FINAL REPORT

RECONSTRUCTION OF A GROUNDWATER MODEL FOR BUSTINS ISLAND INCLUDING REVISIONS AND A DATA GATHERING PLAN

Prepared for:
The Bustins Island Village Corporation
Bustins Island, Maine 04013

Prepared by:
MACTEC Engineering and Consulting, Inc.
Portland, Maine 04112

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EXECUTIVE SUMMARY

In 1991, Robert G. Gerber, Inc. (RGGI) conducted a survey of the Bustins Island water supply and the hydrogeologic setting of the island for the Bustins Island Village Corporation (BIVC). With that information, RGGI constructed a groundwater flow and transport model as an aid in assessing then current and future potential impacts on the island groundwater supplies from waste water discharges to the aquifer and groundwater supplies used by island residents. In 1995, RGGI updated that study and included other withdrawals and discharges to the aquifer that had been installed in the intervening years. Recently, BIVC attempted to have additional runs made with the model only to learn that during, or since the acquisition of RGGI by another firm, the model files had been lost. In an effort to reinstate the model, BIVC issued a statement of work to reconstruct that model, among other tasks. MACTEC Engineering and Consulting, Inc. (MACTEC) submitted the winning proposal to perform that work. This draft report presents the efforts to reconstruct the Bustins Island groundwater flow model, to carry it forward to enable BIVC to model future development on a lot-by-lot basis, and to propose data gathering activities that BIVC might carry out to improve the model and the understanding of the island's hydrogeologic system and to adopt appropriate guidelines for the protection of the island's water supply.

The model constructed by RGGI was poorly documented in the 1991 and 1995 reports. From the information supplied and the representative model outputs, it appeared that the model might be reconstructed with only slight effort. However, when actually engaged in reconstructing the model, it appeared that more detail was included than suggested in the reports, and that, as a result, the values of many more parameters were unspecified. MACTEC has employed a looping process between the steady-state flow model and the transient transport simulations to develop a suitable replacement model that closely mirrors the results of the RGGI modeling. While some differences are straightforward, the factors underlying some of the subtle differences between the original RGGI model and this reconstruction may never be completely known unless the original model files were to come to light.

The reconstructed steady-state flow model actually displays slightly better fits to the target water level data used for the original RGGI model calibration. The potential zones where long-term effects from wastewater discharge to the subsurface may be excessive are similar between the original 1991 model and the reconstruction. However, the potential impacts as modeled in the 1995 version by RGGI shows less of an impact, and it is unclear why this might be so. The 1995 report is less detailed in presenting the results of the simulations, which were run for a simulated period of about 8 years to achieve assessment of a near steady-state final impact. The MACTEC model produces potential effects that are somewhere between the two previous RGGI models, but closer to the original. None of the models includes any degradation or retardation of any constituents in the waste water, only declines in concentration that are caused by mixing with groundwater and changes in flow direction due to the periodic nature of the precipitation and recharge over the island and the seasonal nature of the withdrawals and returns. MACTEC is confident that the resulting model reconstructed will serve as an equivalent tool to the previous modeling effort.

MACTEC then moved forward to refine the model such that it could be used to evaluate exchanges of groundwater on a lot-by-lot basis. In the original model, block sizes were as large as 100 feet by 100 feet. This meant that, since the model places the point of recharge at the center of the block, well positions could be a far off as 50 feet in the model. With a refinement to 20-foot blocks, wells can be located to within 10 feet of their actual position in the model. MACTEC also refined the boundary condition and hydraulic conductivity and recharge zones to reflect the improved resolution.

MACTEC has included a program of recommended low-cost activities that could be implemented to provide additional data with which to improve the model and the understanding of the hydrogeologic system at Bustins Island. These include:

- Update and maintain water use inventories (i.e., update RGGI's 1995 Table 1)
- Elevation survey of wells used for water level measurements
- Establish elevations at key locations, e.g. at suspected depressions where groundwater may be present at ground surface, and also at fire ponds
- Use a Global Positioning System unit to establish more accurate location of wells, or locate on a map relative to lot corner markers. This information can be entered into and preserved within the model preprocessor.
- Collection of water level data at monthly interval during the summer
- Compilation of well installation diagrams, existing or new
- Establish some v-notch weirs at culvert crossing locations; collect flow data regularly, but especially after storm events or periods of extended good weather
- Compile records of precipitation

MACTEC also reviewed RGGI's considerations of the potential effects of saltwater intrusion and concurs with the conclusions that most locations that have been or might be developed as water supply wells have a small potential for impact by salt water intrusion. The application of the Gyzben-Hertzberg principal is probably not a concern since water supplies below 300 feet are unlikely, and, if applicable near the edge of the island, the slope of the interface is steep and, relative to well depth, the interface does not extend very far inland. The well supplies are small and local groundwater is sufficient to supply demand. The net exchange rate of water from the aquifer is small, currently estimated as less than 1 gallon per minute from the aquifer. The water demand is seasonal, and the aquifer has ample time to recover from the end of one season to the beginning of the next. Nevertheless, in light of possible higher usage rates, the adoption of a setback from the edge of the island for future development is probably warranted. Periodic testing of well water for specific conductance or salinity may be advisable for wells near the shore and/or if net withdrawals of groundwater increase dramatically in the future. Wells with intakes above sea level and dug wells are likely not at risk from seawater intrusion.

While the model has limitations based on data gaps and the estimated values of some model input parameters, it provides a useful tool in combination with good common sense for BIVC in log-range planning regarding water supplies for the island.

Note: While this document is intended to convey an overall appreciation of the model and its use, it also serves to document the reconstruction and modification of the Bustins Island groundwater flow model. Some readers will find much too much technical detail in this report; however, these readers should skim these details and concentrate on the main points as contained in the Executive Summary and in discussions of the model, its application, and its limitations. A list of definitions for some terms used in this report follows the Figures.

1.0 INTRODUCTION

In 1991, Robert G. RGGI Inc. (RGGI) prepared a groundwater model of Bustins Island for the purpose of serving as an aide in helping the Bustins Island Village Corporation (BIVC) develop groundwater supply protection guidelines for potential future island development. In 1995, RGGI conducted further studies aimed at providing updated information to support the groundwater modeling effort. Recently, BIVC attempted to have additional runs made with the model, only to learn that with the acquisition of RGGI by another firm, the groundwater model files had been lost. BIVC then issued a statement of work and request for proposal to reconstruct the model and secure the model and requisite model software in BIVC's possession to avoid another such instance. MACTEC Engineering and Consulting, Inc. (MACTEC) was selected as the successful bidder. In partial fulfillment of the scope of work, MACTEC has reconstructed as closely as possible, the original RGGI model from the limited information available in RGGI's 1991 and 1995 reports. Also as part of the SOW, MACTEC has refined the resultant groundwater model to allow evaluation of the potential impact of future development on water supply on a lot-by-lot basis. This draft report presents the process of reconstructing and refining the original model, and presents a Data Gathering Plan with recommended steps for potentially improving the dependability of the model in the future.

This draft report consists of three main sections: Section 2.1 summarizes MACTEC's reconstruction of the previous Bustins Island groundwater modeling, with a discussion of the limitations of this and any model; Section 2.2 summarizes the conversion of the model to a finer grid structure that will allow BIVC to refine water supply withdrawal and waste water recharge locations on a lot-by-lot basis, something the coarser grid of the RGGI model would not permit; and Section 3.0, which makes observations and recommendations, i.e., a Data Gathering Plan, that will help BVIC and island residents to better understand the workings of the model and provide steps that may be taken to improve the model and the understanding of the potential effects of development on the island water balance and water quality. Section 4.0 presents a further discussion of the potentials for impact on water supply wells by the salt-water interface which may underlie the island's freshwater supply. Tables, Figures and a brief list of definitions of hydrogeologic and modeling terms follow Section 4.0. Appended to the report is a brief description of how to run the model; this is to be supplemented by notes and handouts provided at the training sessions for BIVC personnel to learn how to modify and run the model.

2.0 MODELING RECONSTRUCTION AND REVISIONS

This section presents the reconstruction of the Bustins Island groundwater model, and the conversion of the model to a finer grid allowing lot-by-lot evaluations with more accurate definition of water supply extraction and waste water recharge locations.

2.1 RECONSTRUCTING THE GROUNDWATER MODEL OF THE ISLAND

2.1.1 Background

Information with which to reconstruct the Bustins Island groundwater model based on RGGI previous modeling reports are limited to a few specific values and some figures showing input and output results from the model presented and/or cited, in the 1991 and 1995 RGGI reports. While, if a simple model had been constructed, these data might have been sufficient to reproduce the RGGI model nearly exactly, the apparent more complex nature of the model as revealed in the reconstruction process, requires assumptions as to the values of many input parameters and allows only a reasonably close reconstruction of the model and its outputs. RGGI's original groundwater flow model and MACTEC's reconstruction are both set within the USGS MODFLOW finite-difference code. The transport of waste constituents in groundwater is modeled with the USEPA-sponsored model code MT3D. MACTEC utilizes an updated version of that code (MT3DMS) from the version available to RGGI at the time of the original modeling. This updated version is computationally more efficient and accurate, resulting in shorter model run times.

MACTEC first reconstructed the groundwater steady-state flow model, comparing it to the steady-state model results cited by RGGI, and then used this as a basis for reconstucting a transient transport model similar to that RGGI used to evaluate the potential impacts of waste water discharges to the subsurface on water supply water quality. Given the few input data, it is possible to closely match the steady-state model computed head contours with a wide variation in input values. However, when the transport model is implemented with contaminant transport, then it becomes apparent that some input values need to be adjusted in addition to the transport parameters that have no effect on head contours and groundwater flow direction in order to more closely approximate model outputs results. Thus, the process of deriving a closely matching model is a loop of redefining steady-state model parameters and rerunning the transient transport model until satisfactory results are obtained. MACTEC used best judgement in developing the present model where data were lacking.

Table 1 lists some of the specified values and outputs presented in the reports that were used in model reconstruction, and also indicates where MACTEC was forced to assume model input parameters to approach the RGGI model outputs as presented. The table is somewhat abbreviated, and, where applicable, more discussion is presented in paragraphs following the table.

2.1.2 Additional Detail on Some Input Parameters

The following paragraphs may contain more technical detail than the reader may want to wade through. In this case please move forward to section 2.1.3

Layer thicknesses: Layer thicknesses were also assigned partly based on information in the RGGI report which showed some dug wells in layer 2. Layer thicknesses are not critical if they have the same properties assigned to them.

Boundary conditions: Boundary conditions are a very important component of the model as they establish observed conditions of head or flow within the model and frequently are more important than the aquifer properties in determining how the simulated groundwater will behave in the model. The ocean establishes a vast sink for the island groundwater flow, and all of that flow, with the exception of that withdrawn and not returned, eventually finds its way to the ocean. In a steady-state model, we chose the average ocean level, or zero head as a constant condition (called a constant head boundary condition) at the edge of the island. This may vary with depth due to the presence of the saltwater wedge. However, this surface is quite steep, and even at the base of the model, is not too far inland. In the model we have ignored this slight variation, but have established a no-flow boundary condition in the bottom layer to force some groundwater flow to shallower depths as it approaches the ocean. In actuality, most of the freshwater flow from the island would discharge to the ocean during the low tide cycles, during which more of the ocean floor would be exposed. As a result of this approximation and the coarseness of the model discretization, groundwater flow very near the ocean may behave differently than shown in the model.

The third kind of boundary condition assigned to the model is called the drain package in MODFLOW. This works by establishing the level (called the invert) at which the drain operates. When groundwater rises to this level, the drain package begins to remove water from the model and maintains the computed water surface near the drain invert elevation. This is useful in simulating actual drains, such as French drains used to dewater areas, but also in the case where the model shows that the water table would actually rise above ground surface, say at springs or seeps. By including drains in the model in these areas (usually topographic lows or depressions, like swales, the model shows the water table at ground surface, but not above. The model also keeps track of how much groundwater flow is lost to drains or seeps. In MACTEC's model, we have included two such areas. RGGI also appeared to include the simulation of this kind of effect (indeed he attempted to map where these swales appeared to exist), but did not specify what he used as a model boundary condition. One of these areas is common to both models, while RGGI included an area that, from our interpretation of the ground surface elevation and that of the modeled groundwater, would not appear to intersect the water table. We did not include this area. However, in another area, RGGI's model would appear to produce water levels as high as 10 feet above the USGS interpreted ground surface contours. We did include a drain in this area (see Figure 1 for the location of the drains in the MACTEC reconstruction of the model). Residents may be aware of the general drainage patterns on the island. Several culverts beneath main pathways direct both run-off and groundwater seeps in these depressed areas along the north and northwest sides of the island, while such culverts are absent or rare on the south and southeast side of the island.

<u>Layer conditions:</u> MODFLOW requires that the modeler specify whether each layer will be confined or unconfined. Unconfined means that the pressure surface of the groundwater (the water table) lies below some confining unit elevation (a layer of very low hydraulic conductivity). In the shallow surface, usually there is no confining unit present and in MODFLOW, only layer 1 can be specified as water table. Lower layers, if there is no confining layer, may behave as if part of the unconfined water table unit. If so, the model does not produce different solutions to the equations of flow. However, if there are confining units present, then withdrawals of water may result in two distinctly different responses, initially a high head loss to flow rate, and later, when the head drops below the confined layer top elevation, there will be less head loss with the same flow rate. MODFLOW handles this by assigning a convertible status to the layer. In the MACTEC model, the uppermost layer 1 is unconfined, while the remaining layers are convertible. It is not known how RGGI may have assigned these conditions.

<u>Hydraulic conductivity:</u> Hydraulic conductivity (abbreviated as K) is often also referred to as the permeability of a water bearing unit. The higher the K value, the easier it is for water to move through it. Sands and gravels have high K values, while silts, clays, tills and bedrock usually have low K. RGGIs assigned K values are only an approximation, and could vary quite widely from point to point across the island.

Henri Darcy showed that the rate of flow of water per unit area was equal to the K of the material, and the hydraulic gradient he applied across his test apparatus. A third factor in the productivity of an aquifer is its thickness. The thickness and K of the aquifer are combined as the product of the K and thickness to yield a quantity called the transmissivity of the aquifer. RGGI has indicated two bedrock K zones, a lower K zone in the center of the island, and a second, higher K zone around the perimeter. He cites these as 1.2 and 2.4 square feet per day, indicating a fairly low hydraulic conductivity. It is not clear in the model report if he actually included an area of soil in his layer 1, which would have a much higher K, but unspecified. MACTEC believes he did, but the areal extent of this zone is not known. He did, however, indicate areas on the island that he inferred had a soil cover greater than 5 feet. MACTEC's reconnaissance visit to the island would infer that such soil zones may be more extensive.

<u>Anisotropy:</u> Geologic processes in acting on rock and soil, often produce anisotropy, that is, the aquifer material is more conductive in one direction than another. In a horizontal sense, this is quite frequently the case in bedrock. RGGI, based on knowledge of regional bedrock, and observations on the island, concluded that there was likely to be anisotropy in the bedrock, and assigned a value of 10 to 1 (10:1) for this factor. It is for this reason that the model is aligned along the major and minor island axes. The value of 10:1 is a generally accepted starting point for modeling, however, the true value would not be known without pumping tests, and may vary across the island.

Recharge: Recharge is defined as that portion of the precipitation that eventually percolates through the unsaturated zone and into the groundwater table. RGGI defined two zones (areas where the same parameter value is assigned) of recharge across the island based mainly on Gerber's interpretation of the zones where 5 feet or more (6.45 inches per year recharge applied) or less than 5 feet (2.15 inches per year recharge applied) of soil are present. This is a simplification, as types and extent of vegetation, slopes, and local drainages will affect this. However, it establishes a reasonable total water balance for the island of about 22 to 23 gallons per minute on average over the year. In the transient simulations, he later subdivides this based on average precitipation records for Portland into 12 monthly rates (not specified, but calculable), with conservatively no recharge allowed during the summer when water use is greatest.

Storage coefficient, specific yield and porosity: Porosity refers to the total void space in the aquifer that can be filled with water. When the water table is drawn down, for example, by pumping, then the water given up by the aquifer matrix is usually less than the total porosity. Very high-K materials like coarse sands and gravels may give up most of their water, but low-K aquifer materials, like silts and clays, will give up only a small portion of their water. In confined units, the storage coefficients represent the small amount of water released as the pressure on the aquifer is decreased, at least until the aquifer layer becomes unconfined and the specific yield becomes the factor. Storage coefficients are not needed for steady-state models as the porosity and storage coefficients only determine how rapidly one approaches the steady-state condition.

Dispersivity: In modeling the movement of contaminants through the subsurface, it is often noted that contaminants appear to spread out wider than the average groundwater flow conditions would indicate. This is due to small scale variations in aquifer conditions, and, in this case, in the fractured nature of the bedrock) aquifer. These variations from the average conditions are captured in a term called the dispersivity. Dispersion can occur in all three dimensions, so a factor is specified in each of the two horizontal and one vertical directions. The values used in the RGGI model were not specified, and, even if specified, would only be estimates of what the true dispersion might be. In modeling, unless there is some specific set of observed concentrations that can be calibrated to, a sensitivity analysis is usually conducted to see the sensitivity of the interpreted results to variations in this parameter. In MACTEC's reconstruction of the model, we have assigned dispersivity values that appear reasonable and to produce results akin to those shown by the RGGI model.

Schedule of water supplies and waste water disposals: In the 1991 report, RGGI prepared a table of well water and rain barrel use with estimates of daily use and return of waste water to the ground (assuming a 90 percent return of water withdrawn from the aquifer). This table was updated in the 1995 report. Note that RGGI has also assumed that the water withdrawn from the aquifer at each well occurs within one specified layer. Except for dug wells which draw from Layer 1, the principal layer is layer 5, 100 to 200 feet below ground surface. Well logs may, indeed, indicate that this is the main water producing interval, but some contribution would be expected all along the open borehole or screened interval.

The structure of the model is presented graphically in Figures 1 through 3. Figure 1 shows the domain of the model with the RGGI finite-difference grid overlain, and also the boundary conditions (constant heads and drains) specified in model layer 1. In model layer 6, a no-flow boundary replaces the constant head which is carried down through layer 5, and drains were applied only in layer 1. Figure 2 shows zones of hydraulic conductivity assigned to the bedrock; the extents of these zones are estimated based on figures in the RGGI report, but involves some judgment as to assigning values to some blocks since his interpretation of extent only partially overlaps some blocks in the finite-element grid. Figure 3 shows the two zones of recharge assigned over the island. As noted above, these zones roughly correspond to the RGGI interpretation of where soil thickness may be greater than 5 feet, where greater recharge is allowed, and where soil cover is less than 5 feet, where the lesser recharge rate is applied.

2.1.3 Flow Model Calibration

Model calibration is the process of adjusting model parameters and boundary conditions to achieve a match to some pre-specified target. For RGGI, this target was a set of water level measurements made probably in 1990 or 1991, in wells at 28 locations about the island. He then adjusted mainly the recharge and hydraulic conductivity to make the model agree with these observed water levels as well as possible within the constraints of the interpretations. For MACTEC, the targets are these same water levels, but also the head contours that resulted from the prior modeling as presented in RGGI's 1991 report. To the extent possible, MACTEC utilized the same parameter values as specified in the RGGI report, but uncertainties in what RGGI actually assigned in his model for some parameters and conditions provides for some slight deviation from these inputs.

