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# EVALUATION OF DARCIAN CONTINUUM PRECEPTS FOR DESCRIBING GROUND-WATER FLOW IN A FRACTURED-BEDROCK AQUIFER

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# EVALUATION OF DARCIAN CONTINUUM PRECEPTS FOR DESCRIBING GROUND-WATER FLOW IN A FRACTURED-BEDROCK AQUIFER

BY

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**Abstract**

Quantitative description of ground-water flow in fractured-rock aquifers is difficult because flow may be non-Darcian and hydrologic parameters are scale dependent. Due to its relative efficiency, the application of a continuum, or equivalent porous medium (EPM) approach to describing flow is desired wherever it can be deemed appropriate. The suitability of imposing such conditions on a ground-water flow model of a prototype fractured-bedrock island aquifer in Narragansett Bay, Rhode Island was investigated following favorable analysis of long-term drawdown data suggestive of Darcian ground-water flow.

A borehole geophysical investigation of the island's municipal production well is corroborative, suggesting that ground-water flow into the well appears to decrease systematically with depth. Geophysical results were also used to develop transmissivity distributions from specific capacity measurements obtained throughout the study area. The distributions were useful for evaluating transmissivity values used in a finite-difference ground-water flow model.

Due to the limited borehole data, surface geophysics were employed to investigate aquifer properties at a larger scale. Very low frequency (VLF) induction electromagnetics were applied across the study area to identify electromagnetically conductive subsurface structural features, perhaps suggestive of preferential flow. Highly conductive features were identified, corresponding with observed lineaments and other geomorphological features. These are interpreted to be large water-bearing fracture zones coincident with

the dominant bedrock foliation and fracture patterns observed in outcrop and acoustic borehole televiewer images. For purposes of finite-difference modeling however, explicit characterization of permeability in these areas is difficult due to the implicit nature of the geophysical method.

A simplified representation of fracture-zone permeability is incorporated into a finite-difference model of the aquifer assuming that decreases in formation factor across fracture zones, inferred from geophysical results, provide a minimum for permeability increases across these zones. The discrepancy between finite-difference model-generated head and field-measured head was minimized using a otherwise horizontally uniform distribution of layer transmissivity values. Finite-difference model transmissivity is higher, on average, than transmissivity estimated from specific capacity, however is within the range of the measured distribution. Model-head discrepancies are pronounced in fracture-zone areas identified in the VLF data. At best, a very generalized description of flow results, such that a description of solute transport is inappropriate.

**Acknowledgments**

Acknowledgment of the following people must be made for their contribution to this work. Their assistance, advice and willingness to help can not go unrecognized. In particular, I would like to thank Dr. Anne I. Veeger for her invaluable guidance and patience. Also, I would like to express my appreciation of Dr. Daniel P. Murray and Dr. Daniel W. Urish for the time spent discussing their experiences with Conanicut Island geology and hydrology. Special thanks go to Mr. Christopher L. Covel, P.G. for the opportunity to apply VLF electromagnetics on Conanicut Island, a technology which would have otherwise gone unexplored. Further, Mr. Patrick Craft is thanked for his guidance during an exploratory investigation of the value of ground-penetrating radar as a surface geophysical tool on Conanicut Island. I would also like to thank Mr. Nasir A. Hamidzada and Ms. Susan J. Ponte for their valuable assistance at the URI Department of Geology. Additional thanks go to Dr. Roger H. Morin at the United States Geological Survey for access to borehole geophysical data measured in Jamestown's municipal wells. Appreciation is also expressed to Mr. Steve Goslee, Director of Jamestown's Department of Public Works and to all those people in that department who provided assistance. Finally, I would like to thank Mr. Joseph Dutra and the landowners and citizens of the Town of Jamestown for access to their property during the collection of VLF geophysical data.

To my family and Rita, without whom this work would not exist.

## Preface

This thesis is written in manuscript form, conforming to the style adopted the journal Ground Water. Part one of the manuscript includes an introduction, methodology, a description of the physical setting, the results with discussion, a summary and conclusions. Part two reports supplementary information, e.g. further analyses, raw data, formulae used for calculations and a description of assumptions used.

