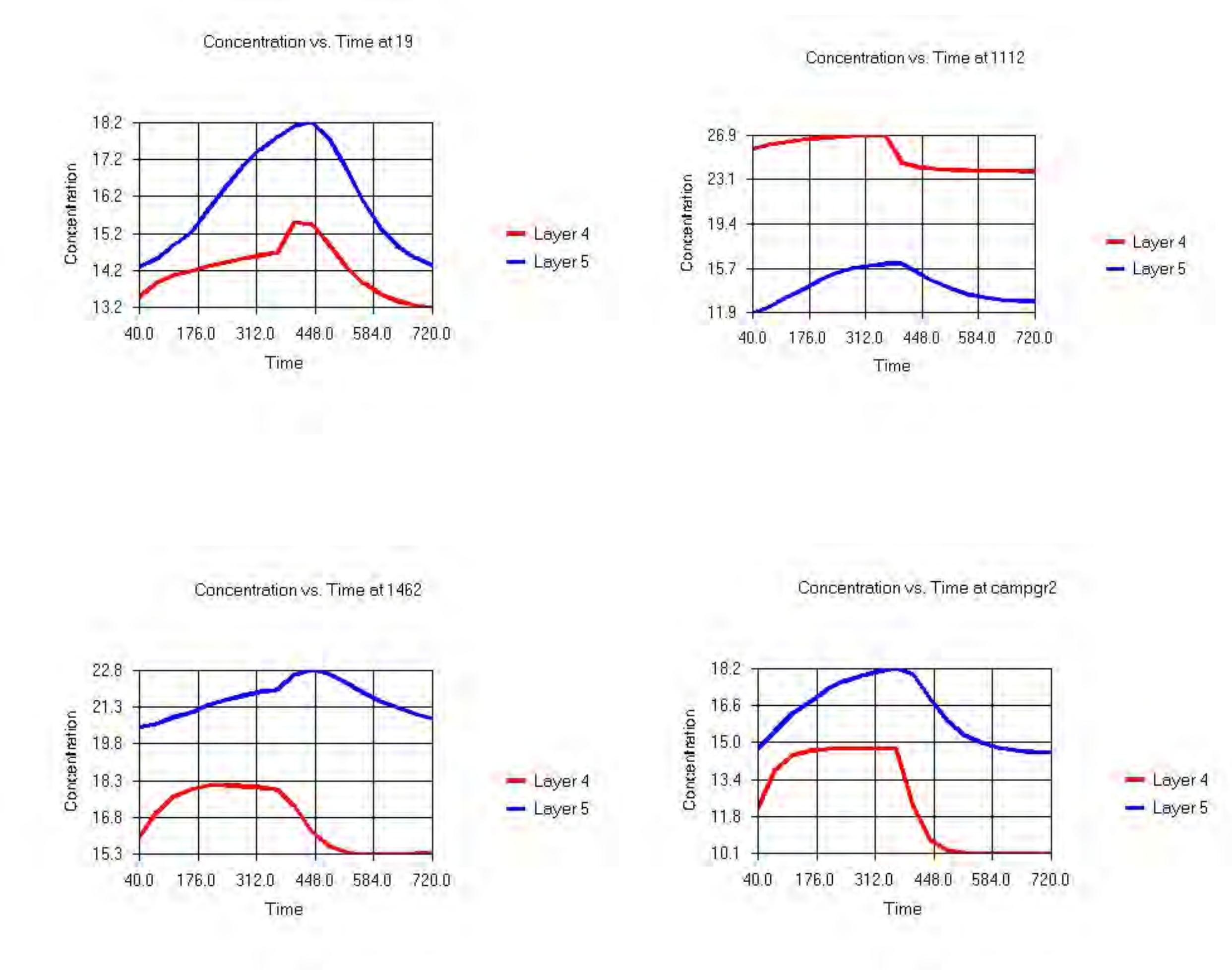
Impact of One-Year Severe Drought on Groundwater Elevations in the Bedrock Aquifer
Future Build Out Scenario
Bar Harbor Hadley Point Groundwater Model



Note: Heads are in Feet above NGVD29

Figure 35

Impact of One-Year Severe Drought on Nitrate Concentrations from Septic Systems
Future Build Out Scenario
Bar Harbor Hadley Point Groundwater Model



Note: Concentrations are Nitrate-nitrogen in mg/L