Evaluation of calibration is part judgment – do the resultant contours make sense – and part mathematical. The mathematical part is termed analysis of residuals. A residual is the difference between the model prediction and the observed value. Common statistics applied to these residuals involves calculating the average (mean) of these values, the absolute mean difference (the average of the magnitudes of the residuals), the sum of the squares of the residuals (SSR), the closely related standard deviation (assuming them to be randomly distributed about the mean), and the ratio of the standard deviation of the residuals to the range of head difference across the model. Another telling process in residuals analysis is to plot the computer generated heads against the observed values; if the model is a perfect fit, then the points plotted should lie along a 45-degree slope line. While this ideal may be approached with some simple hydrogeologic systems, usually the real world is not so simple, especially where fractured rock systems are involved. Desirable results for the point-wise fit residuals analysis would have the mean close to zero, the absolute mean and standard deviation also as small as possible, and the ratio of standard deviation to range of heads being less than 0.1.

For RGGI's steady-state flow model, the assumption is made that the target water level data represent the average water level conditions across the island for the year. Thus recharge is specified as constant across the model. The summary residuals analysis for RGGI's steady-state model as compared to the MACTEC model are presented in Table 2, while a complete listing of residuals is contained in Attachment A. Note that in RGGI's analysis, the residual is defined as the model head minus the observed, while in Groundwater Vistas, the residual is defined as observed minus model. We have reversed the signs on RGGI's residuals analysis where appropriate (it only matters for computing the mean) to facilitate comparison in Table 2.

Figure 4 shows the plot of the computed to the observed water levels.

The approximate nature of the residuals analysis should be emphasized. Water levels for calibration were obtained by measuring the depth to water from a reference elevation that was approximated from a topographic map (source not given). MACTEC also estimated elevations from the USGS map, and found that several of the approximate elevations at estimated well locations disagreed as much as several feet. Thus the water levels at any location may be good only to plus/minus a couple of feet. One of MACTEC's recommendations to improve the model would be to survey in these locations and a few others to improve the accuracy of the target data set. Since one goal was to first reconstruct the RGGI model as closely as possible, we have retained the target water levels as presented by RGGI. However, it should be noted that, due to the limited detail in Gerber's reports relative to the model, many model input parameter values have necessarily been selected by MACTEC based on best modeling judgement.

In comparing the RGGI model head contours to those provided by MACTEC's model, two figures were prepared. Figure 6 shows the RGGI model contoured heads in model Layer 1 superimposed over the same base map MACTEC has used for the reconstructed model, while Figure 5 shows the MACTEC model results, both for Layer 1. Due to the steep hydraulic gradient on the ocean side of the island, small variations in head contour location may be associated with relatively large residuals. However, the general flow directions are the same in each model. The only apparent differences are related to locations near the crest of the island and associated with the USGS-interpreted 40-foot topographic contour. MACTEC has assigned drain node elevations based on the USGS contours to keep the model computed heads close to ground surface in these locations, whereas the RGGI model shows heads considerably above ground surface in these areas. Given the uncertainty about the true ground surface elevations, either may be correct; however, given the lack of source for RGGI's topographic assignment versus the USGS contours, we have greater confidence in the USGS interpretations. These slight differences do not appreciably alter the conclusions of the transport modeling.

2.1.4 Island Water Balance

Another check on the comparability of the two models is RGGI's estimate of total recharge to the island. Based on an estimated area for the island and an assumed average annual recharge rate, RGGI estimated a total average recharge rate to the island of about 23 gallons per minute. The rate as contained in his model was not specified. The average rate as contained in the MACTEC reconstruction is 22.6 gpm; this rate should be the same as RGGI's model since it is based on the same grid area and recharge rates. Interestingly, if one calculates the difference between the withdrawals and recharges of waste water to the island over the summer months as contained in Table 1 of RGGI's 1995 report, the difference is a net loss of only about 0.3 gpm over the summer months. Based on these estimates, the water inventory for the island in 1995 was certainly well balanced. The decline in the water table over the summer months is then largely due to the lack of recharge and the natural flow of island groundwater to the ocean. In the MACTEC model, flow to the drains as expressions of seepage to the ground surface amounted to about 3.5 gpm. The comparable loss of water in RGGI's model is not known. Evidence of this loss is apparent in flows in drainage ways that residents may observe where these cross paths in culverts. The flow in these ditches is a combination of storm water run-off and groundwater seepage (also called base flow).

2.1.5 Transport Model Calibration

In essence, there is no true calibration to waste constituents in groundwater as data are largely lacking to perform this type of calibration. What is known is that for a few wells which have been analyzed, there is little evidence of impact to water supply wells tested as of 1995. The model is used (using the MT3DMS adjunct to MODFLOW) to help evaluate those areas potentially at risk to future conditions. RGGI assigned a nominal 100 value as the concentration for waste water recharge locations. We interpret from the report that RGGI had all wells and returns operating for the three summer months as a conservative measure, and that recharge and well rates were assigned in the model on a monthly basis). The results of the modeling after a transient run period of over 7 years to allow concentrations to approach their final levels could then be interpreted as a percent of the initial concentration. However, it should be recognized that each individual recharge location would have its own signature. The main addition to the modeling process is the establishment of monthly recharge rates and running the transient flow model and transport model for a period of about 8 years to approach equilibrium. While transient recharge rates were incorrectly labeled on a graph in RGGI's 1991 report, MACTEC recalculated the proper rates for each monthly period. MACTEC also set up the reconstructed transport model to allow for up to 10 years of simulation in case proposed locations might require a slightly greater period of time to equilibrate. Note that the model cycles these rates from year to year rather than use past records, as future conditions of precipitation are not known. Figure 7 shows the dug wells and recharge locations in model Layer 1, while Figures 8 through 12 show the water supply wells in model Layers 2 through 6.

The results of the transport modeling are not entirely consistent between RGGI's 1991 and 1995 modeling. In the 1991 modeling report, he generally shows larger zones of potential impact at higher potential concentrations for fewer recharge locations than the results in the 1995 report, where he just shows results for an unspecified (layer) "shallow" and "deep" groundwater. The outputs MACTEC determined from the reconstructed model are shown for each model layer (concentrations starting at 1 and at a contour interval of 4 units) in Figures 13 to 18.

MACTEC conducted multiple runs of the transport model as a basis for returning to the flow model to make adjustments that would more closely reflect the RGGI transport model runs. The uncertainties in several of the flow model and transport model parameter values make this exceedingly difficult to accomplish. However, the resultant model produces similar areas of potential concern as the RGGI model, and is considered to be an equivalently useful tool for evaluating potential impacts for future development. This model then becomes the basis for further refinement under the next task item of this modeling project.

Table 3 shows the model parameter values used in the final model.

2.1.6 Conservatism in the Transport Model

While the groundwater flow model shows the general direction of flow of a contaminant dissolved in groundwater, there are several processes that can act on how quickly that contaminant moves, and at what concentration it will be present at as it moves along the migration pathway. The four main processes that determine these in a transport model are dispersion, sorption, dilution and degradation.
Dispersion is a measure of how a plume spreads as it migrates downgradient. Dispersion is a product of shifts in groundwater flow direction which may result from seasonal variations in recharge and groundwater boundary conditions (like wells turning on and off, or groundwater intersecting the ground surface in wet weather). The dispersion can take place longitudinally (in the direction of flow), laterally (it spreads wider), and vertically (it spreads up and down). Dispersion of a plume is designated in a transport model by assigning a dispersivity value. MACTEC has used values for dispersivity which appear reasonable and are in agreement with recommended ranges. However, the dispersivity is only an approximation, and actual plume spreading will vary from location to location. Typically, values of dispersion are lower in bedrock (where flow is confined mainly to specific fractures) than it is in soil overlying rock. Dispersion will also be more apparent where there are few waste returns to groundwater than where there are many contributing sources.

Sorption occurs where the soil (or organic carbon in the soil) has an affinity for the particular contaminant. Some very soluble constituents, such as nitrates or chlorides, are sorbed very weakly to soil, and even less so to rock. These travel along at the same rate as the groundwater. Some constituents, such as pesticides (used here only as an example) are strongly attached to organic carbon in soil and are sorbed strongly. These migrate very slowly compared to the rate of groundwater movement, and also, due to their affinity for sorbing to soil, have relatively low concentrations in groundwater.

Dilution occurs when the contaminated water mixes with clean water. This can happen when clean water percolates down into the aquifer into areas where contaminants are present. The two can mix, resulting in a lowering of the concentrations. This is less likely to happen in a fractured bedrock setting where flow is mainly confined to individual fractures than in soil, where such mixing could occur.

Finally, some contaminants can degrade biologically. This is what happens in septic systems, where bacteria can reduce the organic content of wastes and actually purify the water. This takes time and depends on the presence of the right conditions for the bacteria and their food source. Where groundwater or the contaminants move slowly, the bacteria have more time to accomplish their job, and for small sources, the contaminant downgradient extent of a plume from any one waste source may become stationary. For multiple sources, the picture becomes more complex, and a model is a good way to explore what may happen.

For this model, MACTEC has assumed some dispersion consistent with experience, and the dilution that occurs as a result of mixing happens within the model naturally. MACTEC, however, has assumed no sorption, since several constituents of concern, such as nitrates and chlorides do not sorb appreciably, especially in fractured rock. MACTEC has also assumed no degradation. While some of the organic wastes will degrade, and some researchers suggest this may happen within a couple hundred feet of the source, some wastes will not degrade, such as chloride. Unless site-specific data are available with which to calibrate a transport model to and to evaluate and prove degradation, it is usually more prudent to assume no degradation until this can be definitively shown to occur with predictability.

2.2 MODEL REVISIONS TO ALLOW LOT-BY-LOT EVALUATIONS

With the basic steady-state model re-established, MACTEC then refined the model so that it could be used to evaluate potential water quality problems on a lot-by-lot basis. This revision to the model entailed 6 steps: 1) replacing the previous coarse model grid with a finer, uniform 20-by-20-foot grid spacing to allow more accurate location of wells and waste water returns; 2) importing ground surface again to take advantage of the finer mesh; 3) refining the zones to conform more to the interpreted extents shown in the 1991 RGGI report; 4) revising the locations of the target head locations based on the refined grid; 5) running the model to make sure it produced comparable results to the coarser grid model; and 6) making adjustments as necessary to improve the calibration. MACTEC first refined a steady-state version to be able to compare the point-wise statistics; made adjustments to that model; and then converted this into a transient model to allow evaluation of potential impacts to the Bustins Island groundwater supply.

The new grid and refinements of the boundary condition locations are shown on Figure 19. The results of the new model run showed it to vary from the coarser grid model due to refinement of zones of recharge, hydraulic conductivity and the representation of the boundary conditions. The new refined model was adjusted to improve the fit and to provide closer agreement with the heads derived for the reconstructed coarse grid steady-state model. This also included relocating the target well locations based on the plotted locations shown in RGGI's 1991 report. (Some locations, e.g., well 61, were shown to be incorrectly located, while 3 wells were duplicated.) Summary point-wise statistics for the new model are also shown on Table 2 (complete residuals analysis is contained in Attachment A). The model-generated head contours for model Layer 1 are shown on Figure 20 for comparison to Figure 5. Relocating wells and recharge areas within the new model is one aspect of the recommended Data Gathering Plan (see Section 3.0) and future model updates.

During this phase, MACTEC attempted to bring in the most recent version of the survey map for the island. This map includes lot boundaries and would be an ideal base map for the model. However, when the map was imported into Groundwater Vistas, there was a significant discrepancy, mainly in the length of the island, between the survey map and the island outline in the RGGI model (see Figure 21). This discrepancy prevented the simple overlay of the model grid onto the survey map. One of the recommendations is to resolve this discrepancy so that either the map may be adjusted, or the model grid and boundary conditions redefined.

Following recalibration of the steady-state refined grid model, the adjusted parameter values were applied in the transient transport version. Transport parameter values (mainly for dispersivity) were retained as in the previous transient model.

3.0 DATA GATHERING PLAN AND OTHER RECOMMENDATIONS

The major assumptions in reconstructing the groundwater flow model remain as they were with RGGI's model construction since there have been no new data collected in the interim. The basis of the model lies in the assumption of a reasonable recharge rate, identification of approximate areas of similar hydraulic conductivity in the bedrock, and the calibration of the model (including optimization of values assigned for hydraulic conductivity) to a set of water level measurements that are only approximate. These data gaps and assumptions were necessary, lacking actual subsurface investigations and more detailed long-term observations of the water table response to seasonal and annual variations in precipitation/recharge events and water withdrawals and returns.

This section presents some proposed data gather activities which should allow for improvement of the model in its future use for evaluating impacts on present and future water supplies. Suggested data gathering activities include, in order of importance:

Very important:
- Update and maintain water use inventories (i.e., update RGGI's 1995 Table 1)
- Accurate elevation survey of wells used for water level measurements
- Establish elevations at key locations, e.g. at suspected depressions/swales where groundwater may be present at ground surface, and also at fire ponds

Important:
- Use a Global Positioning System unit to establish more accurate location of wells, or locate on a map relative to lot corner markers. This information can be entered into and preserved within the model preprocessor.
- Collection of water level data at monthly interval during the summer

Useful:
- Compilation of well installation diagrams, existing or new
- Establish some v-notch weirs at culvert crossing locations; collect data regularly, but especially after storm events or periods of extended good weather
- Compile records of precipitation

These are discussed further in the following subsections.

MACTEC has not recommended slug or pumping tests in existing wells to determine hydraulic conductivity values since these tests can be an expensive undertaking. However, if BIVC desires to have the model be more than a useful assessment tool (e.g., to withstand legal challenge), then these types of tests, in addition to evaluations of contaminant concentration distribution, with perhaps additional borings and monitoring wells, would have to be made.

3.1 Update and Maintain Water Use Inventories

The inventory compiled by RGGI in the 1995 report (Table 1 of that report) should be updated and maintained as a basis for refining the model and bringing it up to date relative to the 1995 schedule of use which is included in the model presented herein. The combination of refined grid and more accurate locations should allow for a more reliable assessment tool. The balance between withdrawals and recharge of waste water should be tracked to provide an early warning of trends that might threaten the water supply. This can be viewed as a database to be maintained and updated in a spreadsheet format.

3.2 ESTABLISH ACCURATE SURVEY ELEVATIONS FOR WATER LEVEL MEASUREMENTS

Accurate survey elevations for reference elevations are needed to improve the accuracy of the model. The USGS map suggests there is an established bench mark at the northern end of the island. If this is not so, or the marker is lost or destroyed, then some reference marker can be established relative to tide, i.e., to attempt to establish this benchmark relative to mean sea level. This, if needed, would likely lower the absolute error in the measurements at any location, and used to establish elevations for the measurement locations would eliminate the error between wells. In addition, some key low-point elevations at drainage locations should be established. These can be located mainly along existing paths, or relatively open areas within the wooded section, so that no brush clearing is necessary. These locations can be marked and located coordinate-wise with a GPS unit. This should be coordinated with the island's surveyor.

3.3 MORE ACCURATELY LOCATE WELLS/RECHARGE AREAS

The RGGI report includes coordinates for a few wells, but the source of this information is not specified. In most instances (especially for Table 1 of the 1995) report, and for the location of the target water level well locations (Table 2 of the 1991 report), RGGI just identifies the row, column and layer in which the point is located. In about 9 instances, two wells or recharge areas fell within the same block and required combining. In MODFLOW, the locations of sinks are assumed to be at the center of the grid block. Hence, where grid blocks are 50 feet, the well could be up to 25 feet misplaced, and where the blocks are 100 feet (at the mid to northern end of the island), the wells could be as much as 50 feet off. Refining the grid spacing to 20 feet implies that wells could be positioned within 10 feet of their true location as long as the wells can be located accurately on the ground. This can be done with Global Positioning System units, or by measuring off locations relative to lot corners and marking them on a map. This information can then be transferred into the model preprocessor. Resolution of the base map problem identified by MACTEC would also allow easier positioning or conformation of locations in the model (see Section 3.7).

3.4 COLLECTION OF WATER LEVEL DATA AT MONTHLY INTERVALS

The RGGI reports indicate that several residents volunteered to have water level measurements performed in their wells over a period from 1991 to 1994. Water level data provide information with which to calibrate the steady-state model and obtain an idea of seasonal variations. When collected for a number of years, the data can also be subjected to trend analysis to observe if any long-term trends in water levels are apparent on the island, and in which sections. Some of the wells where water levels were measured by residents were available for measurement from April to October, but the important period for most wells is the summer season, June1 to September 1. Depth to groundwater within the well can be measured by "plopper" and tape from a reference elevation established for the well. RGGI presented a procedure for doing this in his 1995 report. In the past, the reference elevation was established by assuming ground surface elevations (source of topographic references unknown); but further refinement of the understanding of groundwater flow really rests on being able to improve on the accuracy of these measurements, i.e., establishing accurate reference elevations for the measurements. The results of the measurements should be kept in an electronic spreadsheet.

3.5 COMPILE WELL INSTALLATION DIAGRAMS OR BORING LOGS

Boring logs and well installation diagrams generally provide much needed information on both the geology encountered, and the intervals in which water yields were greatest, i.e., the principal water-producing fractures. In addition, the depth to bedrock and a general description of the soils encountered provide additional important information that can be used to refine the thickness of layer 1 in the model and define areas of soil that may behave differently than the shallow bedrock. BIVC should (if they do not already have this information) compile available well logs and require that owners of any new wells installed should provide a copy of the well log. In addition, if any relatively deep excavations are performed on the island that encounter bedrock, the location of the excavation on the depth to rock should be recorded and logged.

3.6 DRAINAGE FLOW MEASUREMENT AND PRECIPITATION EVENTS

During periods of low precipitation flow to some drainage ways may still be noted. This is called base flow, and can be used to help calibrate the model as well as to provide general information relative to the hydrogeology of the island. Measurement of flow during or shortly following storm events may provide additional data and further the understanding of the groundwater and surface run-off patterns on the island. To collect these drainage flow data, some V-notch weirs can be constructed from plywood and installed at culvert locations. Estimation of flow rates can be made by establishing a rating curve so that only a measurement of height above the V-notch bottom needs to be made, or a bucket and stopwatch can be used. These data would be collected in a spreadsheet. The island may maintain a rain gauge to provide precipitation data during the summer months while daily precipitation records from Portland can be downloaded for other times, and entered into the spreadsheets to enhance the record and interpretation of measurements. These types of activities might be set up to involve some of the youngsters as a summer project.

3.7 OTHER RECOMMENDATIONS

The discrepancy (about 200 feet in the length of the island) between the Bustins Island outline used in the RGGI model and the survey map of the island should be resolved. It would be extremely useful to be able to utilize the survey map, complete with lot property lines and identifications as a base map in the model. If it turns out that the survey map is correct, then the model may have to be revised in order for the boundary conditions and well locations to be properly located in the model. The true length of the island can be checked with additional GPS unit data. Coordinates of locations corresponding to identified features, such as wharfs, USGS markers or lot corner markers may provide the information necessary.

The model uses an assumed origin for the grid, and features on the island are located relative to this arbitrary coordinate system. If GPS is used, then real world coordinates will be obtained. Relating these two systems and conversions between the two systems may become necessary. Real coordinates can be imposed over the survey map (if this is true or can be adjusted) and this coordinate system imported into the model. This, again, would simplify locating the positions of existing or proposed well or waste water discharge locations.

4.0 CONSIDERATIONS OF THE SALTWATER INTERFACE ON ISLAND WATER SUPPLY QUALITY

RGGI presented an adequate discussion of the potentials for salt-water intrusion into the zone of water supply pumping for Bustins Island in his reports. The model is not capable of defining this interface with any great degree of accuracy due to the complex nature of the fractured rock aquifer. In order to construct a model capable of approximating the real interactions, hundreds of thousands of dollars would have to be spent in order to begin to adequately characterize the true nature of the fracture patterns over such a large area, and an expensive proprietary model code would have to be utilized. Under conditions of an ideal, homogeneous porous aquifer, the rule of 40 applies (the Ghyben-Hertzberg relationship), i.e., that the saltwater interface will reside at a depth below sea level of 40 times the head of fresh water above sea level. For example, if the height of the water table at some location is 10 feet above mean sea level, then the elevation of the saltwater interface with the freshwater collecting above it would be approximately 400 feet below mean sea level. The model is 300 feet thick at the edge of the island. Therefore, where the height of water in the well is greater than 7.5 feet above sea level, which occurs not too far inland around the perimeter of the island, then the salt water interface would be expected to be below the bottom of the model. At the center of the island, where groundwater heads exceed 50 feet above sea level, the saltwater interface would be at a depth of 2000 feet, again if aquifer conditions were ideal and homogeneous.