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## Introduction

Quantitative description of ground-water flow in fractured-rock aquifers is difficult because flow may be non-Darcian and hydrologic parameters are scale dependent. Modeling field-scale flow with a reasonable level of resolution is therefore often impossible. This study attempts to illustrate that flow in a small fractured-bedrock aquifer system may be adequately and quantitatively described using Darcian continuum, or equivalent porous medium (EPM), precepts.

The impetus for the extensive study of fracture flow is its importance to contaminant migration in fracture systems. Neretieks (1980) considered the importance of the diffusion of radionuclides from fractures into the surrounding rock matrix, a topic culminating in the passage of the United States Nuclear Waste Policy Act of 1982 and, subsequently, the choice of Yucca Mountain as a potential site for the country's nuclear waste repository. This spawned a wealth of papers geared to the study of advective processes in fractures themselves, some of which have utilized the continuum approach (Bibby, 1981, Huyakorn et al., 1983a&b, Pankow et al. 1986, Endo et al., 1988, and Johnson and DePaulo, 1994).

Numerous studies have been conducted in an attempt to model ground-water flow in fractured-rock aquifers, many of which have taken the EPM approach. Applications of the continuum concept to fractured environments include a regional study using a one-mile grid spacing (Gerhart, 1984) and a twodimensional continuum model developed by Harte and Winter (1995) for the hypothetical study of the hydraulic exchange between crystalline rock and glacial deposits. Endo et al. (1984) developed criteria for the recognition of EPM behavior in an anisotropic medium based on effective hydraulic porosity using specific discharge and flow velocity. Berkowitz et al. (1988) used numerical methods to establish appropriate "equivalent" porosities for purposes of validating the continuum approach and suggested means for applying the principles to field-scale experiments. The problem associated with applying the EPM approach to field applications is that required representative elementary volumes (REV) are often at scales beyond the resolution desired. A stochastic representation of permeability has been developed by Neumann (1987) such that the continuum approach can be employed in resolving field-scale problems using aquifer units smaller than the traditional REV. Generally, for problems at scales smaller than REV's, fracture network models recognizing the characteristics of discrete fractures are required, but their employment solving field-scale problems is difficult due an inability to describe fracture geometry. Models of this type have been studied and modified by researchers such as Raven et al. (1988), Moreno et al. (1988), Brown (1989) and Ge (1997).

Due to its relative simplicity and efficiency, the application of a continuum approach to modeling flow is desired wherever it can be deemed appropriate. A prototype for such an aquifer may exist in Rhode Island, evidenced by what appears to be Darcian behavior in long-term drawdown data. The Town of Jamestown, located on Conanicut Island (Figure 1), is facing current