The fractured nature of the bedrock aquifer makes the situation much more complex. The principal water yielding fractures in bedrock in Maine typically tend to decrease with depth, which is probably why RGGI selected a maximum depth of 300 feet for the model in addition to the fact that most Bustins Island water supply wells do not penetrate below ground surface more than 300 feet. The greatest potential for salt-water intrusion for impacting Bustins Island water supply wells probably lies in lateral migration from fracture sets that extend out beneath the ocean. However, only one well was identified (the Carr well) in the RGGI reports that appears to be connected well enough to such a fracture set that it reflects tidal patterns in the water level in the well (this does not mean that it is likely that this well will be impacted by salt water, only that it is better connected than others investigated). [In the interim, BIVC notes that a couple of wells have since reported having problems with salinity. These were located on the west side and southern end of the island.] However, in order for wells to be able to draw in seawater, they have to create drawdowns that would be substantially below sea level, be very close to the edge of the island, and the withdrawal rates would have to be much greater than the local recharge could supply.

RGGI recommended that new wells be installed no closer than 200 feet to the edge of the island as a precaution. Most island wells would seem not to be in any immediate threat of salt-water intrusion, particularly since the water balance is so close, even in summer, and the island water supply has time to recover during the off-season. Also, the daily use rate for most wells on the island is small, and this amount of water withdrawn daily is easily supplied by well borehole storage. For example, withdrawal of 40 gallons at a time only lowers the water level in a 6-inch diameter well by 27 feet. From information in RGGI reports, the recovery rate for a typical well is fairly rapid, so excessive drawdowns should not occur. From MACTEC's observations of the bedrock on the island, it would also seem that wells on the west side and north and south ends of the island would be at greater risk since the dip of bedrock is generally to the southeast for islands in Casco Bay. Since groundwater often flows through bedding plane fractures more easily than in vertical fractures, fractures intercepted by wells on the west side of the island may be rising toward the ocean and daylight in sea water. Whether they do or not depends on the fracture set that the well intersects, and whether those fractures are open to intrusion from the sea.

Periodic checks of salinity in wells, however, is not a bad precaution, particularly if there is a trend of increasing water usage and/or the estimated difference between withdrawal and return widens. A salinity meter is not an expensive investment, and salinity measurements could be made a part of the monitoring program for select well water samples. Periodic water level measurements, particularly for wells that recharge slowly, may indicate if there is a tendency or risk for excessive drawdown in a well.

5.0 LIMITATIONS OF THE MODEL

A model is a simplification of the actual hydrogeologic system. At best it contains as much information as is known about the system and conforms to some conceptual model the modeler or hydrogeologist has about how groundwater moves and is controlled. Although RGGI made a reasonable survey of the known information and gathered additional data, no extensive subsurface investigations were available or made to provide data with which to provide better estimates of the input parameters or their distributions in the model. Many of the input values in the model were assumed and/or adjusted during calibration. In addition, as we have seen, there are uncertainties about the elevations used to calibrate and construct the model. For the transport model, wastewater returns were all assigned a nominal concentration of 100. In actuality, the concentration of each constituent, such as nitrates or chlorides, will vary at each location. The selection of concentration ranges such as 1 to 5, or 5 to 1, and greater than 10, are all arbitrary, and may not reflect correspondence to any known water quality criteria (i.e., drinking water standards).

This being said, a model which does reflect the known information and conforms to the conceptual model of groundwater flow provides the best available framework for answering questions concerning, or estimating responses to, changes in conditions or patterns of groundwater withdrawal and wastewater return.

However, the results of the modeling must be considered with the uncertainties in mind. Some of these uncertainties may be resolved through a sensitivity analysis in which uncertain model parameters are varied to create a range of probable outcomes. However, the best guide is to use the results of the modeling in combination with good common sense. E.g.,

- Groundwater supplies should be positioned upgradient or cross gradient of waste water discharges (however, a supply at depth may have some protection against shallow waste water returns).
- Positioning of new locations should consider the network of existing wells and waste water return locations.
- Deep water supplies should be situated as far back and at some minimum setback from the edge of the water (dug well supplies probably would not be affected by seawater intrusion).
- Plans for water use should strive to balance withdrawals and returns as much as possible.

ACRONYMS AND ABBREVIATIONS

Anisotropy	like grain in wood, soil and rock can be laid down or formed such that it is easier for water to flow in one direction than another. In rock, horizontal anisotropy is a common factor, whereas in soils, vertical anisotropy is more commonly considered.
Aquifer	a hydrogeology unit capable of conveying water and yielding usable quantities of water
Calibration	the process adjusting model parameters to certain target (observed) hydrogeologic conditions, such as water levels or flows from seeps
Conductance	an input parameter to the model; it indicates the ease with which groundwater will flow into, in this case, the drains representing the ground surface elevations (seepage at the ground surface)
Constant head	a type of boundary condition wherein the modeler assigns a head condition that never varies. In the steady-state Bustins Island model, a constant head is used to prescribe the mean sea level head of the ocean surrounding the island. The constant head is either an infinite source of sink to groundwater flow.
Drains	a type of boundary condition used in MODFLOW groundwater flow modeling that may represent actual drains or seepage face surface elevations that control the local aquifer water levels. The drain can only remove water from the model.
Ghyben-Hertzberg	freshwater recharging island aquifers tends to form a lens of freshwater over salt water. The interface between these is usually sharp. The Ghyben-Hertzberg principal locates this interface as at a depth below sea level equal to about 40 times the height of the watertable above sea level. Thus, if the water table is at 20 feet above sea level, the salt water interface would be expected to be at about 800 feet below sea level.
Head	used to describe the height (of water) above a reference datum (here mean sea level).
Hydraulic conductivity	K, a measure of the capacity of the soil or rock to convey water
Hydraulic gradient	i, the steepness of the head of water in the direction of flow. Together the hydraulic gradient, the hydraulic conductivity and the porosity determine how fast the water moves through the aquifer.
i	the hydraulic gradient
K	the hydraulic conductivity
Matrix	the solid part of the aquifer, either grains of sand or the mass of rock.

Net exchange rate	water is being withdrawn from the aquifer by wells, but is also being replenished with returns of water (e.g., grey water and septic systems). During summer, the potential recharge by rain is minimal due to plant uptake. The difference between withdrawal and return is the net exchange rate.
No-flow	another type of boundary condition assigned where the modeler believes no groundwater flow will cross.
Piezometric head	this is a general term for potential head or height of water, e.g., in a well. If the aquifer is unconfined, it is the water table head. If the aquifer is confined, then the piezometric head may be greater than the elevation of the bottom of the overlying confining unit (artesian). If the piezometric head is above ground surface (or above the top of the well), then the well is flowing.
Porosity	the void portion of the aquifer is the porosity.
Recharge	that portion of precipitation that infiltrates the soil (or rock) and becomes part of the aquifer. Recharge is typically the total precipitation less runoff less evaporation less water taken up and transpired by plants.
Specific yield	when a saturated unit volume of soil or rock is allowed to drain, not all of the water present in the pore space will drain away. The amount of water that will come out of storage is called the specific yield. It is a useful parameter when computing the rate of lowering of the water table when subjected to pumping stresses over short periods of time.
Steady-state	models are either steady-state or transient. In steady-state, inflows balance with outflows and no head changes occur in the model with time.
Storage coefficient	the decrease in water level per unit decrease in head for a confined aquifer. When aquifers are confined, the drawdowns are high relative to the well yield.
Stress period	a period of time in a model simulation when all properties and boundary conditions are constant
Time step	an increment of time specified in a simulation. In solving transient models, it is usual to specify several time steps for each stress period to allow for a smoother solution of the model equations.
Transient	the model conditions change with time; the model output is head values at each grid location for each specified time step and/or stress period.
Transmissivity	while the groundwater velocity is determined by the hydraulic conductivity, the hydraulic gradient and the porosity, the total water that the aquifer can produce also is dependent on the thickness of the

	aquifer. The transmissivity, T, is the product of K and the aquifer thickness, b.
Zone	a collection of adjoining grid elements in a model grid that share the same property, e.g., of K.

FIGURES

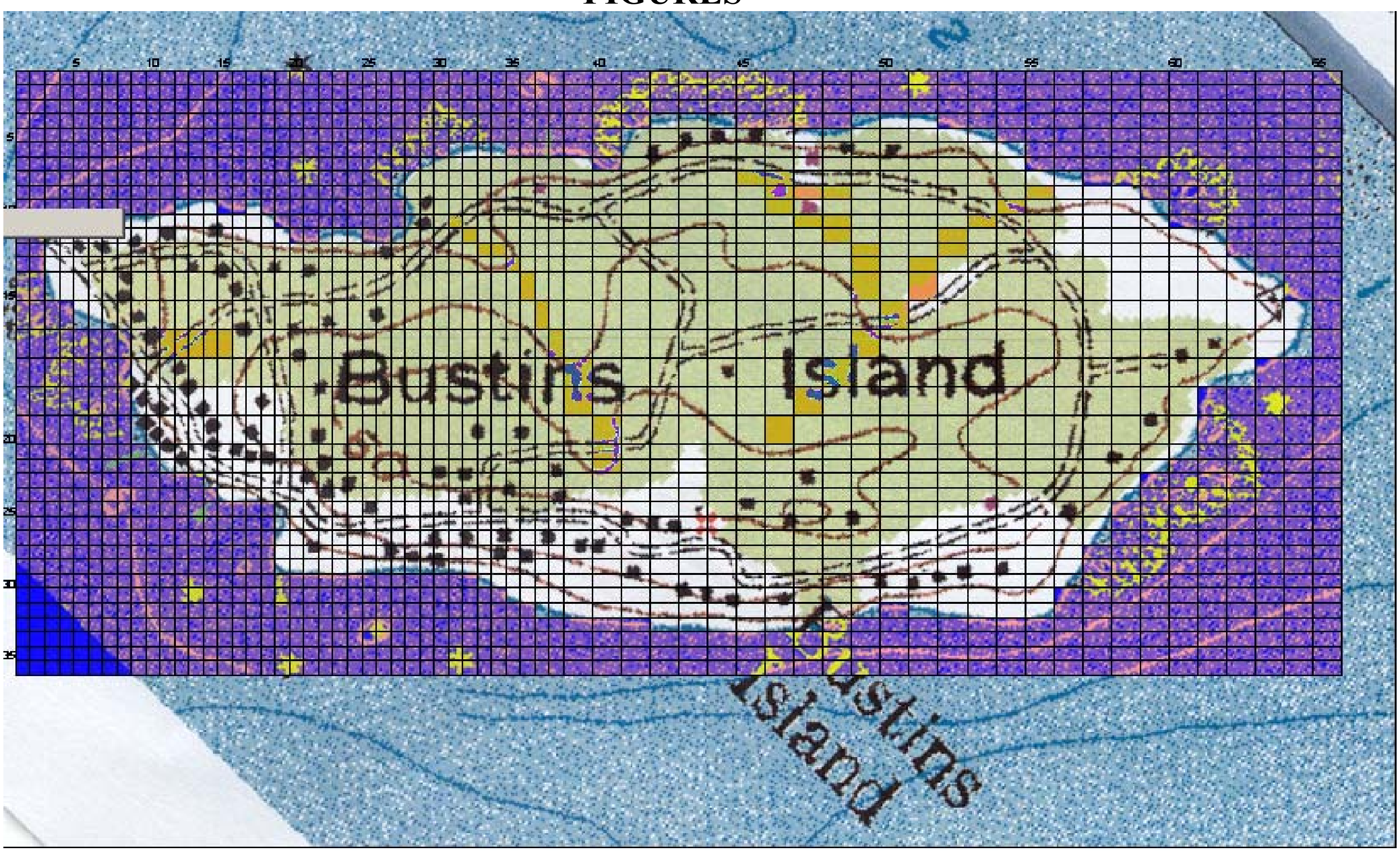

Figure 1: The model domain and grid matching the RGGI original model. Purple/blue shaded areas within the grid area are constant heads set at 0 ft mean sea level and extend down through Layers 1 through 5. Yellow blocks are drain nodes to represent areas where seepage of groundwater to the surface can occur in Layer 1, and also the potential influence of the fire ponds.

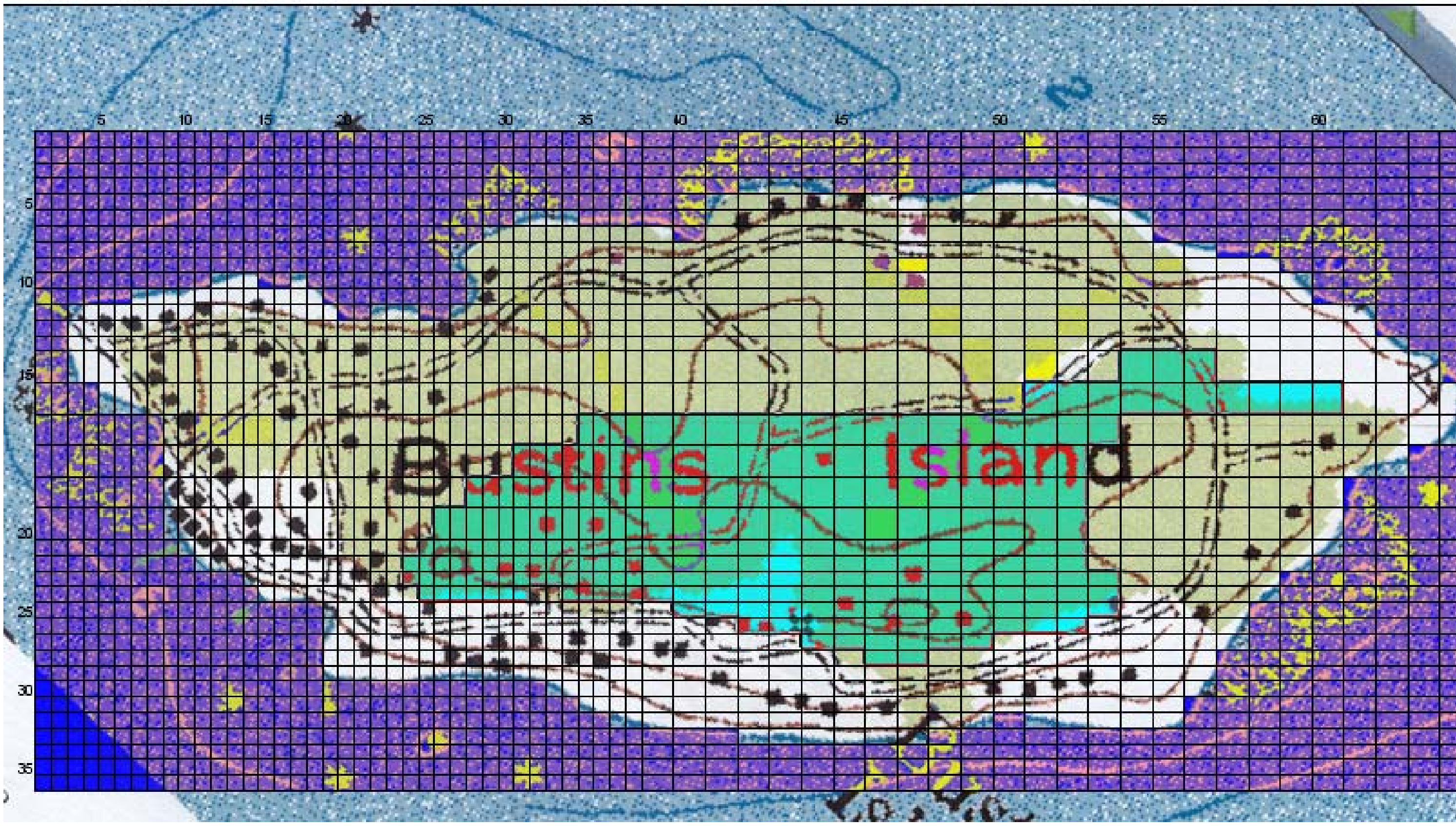

Figure 2: Zones of hydraulic conductivity for the bedrock. The green, low-K zone is surrounded by the higher K zone.

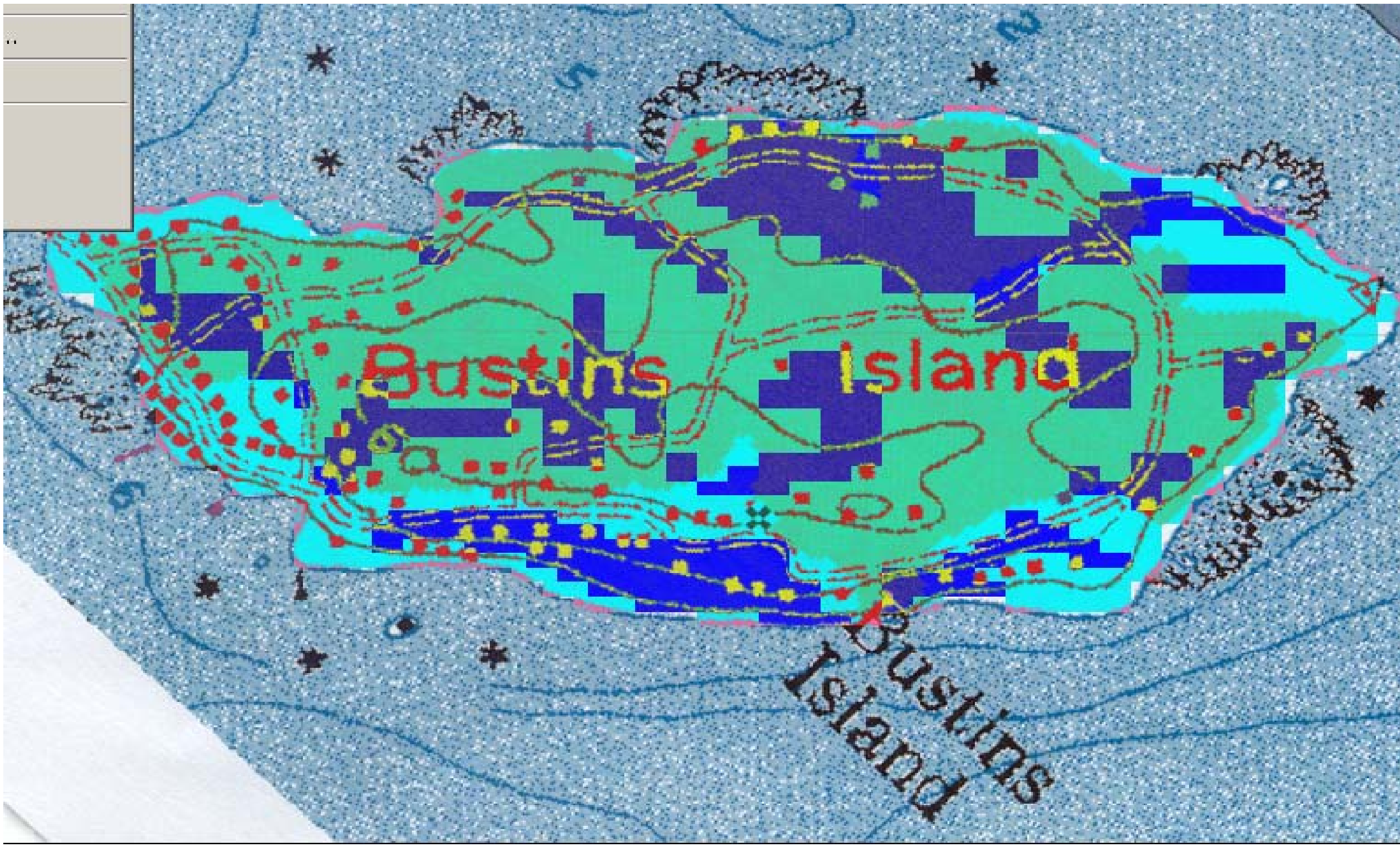

Figure 3: Recharge zones as specified in the RGGI model. Light blue and green areas, where soil cover was interpreted as less than 5 feet, accept 2.15 inches per year, while dark blue areas, where soil cover exceeds 5 feet, accept 6.45 inches per year. The total average recharge is about 22.6 gallons per minute.