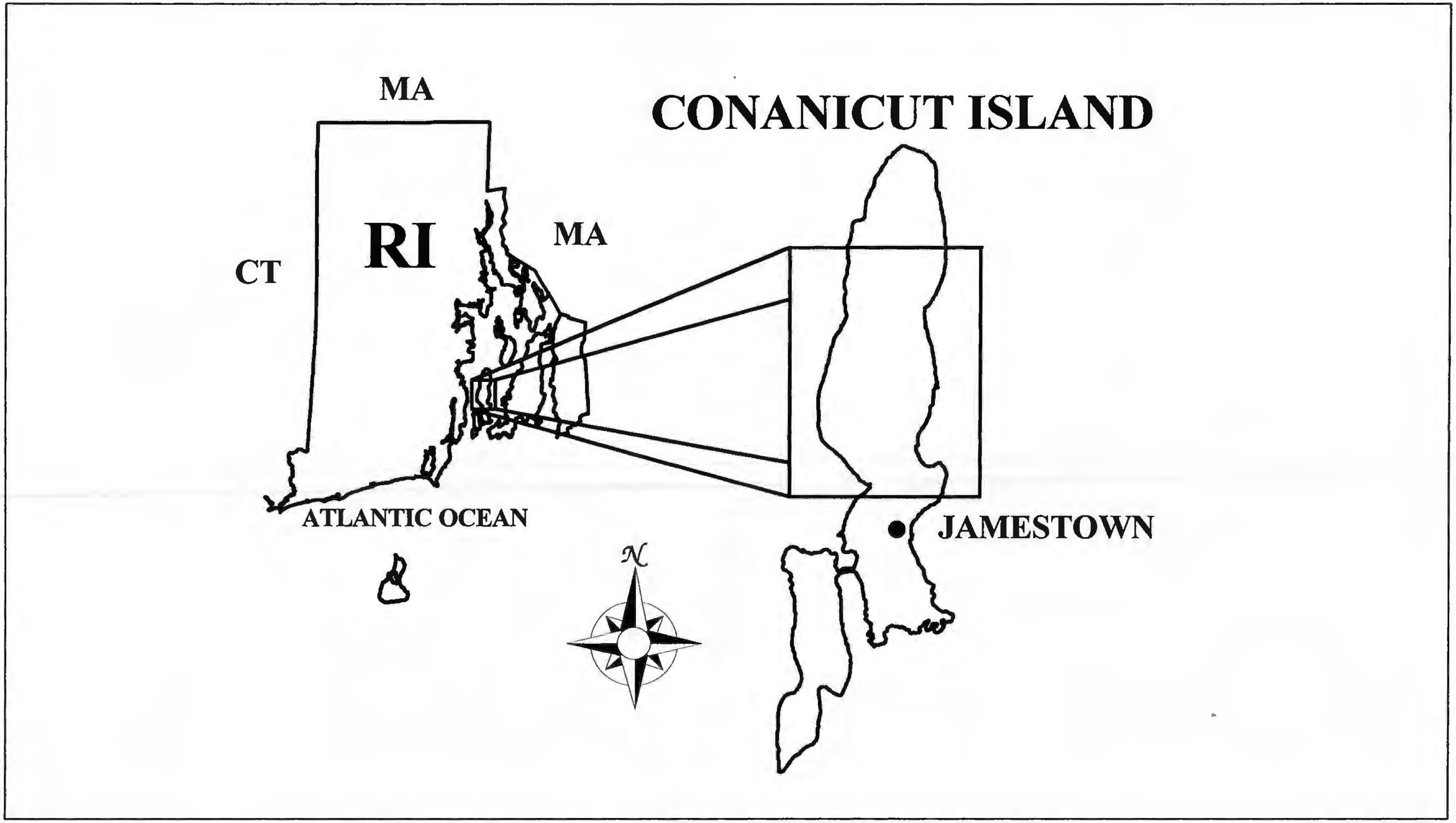


Figure 1 Location of study area on Conanicut Island, RI

and potential problems regarding its water supply. Water quality and quantity are issues the town must face in the short term. Water quality problems impacting the fractured-bedrock aquifer at central Conanicut Island, from which a portion of the municipal water supply is derived, range from salt-water intrusion to the introduction of anthropogenically derived nitrate and the potential proliferation of coliform bacteria (Veeger et al., 1997; Sandorf, 1998). The behavior of these contaminants and the required preventive and remedial efforts are dependent on the sources of the contaminants and their mechanical, as well as diffusive, behavior. The former type of behavior, which is linked to water flux, provides the impetus for this study. A successful quantitative description of the aquifer's flow characteristics provides a critical step towards an understanding of advective processes in the Conanicut Island ground-water system and the proximity and behavior of the fresh water-salt water interface to Jamestown's municipal well.

**Methodology**

The employment of a range of analytical techniques to the study is considered important in order to avoid relying too heavily on any one method. The following analyses provide the basis for an investigation of the validity of imposing Darcian continuum conditions on a quantitative description of the prototype aquifer: 1) time-drawdown behavior, 2) borehole and surface geophysics, and 3) analysis of a finite-difference ground-water flow model of the prototype aquifer.