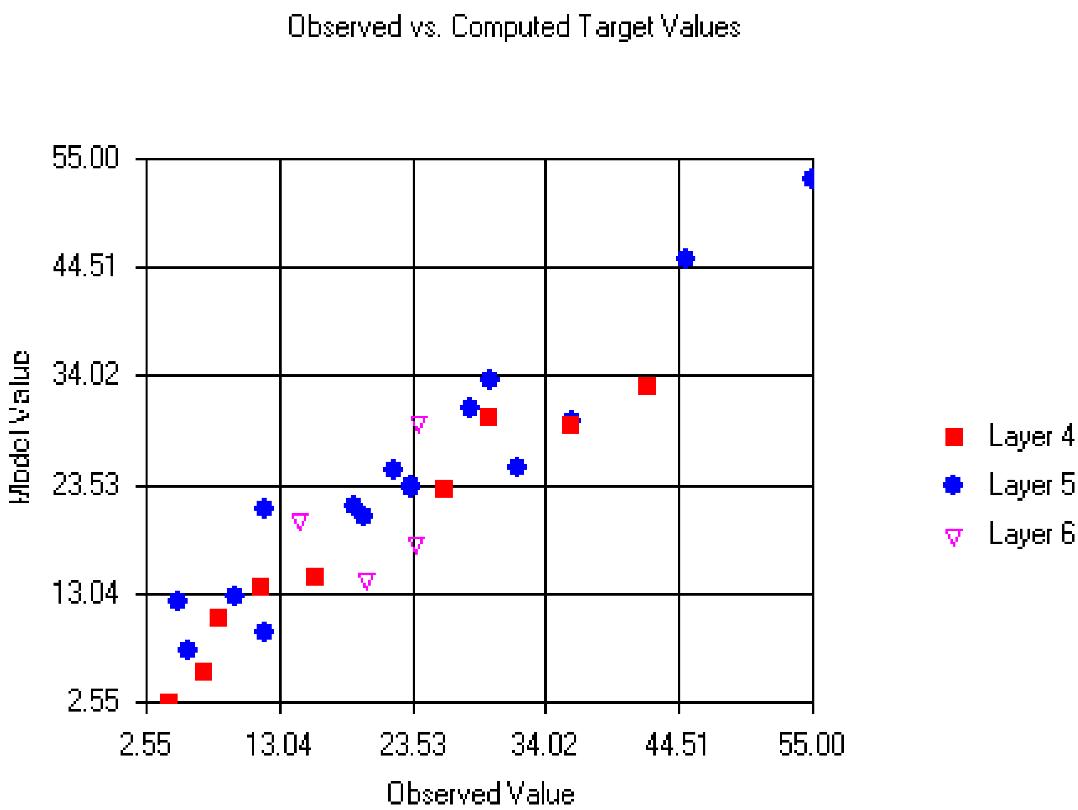

Figure 4: Plot of observed versus computed target values for the calibrated steady-state flow model

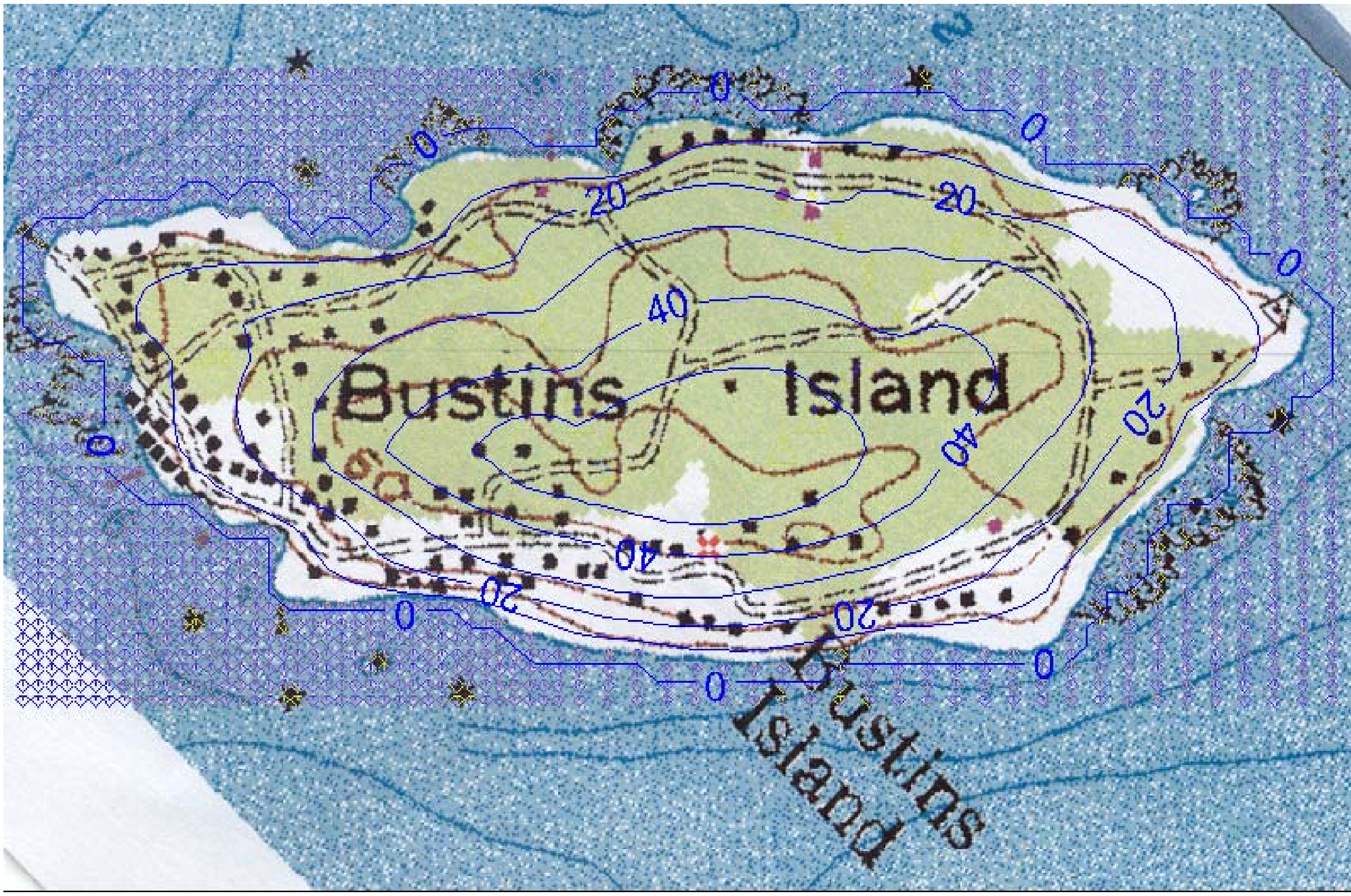

Figure 5: Head contours of calibrated reconstructed steady-state model.

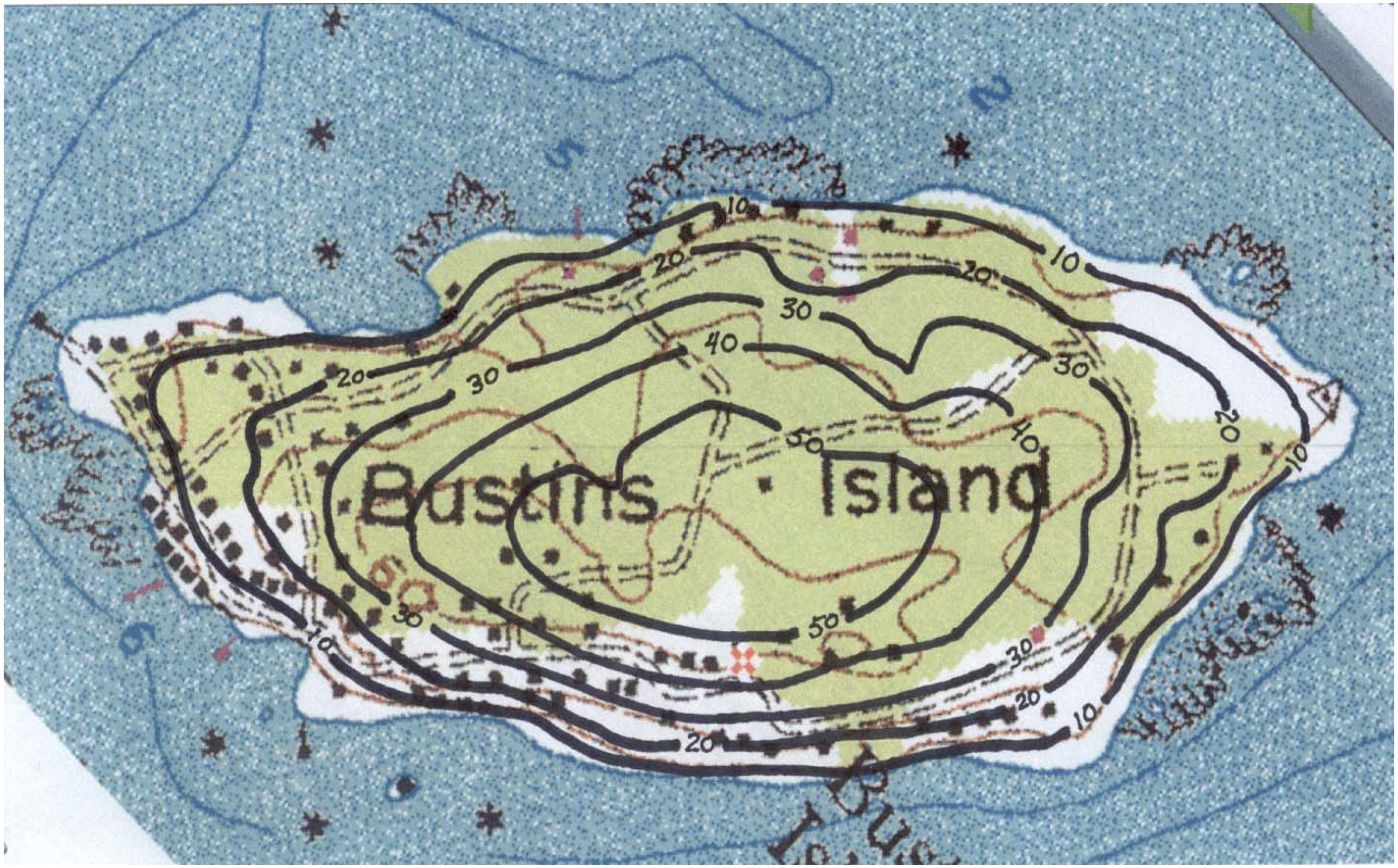

Figure 6: Head contours from the original RGGI steady-state model.

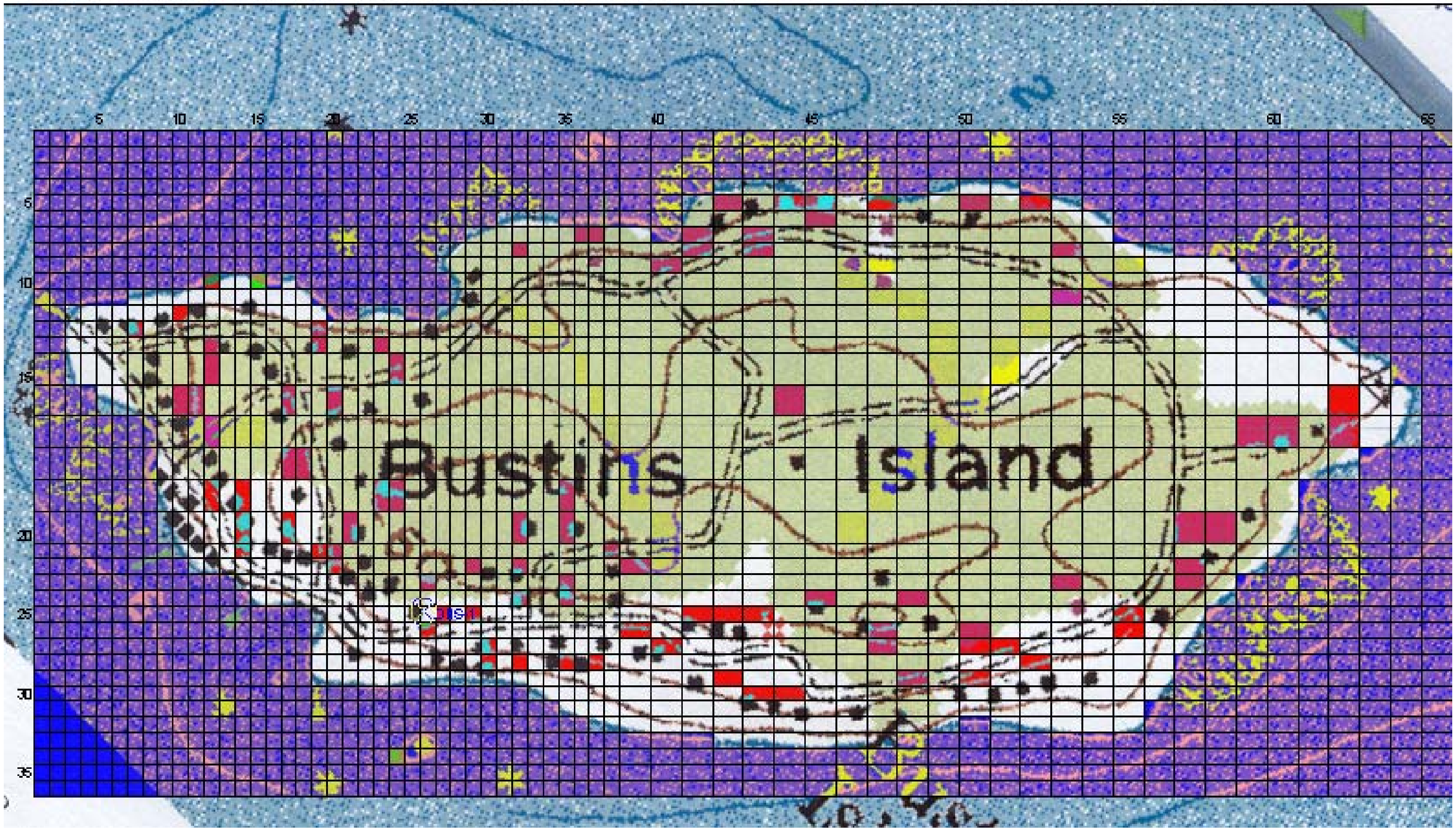

Figure 7: Location of dug wells and waste water returns in model Layer 1.

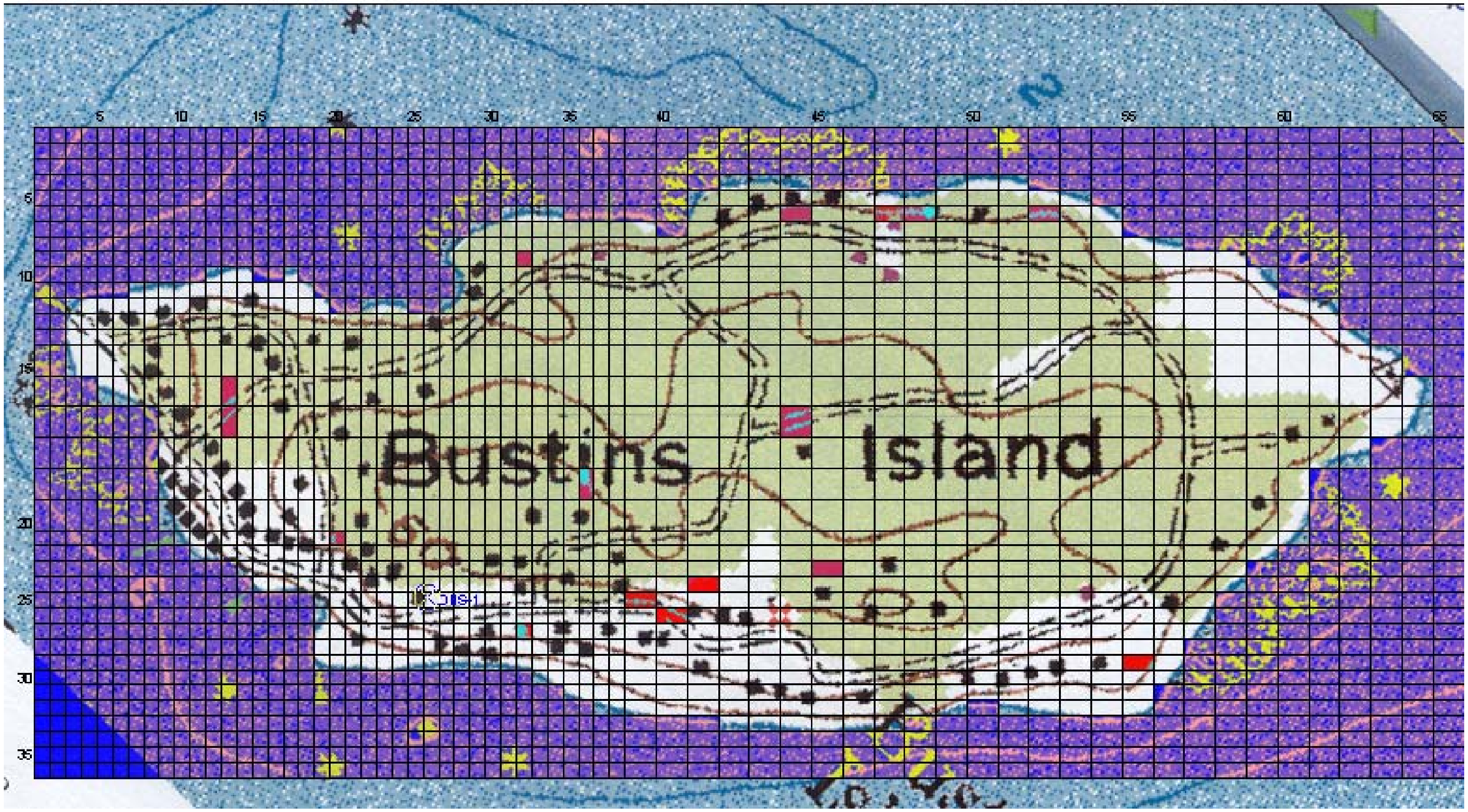

Figure 8: Location of wells assigned to model Layer 2.