Although calibration of a finite-difference model assuming Darcian continuum conditions supports the use of EPM precepts, additional evidence is desired to corroborate suitability. Long-term drawdown curves are suggestive of Darcian behavior if they exhibit linear behavior when plotted on semi-log axes (Cooper and Jacob, 1946). The application of long-term drawdown data to the investigation of fractured-rock aquifers has been studied by Gringarten and Witherspoon (1972) and Gernand and Heidtman (1997) with an emphasis on the impact of single-fracture flow on drawdown curves. Long-term drawdown data, although not widely available for the study area, provide a detailed look at the aquifer's response to pumping at the scale of drawdown and estimates of rock transmissivity and storativity for model construction.

Borehole geophysical data, specifically heat-pulse flow meter and acoustic borehole televiewer results, are employed to characterize the vertical distribution of fractures and ground-water flow. These methods provide information about apparent flow "continuity" at drawdown and borehole scales. Borehole geophysics have been used extensively for the purpose of characterizing aquifer hydraulics. Keys and MacCary (1971), and more recently Paillet and Crowder (1996), have outlined general principles and interpretation methods for different borehole geophysical tools. The application of borehole geophysics to fractured rock has been useful for delineating fracture orientations and yield. Morin et al. (1997) applied a variety of downhole tools, including a acoustic borehole televiewer and a heat-pulse flow meter, to the study of an aquifer in the Passaic Formation in New Jersey.

Due to the limited scale of long-term drawdown and borehole geophysical data, surface geophysics were applied to expand the investigation of aquifer properties. A variety of surface geophysical methods were considered for the purpose of characterizing the aquifer at a larger scale, e.g. geoelectrics, very low frequency (VLF) electromagnetics and ground-penetrating radar. With the first two methods, significant current density anomalies would indicate the potential for coincident subsurface zones of enhanced permeability. Significant spatial variability over short distances would further be suggestive of a discrete bedrock permeability distribution at the aquifer scale. Earth-resistivity methods have been used quite extensively by geophysicists for the location of water-bearing rock and sediment. More recently, the focus has been on the relationship between the electrical conductance of earth materials and hydraulic conductance or permeability (Katsube and Hume, 1987; Frohlich et al.,1996). The inference of a correlation between current density and hydraulic conductance at Conanicut Island is intended to identify potential discontinuity of rock permeability, i.e. to refute the continuum hypothesis set forth above.

VLF was chosen for this study due to its apparent suitability for use in the fractured environment being investigated (Michaud and Covel, 1998). VLF induction electromagnetics data are used to investigate the spatial variation of inferred current density across the study area. An explanation of VLF geophysics and theory development can be found in the Appendices. It suffices here to note that the method involves discrete measurements of induced electromagnetic field orthogonal to the strike of near-planar, electromagnetically conductive, subsurface features, e.g. ore bodies and/or water-bearing fracture zones. Models of equivalent current densities are developed using an inversion-based filter developed by Karous and Hjelt (1983).

The final step for evaluating a continuum approach to describing ground-water flow in fractured rock is the development and analysis of a finite-difference ground-water flow model. Computer code developed by Mercer et al. (1980) was initially considered for this purpose because of its ability to handle a salt water-fresh water interface. Due to the characterization of ground-water flow as predominantly shallow, changes to the position of the interface have little impact on Layer 1 head. Therefore, MODFLOW (McDonald and Harbaugh, 1988) and the I/O interface program Processing Modflow (Chiang and Kizelbach, 1996) was eventually selected for project simplification. The model is expected to identify areas for which continuum precepts may not be appropriate. Calibration difficulty and unreasonable model behavior are used as criteria against which the suitability of a continuum approach will be measured.

**Physical Setting**

The Pennsylvanian-age Rhode Island Formation of northern Conanicut Island is comprised of highly deformed metasedimentary rock, the history of which is summarized by Burks et al., 1998. During an extensional event marking the onset of the Alleghanian orogeny, the alluvial fan sediments of the Rhode Island Formation were deposited in a transtensional, non-marine basin within the Avalon terrane, and consisted of sandstone, conglomerate and shale, plus subordinate coal. Convergence of the African and North American plates, with associated deformational processes, account for the rock's schistose texture. NNE-trending, west-verging coaxial and isoclinal folds mark the first deformational event which is associated with the dominant foliation in the study area, dipping to the east and subparallel to bedding. NNE and NNW-trending, east-verging open folds are associated with a subsequent deformational event. Amphibolite metamorphic facies are associated with these deformational events, with isograds in the study area ranging from garnet in the east to staurolite in the west. Subsequent deformational events are associated with sinistral followed by dextral shear across the Beaverhead Shear Zone. The shear zone serves as the southern boundary of the study area and separates the Pennsylvanian rocks in the study area from Cambrian rocks of the Jamestown Formation to the south.

Relatively little bedrock exposure exists on the island such that outcrop measurements in the study area are limited to an exposure on the western shoreline (Figure 2). Quartz veins parallel to the dominant foliation (oriented approximately N17E, 33E at the western shoreline) are observed in the rock outcroppings. Veins can also be observed cutting across the foliation, coincident with near-vertical E-W trending fractures described by McMaster et. al. (1980). The near-vertical fracture system, oriented approximately N86W, 89N, has non-uniform spacing ranging from approximately 3 cm to 3 meters. Fractures appear to be discontinuous, pinching out in the more quartz-rich layers. A fracture system nearly orthogonal to the dominant foliation and oriented approximately N24E, 48W at the western shoreline suggests a possible conjugate relationship