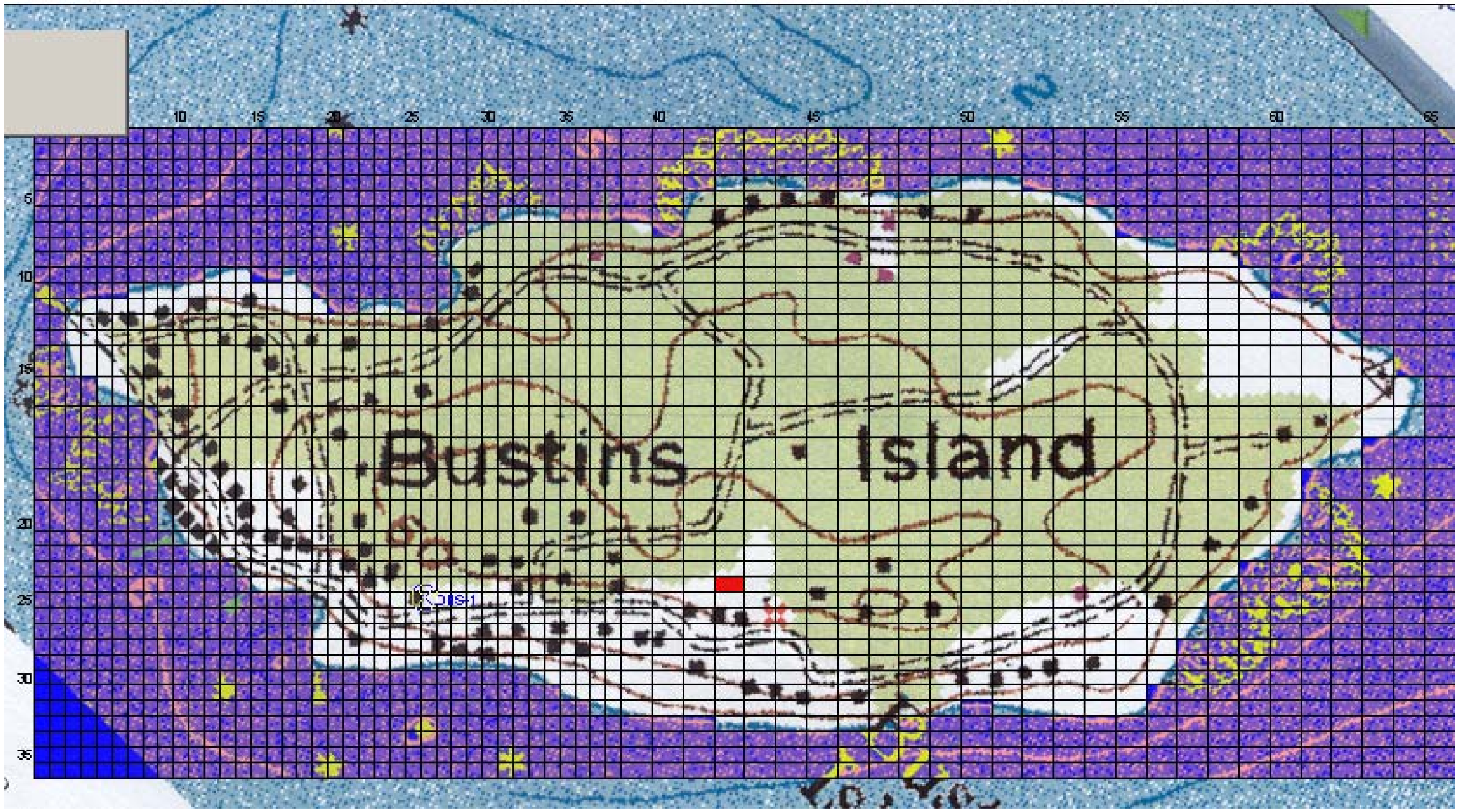

Figure 9: Location of well assigned to model Layer 3.

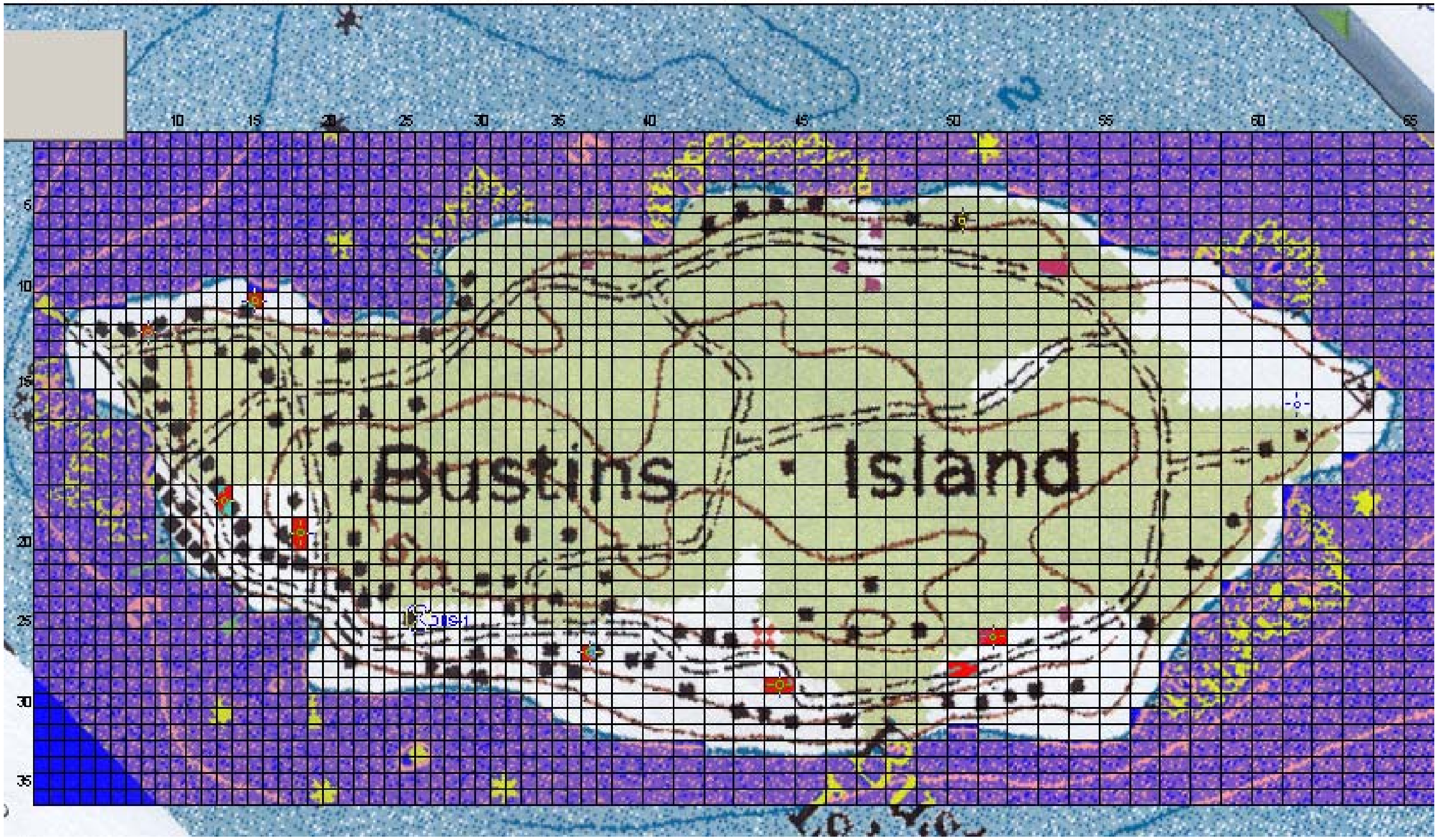

Figure 10: Location of wells assigned to model Layer 4.

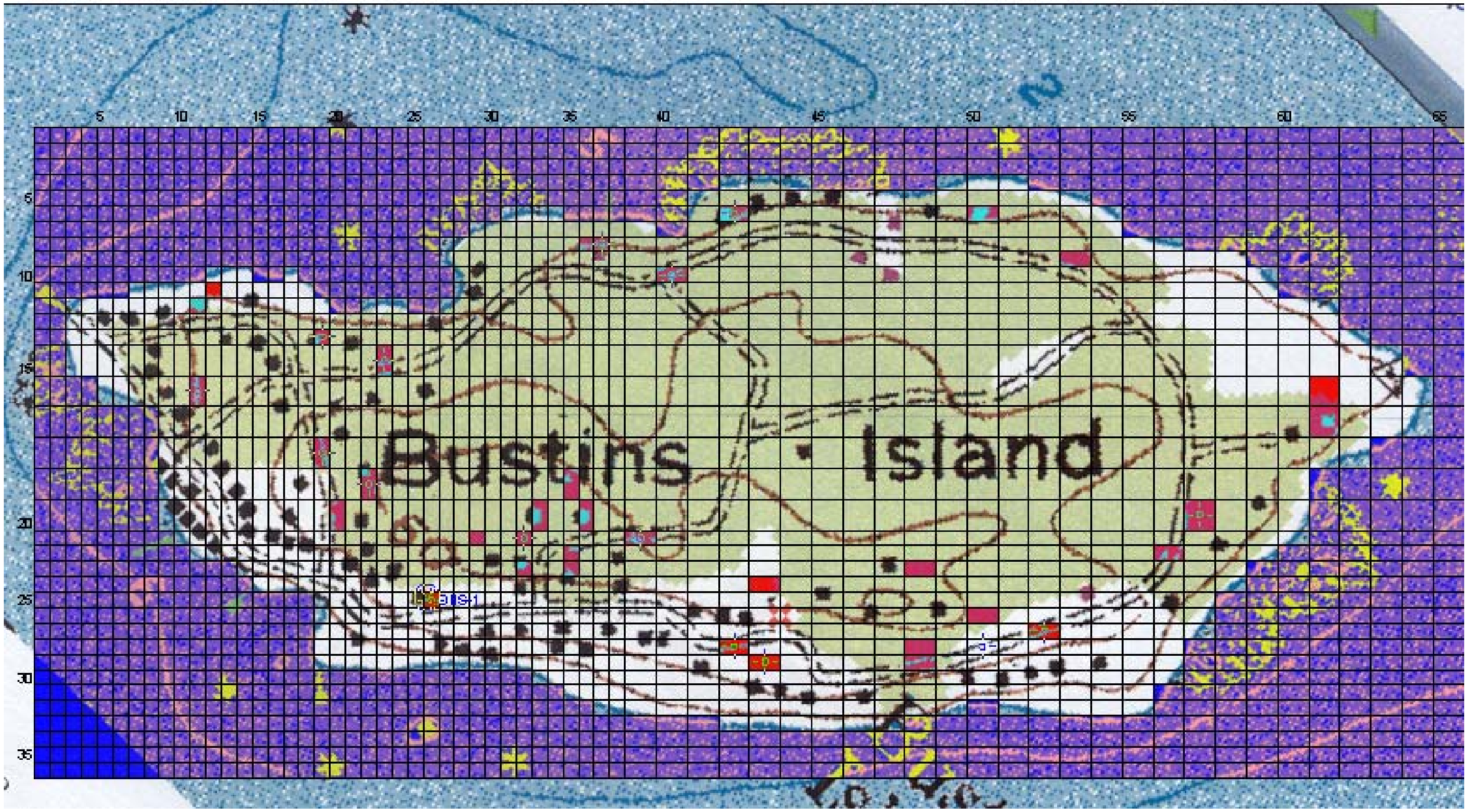

Figure 11: Location of wells assigned to model Layer 5.

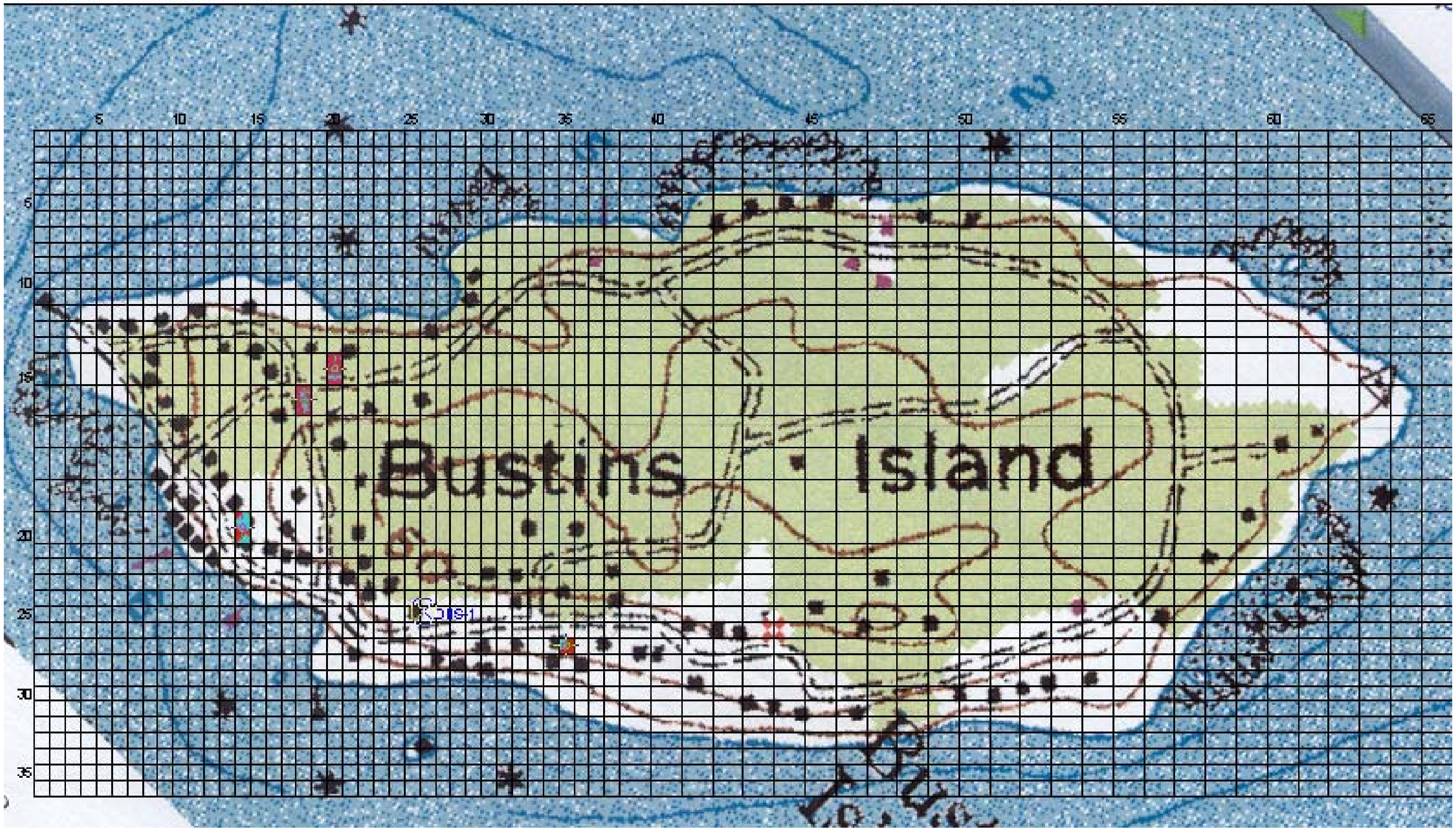

Figure 12: Location of wells assigned to model Layer 6.

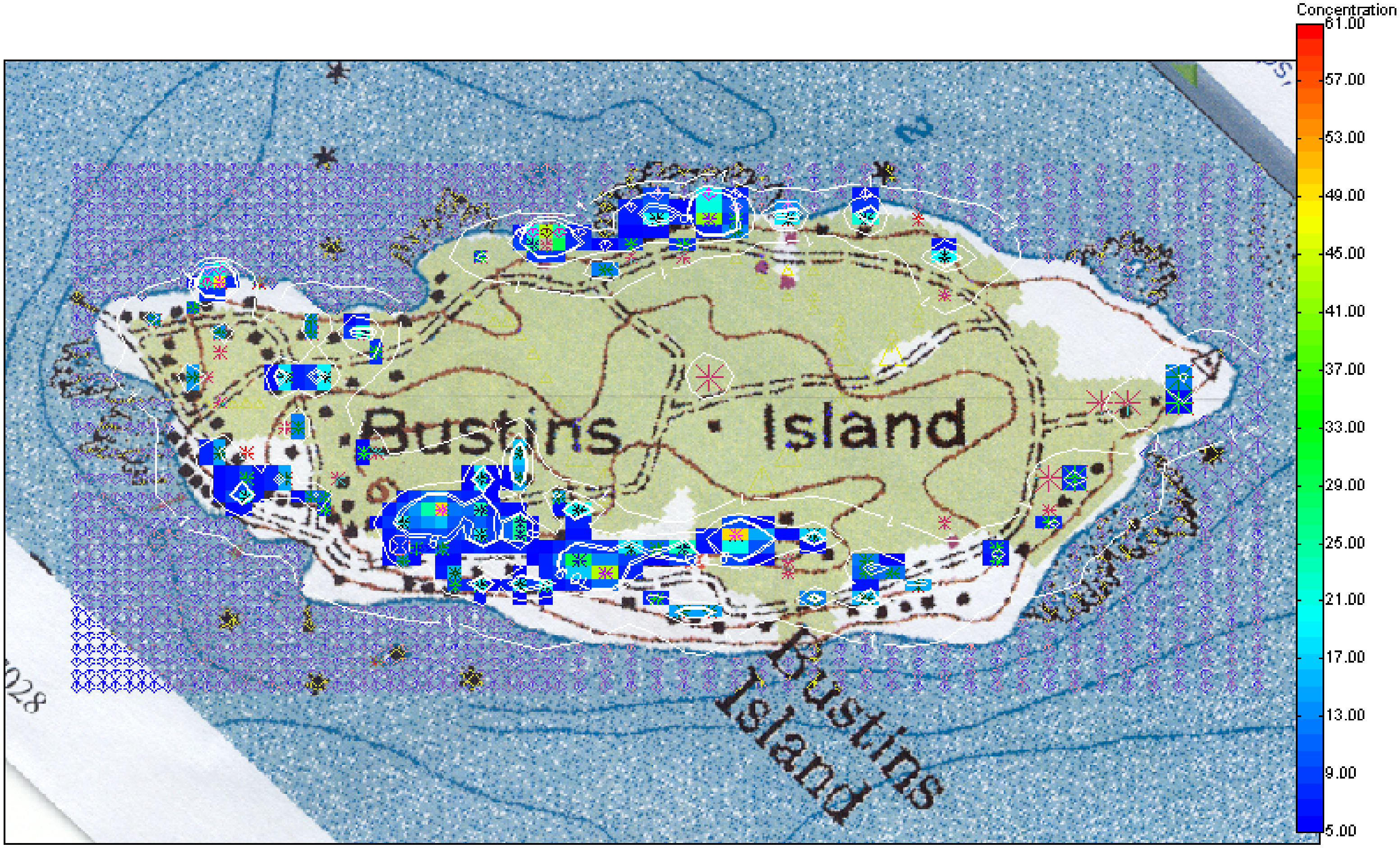

Figure 13: Concentrations in model Layer 1 after 10 years, end of summer period (August 31). Concentration interval of 4 units. At risk areas indicated by color flood, minimum concentration of 5.