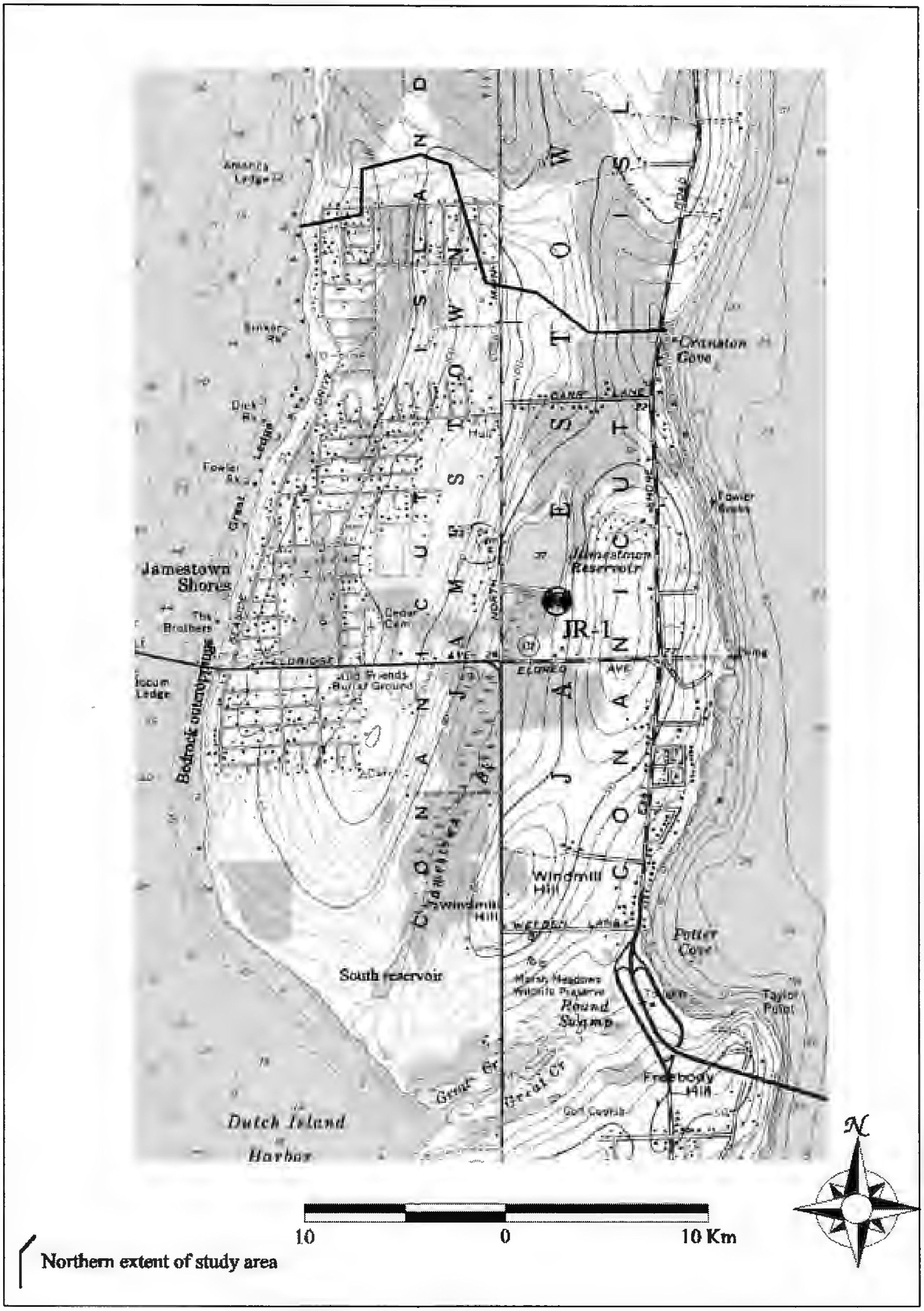


Figure 2 Study area

(Figure 3). Other surfaces that comprise potential water-conducting systems can be observed in outcrop, including a pair of fracture systems oriented approximately N17W, 74W and N61E, 76N. These systems may be tied to sinistral and dextral shear during post-Devonian tectonics as suggested by McMaster, et al. (1980).

Fractures and other surfaces related to stresses experienced by the rock are expected to provide for secondary porosity and preferential ground-water flow. The nature of the strain responsible for the surfaces, i.e. brittle vs. ductile strain, may determine the sequence of fracture formation and fracture aperture. Surfaces that formed contemporaneously with metamorphism, e.g. the dominant foliation on Conanicut Island, are expected to have a smaller aperture than those experiencing brittle strain. These foliation surfaces, however, are more pervasive. For purposes of quantitatively describing ground-water flow through fractures, the focus has traditionally been on discrete systems. Fracture interconnectivity and continuity of permeability, however, would allow for the use of continuum methods for describing the flow of ground-water.

Although the hydrogeology of Conanicut Island is dominated by fracture flow, the water table resides in surficial glacial sediments. Till comprises much of the sediment overlying bedrock, particularly on ridges and elevated areas, averaging 10 feet (± 7 feet) in thickness. Water-table depths in till average 6 feet (± 2 feet), indicating an average saturated till thickness of approximately 4 feet (Appendix I). The water table mirrors topography closely, suggesting low