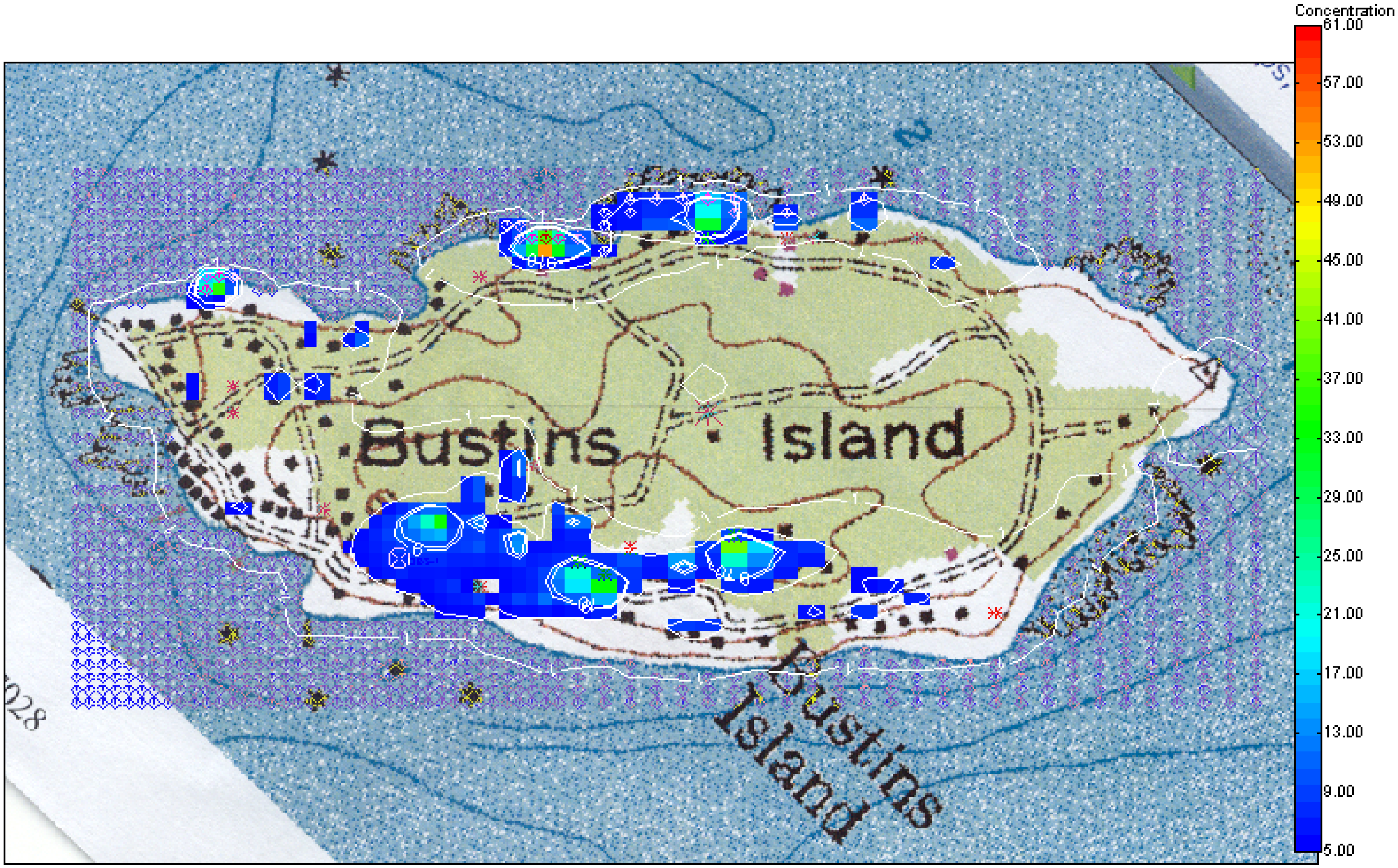

Figure 14: Concentrations in model Layer 2 after 10 years, end of summer period (August 31). Concentration interval of 4 units. At risk areas indicated by color flood, minimum concentration of 5.

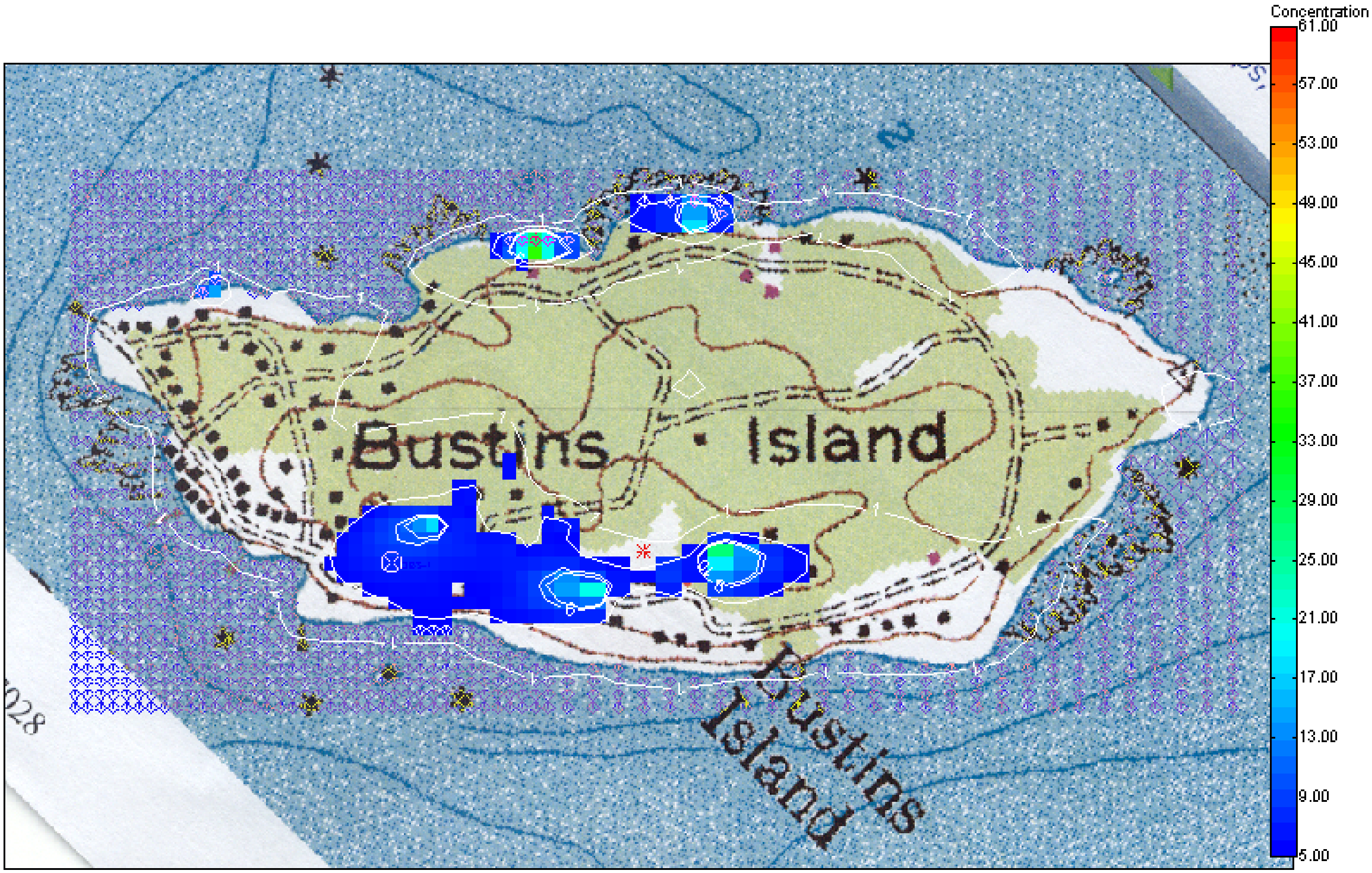

Figure 15: Concentrations in model Layer 3 after 10 years, end of summer period (August 31). Concentration interval of 4 units. At risk areas indicated by color flood, minimum concentration of 5.

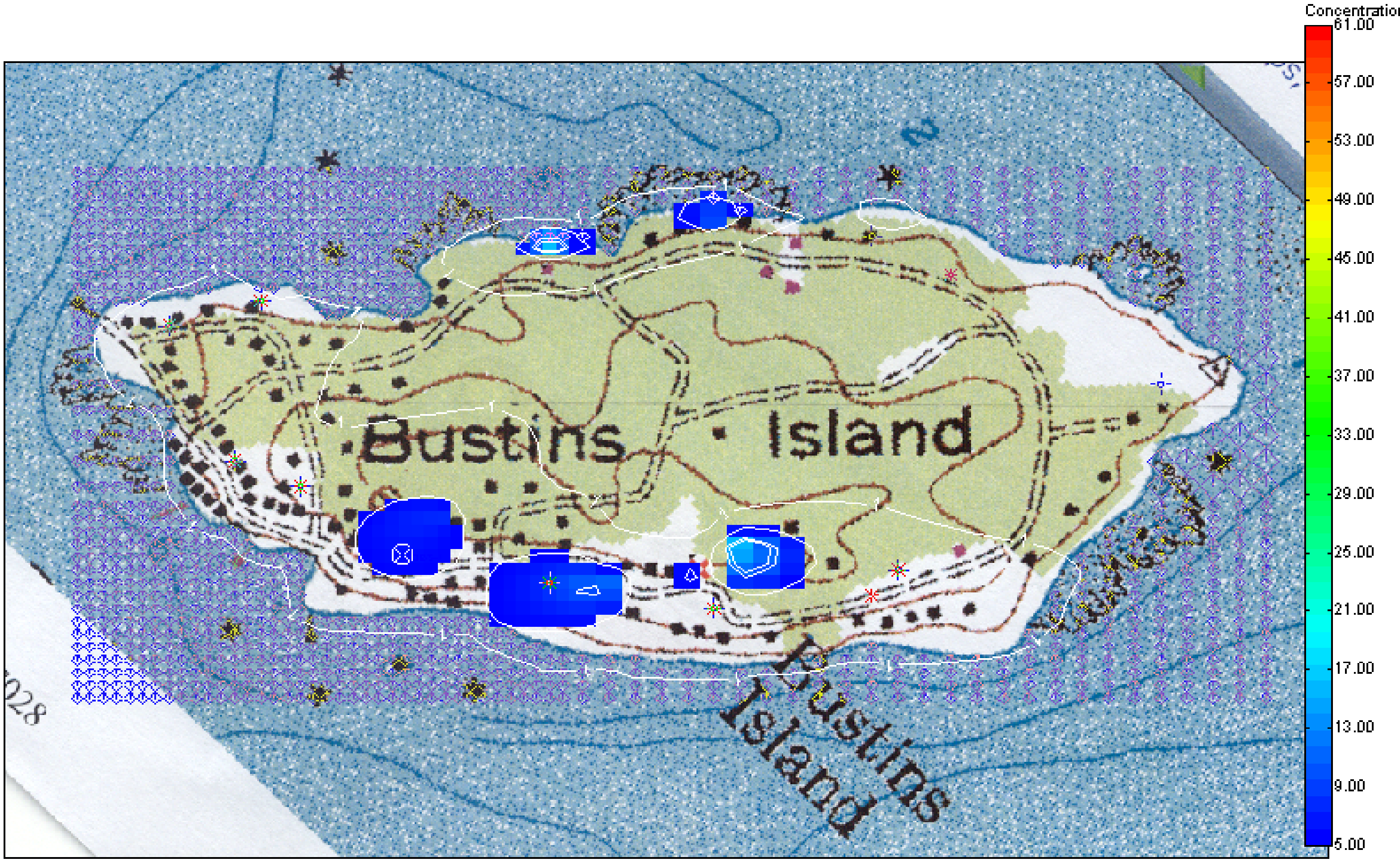

Figure 16: Concentrations in model Layer 4 after 10 years, end of summer period (August 31). Concentration interval of 4 units. At risk areas indicated by color flood, minimum concentration of 5.

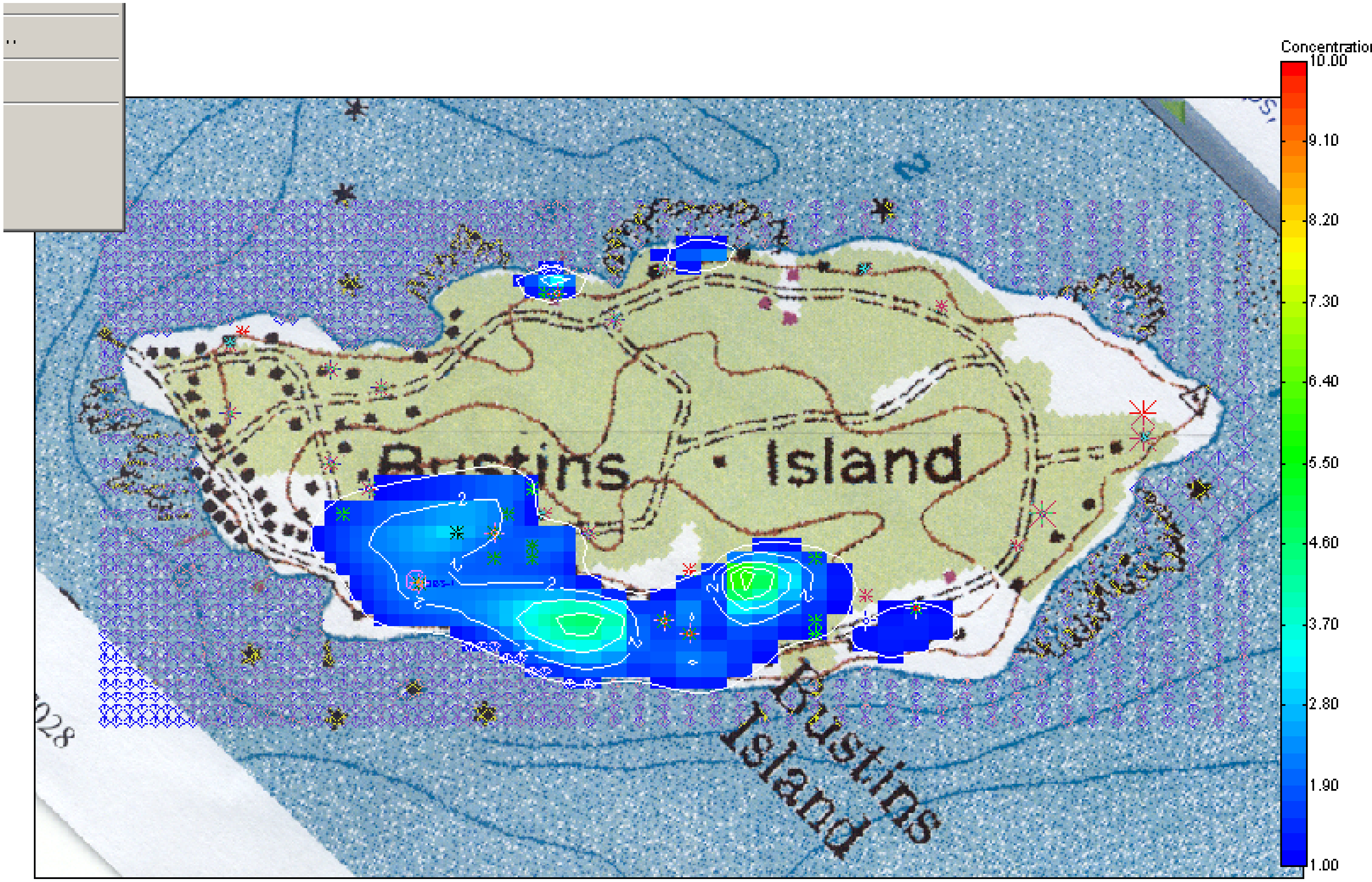

Figure 17: Concentrations in model Layer 5 after 10 years, end of summer period (August 31). Concentration interval of 4 units. At risk areas indicated by color flood, minimum concentration of 5.

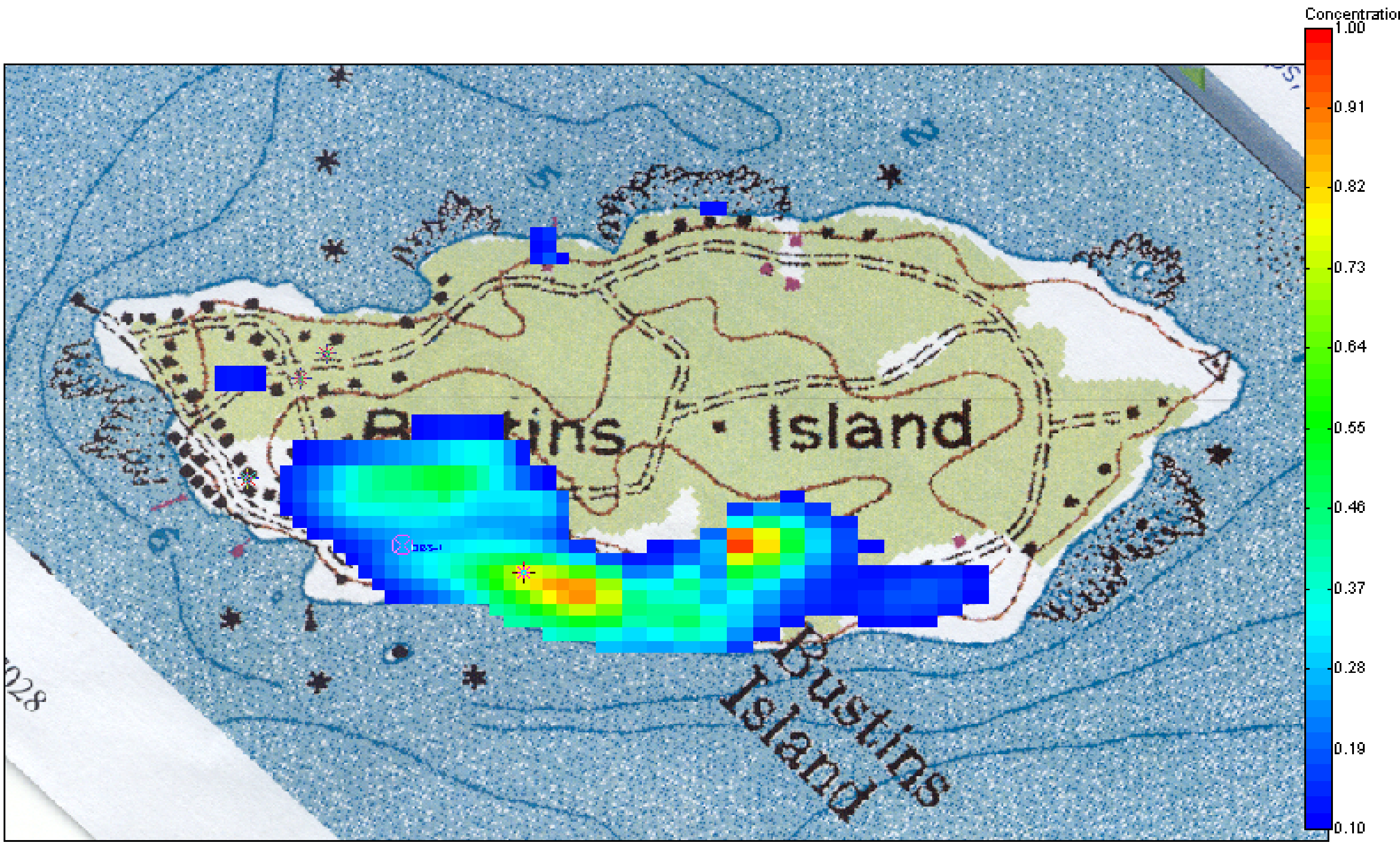

Figure 18: Concentrations in model Layer 6 after 10 years, end of summer period (August 31). Concentration interval of 0.2 units. Minimal at risk area above 5; maximum about 1 in Layer 6.

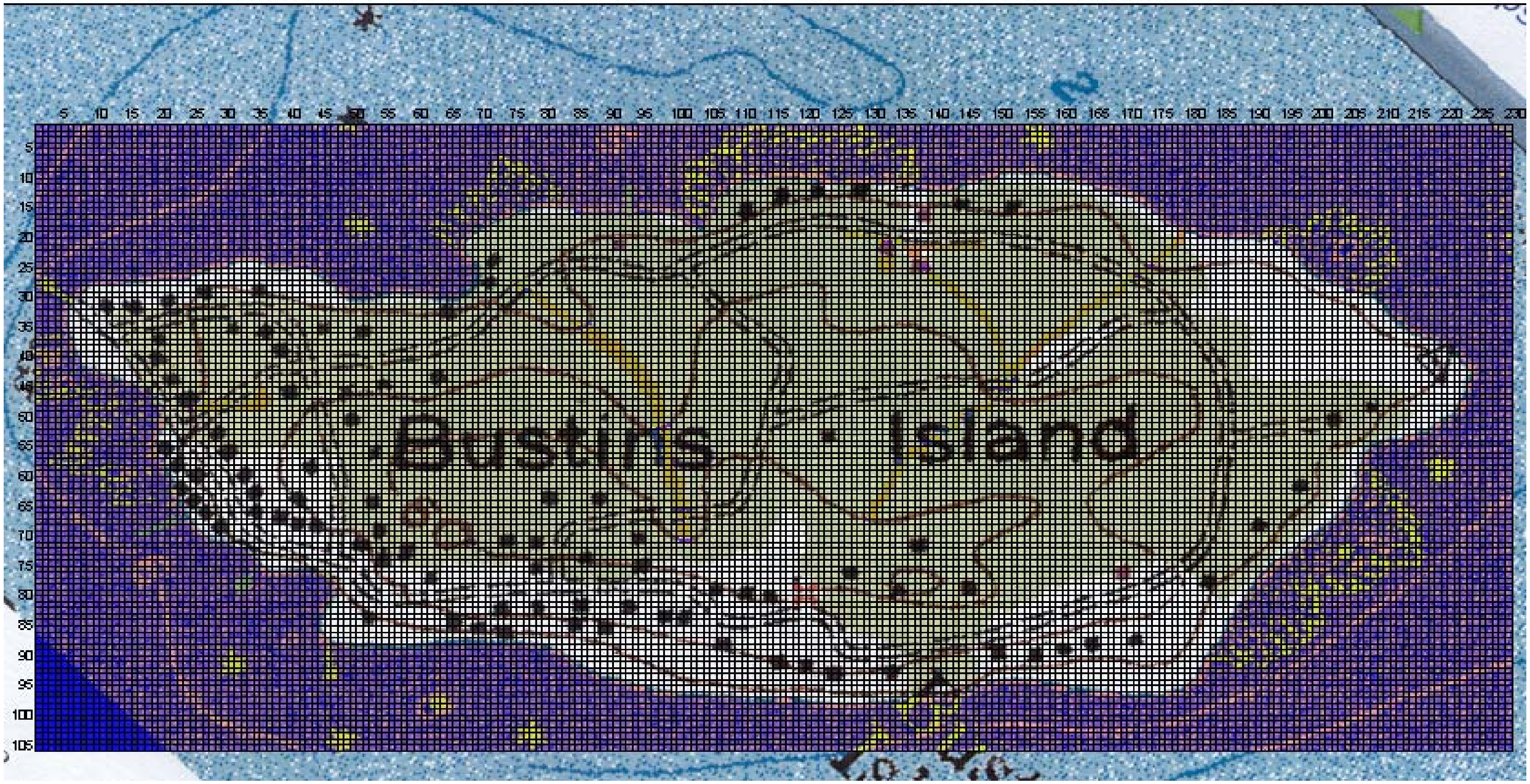

Figure 19. The refined grid to allow lot-by-lot evaluation. This figure also shows the refined drain node locations for potential seepage to ground surface and influence of fire ponds. Model block size is 20 feet by 20 feet.

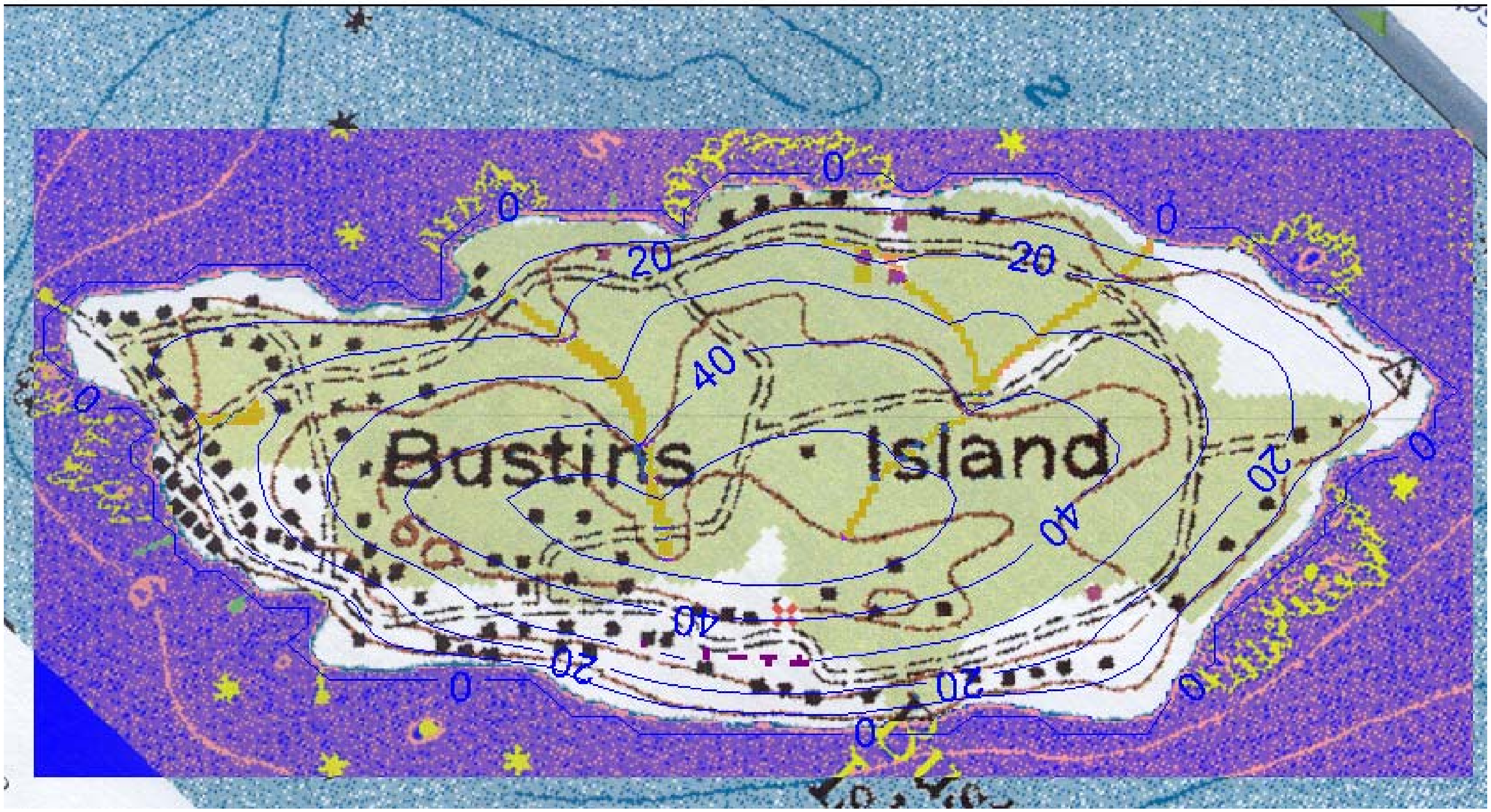

Figure 20. The model generated head contours for the refined model grid.

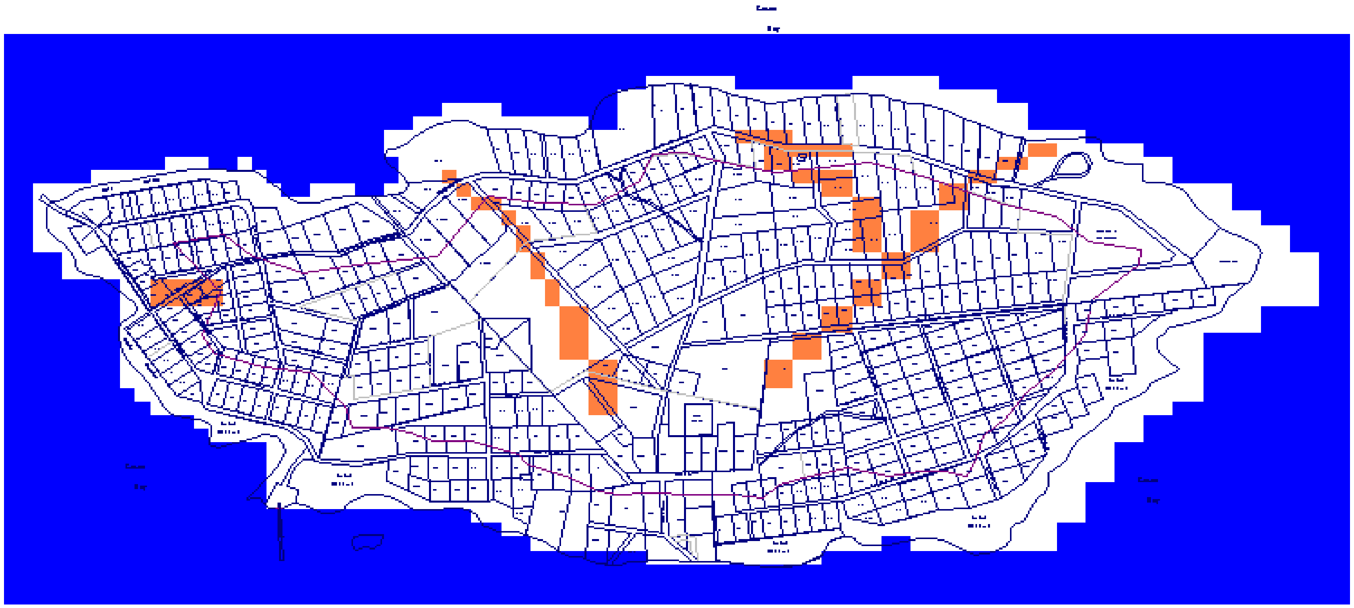

Figure 21. The survey map brought into the outline of the RGGI model active area.

TABLES

RECONSTRUCTION OF A GROUNDWATER MODEL FOR BUSTINS ISLAND INCLUDING REVISIONS AND A DATA GATHERING PLAN

TABLE 1

MODEL INPUTS

Item	RGGI model	MACTEC used or assumed
1. Model grid spacing	50-by-50 to 100-by-100 block sizes; 36 rows; 68 columns; and 6 layers.	Same as RGGI model.
2. Layer thicknesses	Only that layer 5 is 100 feet thick and that the full model is 300 feet thick. less than the overlying layer.	Model layer 5 is 100 feet; model layer 6 is assumed to be 100 feet also as it is not likely to be taken Layers 2 to 4 were varied during model calibration, but were eventually assigned thick-nesses of 20, 25 and 50 feet. Layer 1 thickness is variable due to varying saturation, and is 5 to 15 feet thick.
3. Boundary conditions	Not specified, but plot of drawdowns suggests constant heads at the edge of the island.	Taken as constant heads; naturally conforming to the ocean at mean sea level at the edge of the island Assigned differently at lower layers, with no-flow boundary in bottom layer. Drains assigned to maintain heads near ground surface.
4. Layer conditions	Not specified. Likely unconfined for layer for Layer 1 and possibly confined or convertible for the remaining layers.	Taken as unconfined for layer 1 and convertible for the others.
5. Hydraulic conductivity	Two zones defined for Bedrock, but given as transmissivity. With thickness uncertain, K is approximate. Possible inclusion of soil in layer 1.	Taken initially as RGGI values and adjusted as needed in calibration.
6. Anisotropy	Specified as 10:1 in bedrock with major axis paralleling the long axis of the island.	Taken as 10:1
7. Recharge	Two zones listed with respect to the defined zones of high and low K in bedrock, 6.45 and 2.15 inches per year, respectively.	Taken as RGGI values.

TABLE 1 (Continued)

MODEL INPUTS

8. Storage coefficient	Not specified. Likely to be about 0.0001 for confined bedrock and 0.005 to 0.02 for unconfined (specific yield).	Taken as 0.0001 for confined conditions. Varied from 0.005 to 0.02 for unconfined rock.
9. Porosity	Not specified. Likely to be 0.005 to 0.02 for rock, higher for soil, if included.	Taken in the range of 0.005 to 0.02.
10. Dispersivity	Not specified.	Initial values selected from Experience and varied during calibration.
11. Initial time	Not specified, but likely September 1 based on reasonable modeling practices.	Taken as September 1.
12. Initial concentration	Specified as zero everywhere at the beginning of the simulation.	Taken as zero everywhere.
13. Schedule of wells/ injection	Possible durations listed in table in report, but suspect simplified in model, else far too complicated for the level of data to support.	All conservatively taken as June 1 to August 31, with rates taken as compiled in the table. Total of 162 locations modeled.
14. Base map	A simple outline of the island Derived from an unspecified Map. Probably a SURFER generated .bln file.	A bit map generated by scanning in a USGS quad map of the island with topography and importing into the model preprocessor.

TABLE 2
COMPARISON OF RESIDUALS ANALYSIS

Category	RGGI	MACTEC	MACTEC NEW
Mean	-0.99 ft	0.00 ft	-0.02 ft
Absolute mean	4.12 ft	3.54 ft	3.58 ft
SSR	661	555	519
Standard deviation	4.69 ft	4.37 ft	4.23 ft
Ratio stddev/range	0.092	0.086	0.083

TABLE 3

FINAL MODEL INPUT PARAMETER VALUES

	Coarse Grid		Fine Grid	
Ks	Low K	High K	Low K	High K
Layers 1+2	0.126 ft/d	0.2 ft/d	0.126 ft/d	0.16 ft/d
Layers 3+4	0.03	0.0475	0.03	0.038
Layers 5+6	0.017	0.024	0.017	0.0192
Recharge				
Thin soil area	2.15 inches per year		2.15 inches per year	
Thick soil area	6.45 inches per year		6.45 inches per year	
Recharge rates are varied monthly for the transient model simulations				
Storage coefficients	Layer 1	Layers 2-6	Layer 1	Layers 2-6
Confined	0.0001	0.0001	0.0001	0.0001
Specific yield	0.05	0.01	0.05	0.01
Porosity	0.05	0.01	0.05	0.01
Dispersivity	All layers		All layers	
Longitudinal	50 ft		50 ft	
Lateral	50 ft		50 ft	
Vertical	0 ft		0 ft	

Ks are in the x direction, 10:1 lateral anisotropy, 1:1 vertical anisotropy
No retardation, no reactions in transport model
Layer conditions are unconfined for Layer 1, convertible for Layers 2-6

ATTACHMENT A

RESIDUALS ANALYSIS RESULTS

ATTACHMENT A
RESIDUALS ANALYSIS RESULTS

Results of Residuals Analysis - Reconstructed RGGI Steady-State Model - Coarse Grid - 7/23/04

Name	X	Y	Layer	Observed	Computed	Weight	Group	Residual
1	1825	475	4	41.85	33.23	1	1	8.62
3	675	850	6	19.88	14.45	1	1	5.43
7	1825	1725	5	11.99	9.31	1	1	2.68
9	625	950	4	11.52	13.65	1	1	-2.13
11	2250	425	5	29.73	33.65	1	1	-3.92
13	1575	775	5	45.00	45.32	1	1	-0.32
14	975	1350	6	23.84	18.04	1	1	5.80
15	3050	425	5	31.83	25.24	1	1	6.59
35	875	850	4	25.94	23.21	1	1	2.73
41	3150	525	4	35.96	29.46	1	1	6.50
44	725	1575	4	4.28	2.55	1	1	1.73
45	925	1425	5	9.53	12.67	1	1	-3.14
53	375	1475	4	7.00	5.58	1	1	1.42
55	3250	475	5	23.34	23.52	1	1	-0.18
61	4150	1250	4	15.77	14.64	1	1	1.13
62	1075	950	5	28.00	30.91	1	1	-2.91
63	3050	1825	4	8.29	10.76	1	1	-2.47
68	3750	850	5	12.00	21.15	1	1	-9.15
69	1725	475	6	23.92	29.65	1	1	-5.73
70	1275	575	5	23.38	23.12	1	1	0.26
71	1950	775	5	55.00	53.04	1	1	1.96
74	925	1050	5	22.06	24.89	1	1	-2.83
75	875	1250	6	14.56	20.28	1	1	-5.72
76	525	1250	5	5.00	12.31	1	1	-7.31
77	1125	1350	5	19.63	20.36	1	1	-0.73
79	2350	375	5	36.17	29.68	1	1	6.49
80	2450	375	4	29.52	30.22	1	1	-0.70
81	2050	1625	5	18.98	21.35	1	1	-2.37
82	2250	1825	5	5.81	7.55	1	1	-1.74
Residual Mean						0.00		
Res. Std. Dev.						4.37		
Sum of Squares						555		
Abs. Res. Mean						3.54		
Min. Residual						-9.15		
Max. Residual						8.62		
Range						50.72		
Std/Range						0.086		

ATTACHMENT A
RESIDUALS ANALYSIS RESULTS

Results of Residuals Analysis - Reconstructed RGGI Steady-State Model - Fine Grid - 7/23/04

Name	X	Y	Layer	Observed	Computed	Weight	Group	Residual
1	1837	505	4	41.85	34.68	1	1	7.17
3	692	856	6	19.88	15.63	1	1	4.25
7	1840	1720	5	11.99	10.38	1	1	1.61
9	618	965	4	11.52	14.43	1	1	-2.91
11	2222	430	5	29.73	32.21	1	1	-2.48
13	1572	790	5	45.00	46.76	1	1	-1.76
14	960	1335	6	23.84	20.13	1	1	3.71
15	3085	435	5	31.83	25.12	1	1	6.71
35	870	850	4	25.94	24.84	1	1	1.10
41	3172	535	4	35.96	29.30	1	1	6.66
44	750	1568	4	4.28	3.23	1	1	1.05
45	910	1450	5	9.53	12.09	1	1	-2.56
53	410	1500	4	7.00	5.60	1	1	1.40
55	3198	474	5	23.34	24.76	1	1	-1.42
61	4150	1250	4	15.77	14.41	1	1	1.36
62	1057	955	5	28.00	33.46	1	1	-5.46
63	3022	1828	4	8.29	9.38	1	1	-1.09
68	3780	815	5	12.00	18.44	1	1	-6.44
69	1737	511	6	23.92	30.31	1	1	-6.39
70	1270	568	5	23.38	22.91	1	1	0.47
71	1924	775	5	55.00	52.76	1	1	2.24
74	902	1016	5	22.06	27.11	1	1	-5.05
75	899	1280	6	14.56	21.27	1	1	-6.71
76	522	1230	5	5.00	11.52	1	1	-6.52
77	1101	1410	5	19.63	17.23	1	1	2.40
79	2392	390	5	36.17	29.45	1	1	6.72
80	2428	322	4	29.52	24.76	1	1	4.76
81	2050	1647	5	18.98	21.31	1	1	-2.33
82	2272	1825	5	5.81	6.85	1	1	-1.04
Residual Mean						-0.02		
Res. Std. Dev.						4.23		
Sum of Squares						519		
Abs. Res. Mean						3.58		
Min. Residual						-6.71		
Max. Residual						7.17		
Range						50.72		
Std/Range						0.083		

ATTACHMENT B

RUNNING THE MODEL

ATTACHMENT B
RUNNING THE MODEL

This brief discussion assumes that the user has Groundwater Vistas installed on the computer and is familiar with its setup and operation.

Running the models

1. Establish working directories for the models (RGGI reconstructed steady-state, RGGI reconstructed transient transport, and MACTEC revised steady-state and revised transient transport). These models resided in directories C:\BustinsI\BIR7, C:\BustinsI\BITR2, C:\BustinsI\BIR10, and C:\BITR3, respectively, during development, but BIVC can change these working directories through menus in Groundwater Vistas, as desired. Create these directories (in DOS window or Windows Explorer) and transfer the files for each model into its respective directory. Also create a directory C:\BustinsI\map, and transfer the map files into that directory.
2. Open Groundwater Vistas and open the desired model file (a file with a .gwv extension).
3. To run the model, go to the model tab in the Groundwater Vistas toolbar; click on MODFLOW, then click on “Create Datasets”. When done, click on “Run MODFLOW”. When the model is finished running, it will prompt to process results. Follow the instructions to select the results to import, and also under the Plot menu, select from “What to Display”. You may want to run the transport model (MT3DMS) before displaying the MODFLOW results. Follow the same procedure to create MT3D datasets and to run the MT3D model and to import the results.
4. Results may be output as figures exported to a printer, or saved by exporting the file, or dropping the screenshot bitmap files into a Word document or Powerpoint presentation. The MODLOW and MT3D output files are also available for viewing in Groundwater Vistas or externally with a text editor.
5. New versions or updates of the model may be prepared by creating new folders(directories), copying in the desired base files, modifying these, creating new working directory pathways, changing the root file name, and saving into the new working folder (also see below).

Making changes to the models:

1. Open the appropriate tab on the Groundwater Vistas toolbar – this will be “PROPS”, or properties, for hydraulic conductivity, recharge, dispersivity and storage coefficient/porosity, and “BCs,” or boundary conditions, for wells, constant heads, no-flow, and wells.
2. Select the appropriate tools for modifying the model. Property zones may be altered by inserting, modifying or deleting the present arrays. Values assigned to property zones may be changed through the database selection. For boundary conditions, the same approach may be taken to add, delete or modify, but a screen will come up asking the values you wish to assign to the boundary condition. For transient models, it may be necessary to select the proper stress period to make changes to conditions, or to import these from an edited file.

3. Time period requesting MT3D output should have MODFLOW output available for this time step also.
4. When changes are complete, save the file and proceed with dataset creation and model runs.

Getting output from the model:

1. As indicated above, model output can be imported for post-processing or output files viewed within or outside of Groundwater Vistas. Groundwater Vistas also has tools for summarizing flow rates for selected areas of the model under the Plot and Mass Balance tools. Calibration statistics may be viewed (if targets have been imported and output heads imported) using the Plot and Calibration tools. If the model is transient, then targets must be imported for select time or stress periods.
2. The File and Print/Page Setup tools allow a variety of options in preparing printed or saved output. As these are extensive, consult HELP or the Users Manual for tutorials and specific instructions.

ATTACHMENT C

BIVC COMMENT LETTER AND MACTEC RESPONSES

Bustins Island Village Corporation
Bustins Island, Maine 04013

PLANNING BOARD

11 Cedar Creek Road
Sudbury, MA 01776-1004
September 22, 2004

Mr. Peter Baker
MACTEC Engineering and Consulting, Inc.
511 Congress Street
P.O. Box 7050
Portland, ME 04112-7050

Dear Peter:

Since the MACTEC presentation on August 14 of the preliminary report, the Water Sub-Committee has prepared comments for your consideration before the preparation of the final report. I have listed these below. They generally follow the order in which these items appear in the preliminary report.

ES-1 ¶ 1 It was the BIVC's request to have the previous model run for determining the implications of proposed well drilling that brought to light the fact that it was lost. There was no attempt to update the model.

Response: This will be clarified in the final report.

One of the more useful features of the prior Gerber report was its maps of risk areas for contamination from waste discharges and salt water intrusion. A similar visual presentation should be contained in the final MACTEC report.

Response: Gerber's interpretation of at risk areas from waste discharges was based on an arbitrary assignment of areas with greater than 5 percent or 10 percent of the initial applied concentration. These he shaded in on output figures from the transport model runs. Figures 13 through 18 in the MACTEC Draft Report are intended to show the same thing, but contours were not shaded. MACTEC will use a color flood on the final figures to emphasize these areas.

Gerber's interpretation of at risk areas from salt water intrusion was based on an assumption of the location of the 500-foot contour of the depth to the salt-water interface based on the Ghyben-Herzberg method (the so-called rule of 40). This depth would provide a cushion beneath the typical deepest well on the island. It is interesting that he indicated this zone only on the southern end of the island (perhaps due to the higher concentration of pumping wells on this end of the island). We could provide a figure using the same basic method, but, as we discussed with you, the nature of fractured bedrock makes this method only approximate, as you have experienced from the more recent wells that did encounter salinity problems. Using this method, the area of greatest risk would correspond closely to that area between the 10-foot contour on Figure 5 and the seashore. Gerber's suggestion that there be a 200-foot setback for new wells is reasonably cautionary, but may not be compatible with the layout of the parcels nearer the water and where parcel size may be small. In looking at the island geology during our visit, we would conclude from the general strike (SW-NE) and dip (SE) of the bedding in the rock that wells on the western side of the island might be at greater risk from salt water intrusion, and also wells positioned at either end of the island.

While this methodology suggests areas that would be at greater risk from saltwater intrusion, it should be recognized that, with the relatively low demands placed on the residential wells, drawdowns in these wells are relatively small. The typical well demand is likely supplied by well borehole storage and indicated maximum yields for most wells suggests these wells would recharge over night. Only where a number of wells are concentrated near the shore or wells with relatively large demands would excessive drawdowns be expected that might increase this relatively low risk.

¶ 2 A stronger case should be made that MACTEC's model is technically sound in its own right and justified independent of Gerber.

Response: We certainly feel this way. Reference to the "Gerber" model was meant to show agreement with the previous model (as requested by BIVC), but also as a convenience in referring to the more coarsely gridded model. MACTEC was forced to made several key assumptions in the recreation of the model due to lack of information in the Gerber reports, and, in recalibration, varied parameters to achieve what it feels is a more robust model that better matches observed conditions. We will emphasize this more in the final report.

¶ 3 Is it realistic not to have the model consider any degradation of waste as it moves within the soils?

Response: The waste is comprised of several constituents, some of which will degrade, and some of which will not. The difficulty is in determining what the actual degradation rates are for degradable constituents for this specific setting. Lacking actual chemical distribution data to determine these rates, the most prudent thing is to assume no degradation until such degradation can be demonstrated and quantified. Since the amount of degradation is a function of time of travel from points of introduction to receptor, groundwater velocities will be important. Velocities in fractured rock tend to be higher than in the more porous soil. Hence, other things being equal, there may be greater degradation in groundwater in soils than in the deeper fractured rock.

Will this lack not cause the model to overstate how serious contamination might be? Response: Yes, the model would be conservatively high with regard to degradation, but may also overestimate dilution since it treats the rock as a porous rather than fractured medium.

While this is the conservative approach, it would be helpful to know how much error it may be introducing.

Response: This can only be known with extensive water quality sampling.

Discussion of the movement of septic and privy effluent is of immediate concern. What are the implications for the generating property owner and his neighbors from what is in the ground and what might come up in a well? Is there an attenuation level that is generally accepted as safe?

Response: There is general guidance that a well should be positioned no closer than 200 feet downgradient of a septic system, or about 100 feet up- or crossgradient (also see discussion in Gerber's 1991 report, p. 10.)

More discussion on these points would be helpful since it is a general concern.

Response: We will expand on these points for the final report.

ES-2 ¶ 1 This tabulation of potential thing the BIVC could do is potentially very useful. It would be helpful if each point could be explained in sufficient detail to implement it.

Response: We will expand the discussion in Section 3.0.

¶2 For the uninitiated, an explanation of the Ghyben-Herzberg principal would be helpful. There is salt water contamination in two of the most recently drilled wells and borderline contamination in one old one. Since most of the cottage development is around the shore, having a good handle on the risks of well drilling in that area would be useful. If the technical understanding is sufficiently good, there may be a basis for an ordinance on well location from the shore; but lacking that, just being able to inform people of the risks would be helpful.

Response: We will add some detail explaining the principal more fully.

¶ 3 Would you please be more specific about the data gaps and estimated parameters so that we can take steps to get the necessary data and specifics. It is important that this type of follow-up item be clearly stated in the final report so that it can form the basis for future BIVC action.

Response: We will detail this more in Section 3.

2-1 ¶ 3 Please keep in mind that the BIVC's objective is to have a useful model of the Bustins Island ground water that can be used to assess the impact of waste disposal, well drilling, and well usage on the ground water supply. Re-creation of the Gerber *per se* is not a BIVC objective. Understanding differences between the MACTEC model and Gerber's is important for having confidence in the MACTEC model when it may lead the user to conclusions that are different from those he would have reached with Gerber.

Response: We understand this, and have full confidence that the MACTEC model is a good representation of the BI hydrogeologic system as it is currently understood. However, nearly all this information is contained in the Gerber reports, and without other, more recent geologic, hydrogeologic, or site-specific information, the basis for constructing the Gerber and MACTEC models remains essentially the same. In reviewing the Gerber model and information he based that model on, we did not determine that there were any major flaws in those data or the model (to the extent it was documented). Hence, the Gerber and MACTEC models are quite similar since they share much the same basis. We will add detail in Section 2 that highlights the differences, or assumptions where data were lacking, in producing the new model.

¶4 Where MACTEC had to make assumptions, it should have used its best technical judgment and let the results be whatever they be. When assumptions are made, however, it would be helpful to so note the BIVC can be sensitive to what they are and can be change them in the future as new information is developed.

Response: MACTEC's assumptions, i.e., the selection of parameter values or conditions which were not documented or were in error in Gerber's reports, were made based on experience with similar settings and prior successful representations in models. These selected values are listed in Section 2 of the report.

2-2 ¶ 1 What are the practical implications of the groundwater flow very near the ocean behaving differently than predicted by the model? For example, does the model predict more or less risk of saltwater intrusion than is actually likely to be the case?

Response: This is very difficult to predict. The model would predict salt-water intrusion based on homogeneous subsurface conditions where any well along the shore would be subject to the same potential for saltwater intrusion based on its depth, proximity to the ocean and the pumping rate, either solely or as a cluster. In actuality, each well's response would also depend on the particular bedrock water-bearing fracture patterns that the open well borehole intersects. In some instances, these could extend further toward or under the ocean, and, if connected, could make one well much more susceptible than another in which these fracture patterns are otherwise. Additional discussion has been presented in the response to the second comment.

¶ 4 and 2-3 ¶ 1 Should the island go to the expense of having borings and soils surveys to determine permeability?

Response: This depends on how accurate a model BIVC feels is needed to accomplish its goals. This type of exploration may be prohibitively expensive when more general precautions may be adequate to BIVC's needs.

What is the MACTEC survey to which reference is made?

Response: This refers to the walking tour of the island Ron Lewis made in July to become better acquainted with the island and indications of surface water and seepage areas. We will change "survey" to "reconnaissance".

2-3 ¶ 3 Does recharge mean that there is, on the average, 22 to 23 gallons of water every minute being absorbed into the island's aquifer? If so I get 11, 563,200 gallons over the course of a year.

Response: Yes, this is correct. Remember, however, that the groundwater continues to flow into the ocean all year round, and that in the Summer, the period of peak use, the recharge is at its lowest.

2-4 ¶ 2 What are the consequences of all of the drilled wells' water not coming from layer 5? Is this factor potentially important?

Response: Withdrawing water from different layers in the model (corresponding to different depths of wells) will create locally different groundwater flow patterns and have some impact on where waste contributions would end up.

2-5 ¶ 3 The recommendation to survey well location and more accurately measure water depth is one that we can follow-up on with our surveyor, John Wood.

Response: Noted. Of equal importance is establishing very accurate reference elevations on those wells used to measure the depth of groundwater from.

Again please note, that the goal for the BIVC is for MACTEC to develop as accurate a model of the Bustins Island ground water as possible, not the re-creation of the Gerber model.

Response: This is what MACTEC undertook to provide. This has been discussed in a couple of the previous responses.

¶ 5 The island water balance seems to be something that we need to understand better. Does this mean that the island's use of water over the summer months averages 0.3 gpm? If this compares to a recharge of 22 – 23 gpm, then there is apparently plenty of water available on the average. Correct?

Response: The 0.3 gpm figure is a net withdrawal figure determined from Gerber's survey of water use and return on the island. This included several assumptions as to average usage for many lots. In terms of an overall water management strategy for the island, it is important to maintain a low net withdrawal, so that groundwater levels on the island remain relatively unaffected by excessive withdrawal. If water levels fell too much, then those with dug wells might be affected. However, recognize that the water being returned in the summer is not of the same quality as that withdrawn, so quantities of available water of an acceptable quality decline over the summer. Over the long term, if withdrawals and returns remain relatively consistent, then a pattern of water quality develops that should remain relatively consistent.

2-7 ¶ 3 Being able to use the zoning map as a way of entering the model would make it very much more useful. Users will want to know the implications of something on lot 14 in Section D for example. We would like to explore further with MACTEC and Island Surveys what needs to be done to make this happen.

Response: MACTEC agrees, and would be happy to help with this. Our original attempts to do this uncovered some apparent discrepancies that need to be resolved before this can be achieved confidently.

3-1 Future activity to protect the island's water will be based on the recommendations section of the final report. Consequently, it is important that this section be quite specific, that it be clear in how to go about what is recommended, and that it assign priorities to the various tasks so that the BIVC can allocate its limited resources where they are likely to have the most effect.

Response: We will expand on this and prioritize them as requested at the presentation. Also please recall that Gerber's reports present a great deal of common sense recommendations that were specific to maintaining water quality and management for the island.

4-1 ¶ 2 There are anecdotal reports of wells in addition to that of Carr reflecting the tides. If this is an important factor, it should be relatively easy to monitor the level of several over the tidal cycle.

Response: It was important for the model calibration to have water levels that were unaffected by tidal variance. From a different standpoint, identifying such wells could indicate their possible connection through bedrock fractures to the ocean. While these wells may not be pumping hard enough to be affected by saltwater intrusion, they may be indicative of wells that might be impacted in the future if water balance conditions were to change.

5-1 ¶4 Waste water return locations can be positioned on island map. MACTEC in its walk around identified swale and stream areas that are not on any map. Should the island surveyor mark out the locations of these natural or man-made drainage features and their elevations? If he does, will the model be able to consider them and what would be the expected benefit?

Response: Yes, these could be important controls on how groundwater moves. Such features can be represented in the model, and one such inclusion in the MACTEC model (apparently not contained in Gerber's) shows some differences in some inferred groundwater directions along the east side of the island from those shown in Gerber's model. Based on the uncertainties in the current information, it is not possible to tell which representation is more accurate.

Presentation:

There was a series of maps presenting risk areas that was included in the oral presentation. Would you please include these along with an explanatory discussion in the final report?

Response: Yes, as indicated previously, these will be used in place of Figures 13 through 18.

These maps of contamination seem to show the contamination spreading laterally down to layer 3 then contracting in layer 4 and perhaps also 5. Artesian wells are generally drilled into layer 5. Please discuss specifically the implications for contamination in artesian wells drilled in these areas.

Response: Potentials for contaminants in groundwater to affect wells will depend on their proximity to the areas indicated as being most impacted and the open borehole or screened intervals that each well presents to groundwater flow. Note that the assignment of wells to layers was done in accordance to the locations and depths indicated in Gerber's survey. Better survey and additional information on open hole or screened intervals for the wells will improve the usefulness of the model.

The data gaps table included with the presentation along with some discussion of the items would be very useful in the final report.

Response: This was discussed in a previous response; more information will be added for the final report.

There is a table titled "Point-wise Statistics" that was included in the presentation but not the preliminary report. The significance of this table and some discussion of it is needed for the final report.

Response: This table in the presentation was actually lifted out of the draft report, and section 2.1.3 discusses its significance.

Being able to use a close up for lot by lot or even intra lot evaluations as apparently allowed by the grid shown on "Close-Up of Grid on Survey Map" would be useful for future what-if scenarios. This is where the BIVC would ultimately like to be with the model.

Response: MACTEC would be happy to work with BIVC and John Wood to bring this about as indicated in a previous response.

The tables of "Suggested Data Gathering Activities and "Model Limitation" are what are needed for the BIVC to use and improve the model on its own. If priorities could be assigned to the data gathering and if the limitations could be discussed so that their ramifications could be understood, that would be very helpful in the final report.

Response: Section 3 will be revised as indicated in a previous response.

What are the implications for lot owners whose property falls in an area shown in yellow on presentation handout #14?

Response: This represents a potentially high risk area in terms of a high predicted concentration relative to the assumed nominal initial concentration of 100 units. Note, however, that exactly what this concentration means will vary depending on what is being discharged to ground local to each withdrawal location. Without water quality data, the true risk cannot be determined.

The presentation suggested that the model's results are sensitive to the assumed recharge rate. How sensitive is the recharge rate to the volume of run-off into the ocean? If the run-off rate into the ocean matters, why did you set "no-flow" in layer 6 rather than allowing some part amount of flow into the ocean from or via mud flats?

Response: The recharge rates assumed in the model are typical of "average" conditions. The amount of run-off of total precipitation to the ocean is somewhat a function of total precipitation. In wet years, although recharge increases, so too does the portion that would likely run-off rather than recharge. The opposite is true during dryer years, when a greater proportion of the total precipitation would recharge rather than run off. The model only considers recharge – that portion of the precipitation that actually reaches the aquifer. In looking at where the recharge (to the uppermost model layer) was moving vertically in the model, MACTEC felt that too much was moving deep to discharge to the ocean rather than in the shallower layers. Hence the boundary condition for Layer 6 was revised to limit discharge through model layer 6, and to let it come up to discharge more through the shallower layers. This is more consistent with our understanding of typical discharge patterns.

General Comments & Questions:

The central composting area is mislocated on the maps. This error should be corrected before the final report is done.

Response: The locations of all the withdrawals and returns were based on locations shown on Gerber's maps and surveys. It is likely that several more have been mislocated and should be repositioned based on the newer survey information being collected by John Wood. We can discuss this during the training sessions where we can use this as an example of how to set up new schedules for well operations and locations. It is also possible that the base map is slightly in error and that the location of the central composting area is actually coordinate correct. These details are best resolved when a new base map is imported; the practical importance of a slight displacement in location is probably slight when looking at the combined transport model distribution of concentrations.

Each cottage is a source of grey water and has either a privy or septic system. The model should be able to consider these facts.

Response: The model now has a uniform 20-foot grid. This should allow each withdrawal and return to be positioned horizontally within 10 feet of its true location.

The preliminary report figures lack clear legends for the symbols and colors used. If a symbol is used it should be identified. The background topographical lines overwhelm the lines conveying the information the figure is intended to present. Please clarify the figures for the final report. Making the figures full page size as in the presentation handout would also be helpful.

Response: We will improve the readability and usefulness of the figures for the final report by making them one figure per page and supplying other symbol and color information.

The glossary in the preliminary report was quite helpful and should be included in the final report. There are a few terms that were omitted like, "net exchange rate," "conductance," and "Ghyben-Herzberg principal."

Response: We will add the requested terms to the glossary.

Will the model allow us to examine the impact of high water withdrawals over a short period *e.g.* one multi-household family compound hosts a camp for teenage girls for 1 – 2 weeks?

Response: The current model has monthly changes in water use rates. If such a short-term high-rate use is to be included in the model, there are a couple of choices that BIVC can make. The first is to spread the total water use over a one-month period, and the second, more difficult, is to subdivide the flow and transport model time steps to include such shorter time periods. For long-term simulations, I would doubt that there would be much difference in the model output.

What is the likely modeling result of a low-recharge year or summer, or a high recharge period, assuming that use does not change?

Response: Unless the recharge was extremely low or high for an extended period, the long-term differences in the transport model probably would be slight.

I hope that this feedback will be helpful in the preparation of the final report and enable you to make it much more useful to the BIVC.

I have approved the two bills from MACTEC for payment and forwarded them to the BIVC treasurer for payment.

As you no doubt are aware, I have set with Ron Lewis October 19 and 26 at 10:00 a.m. for John Garfield and me to receive training in the use of the modeling software. I'm looking forward to seeing you again then.

Sincerely yours,

William W. Cooper,

Chairman

Water Sub-Committee

Cc: Ron Lewis – via e-mail