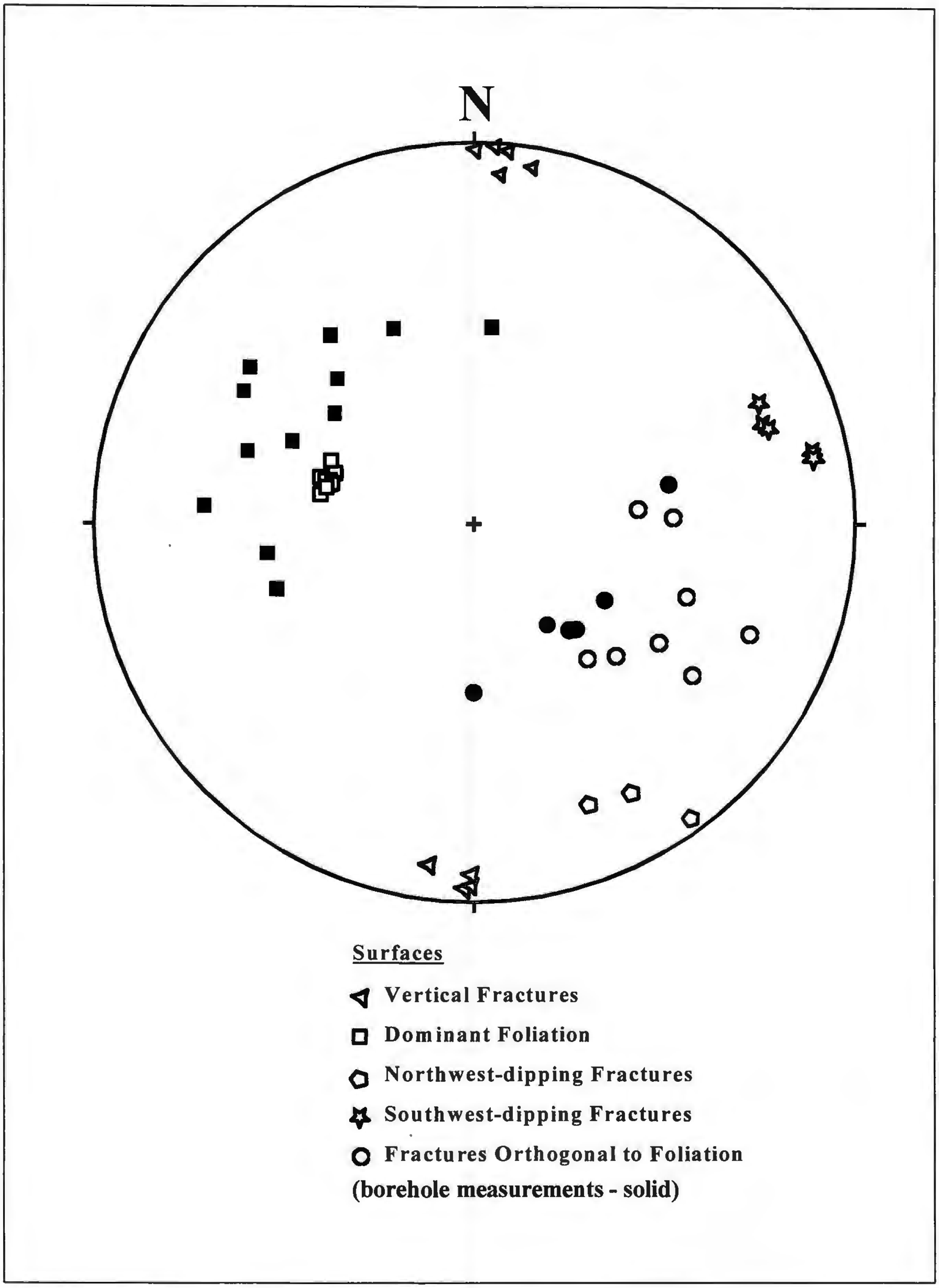


Figure 3 Poles of potential water-bearing bedrock surfaces

hydraulic conductivity. JR-1, the municipal production well serving the Town of Jamestown, is cased through sediments to a depth of approximately 38 feet. A significant amount of ground water is expected to flow through the surficial material in the Jamestown Brook area, much of which appears to consist of stratified glacial melt-water deposits. JR-1 is pumped at a maximum rate of approximately 45 gallons per minute (gpm) for eight hours a day and discharges directly to the municipal water-supply system. Potential for a hydraulic connection between JR-1 and Jamestown Reservoir exists and is the subject of further study.

Conanicut Island ground water is derived solely from precipitation, averaging approximately 3.5 inches per month (Figure 4). Discharge to fresh-water bodies, across the shoreface into Narragansett Bay, well discharge and evapotranspiration account for ground-water loss from the system. For comparable hydrologic conditions on Block Island, Rhode Island, Veeger and Johnston (1996) estimate evapotranspiration to be approximately 50% of precipitation. Ground-water system boundaries include the water table, inferred no-flow (Neumann) boundaries to the north and south (coincident with inferred ground-water divides and streamline boundaries) and the lower boundary defining the salt water-fresh water interface. A conceptual cross-sectional representation of generalized ground-water flow in the vicinity of JR-1 is shown in Figure 5. At the scale of an appropriate REV, fracture orientations discussed above are expected to allow for net ground-water flow in any direction, characteristic of an equivalent porous medium.

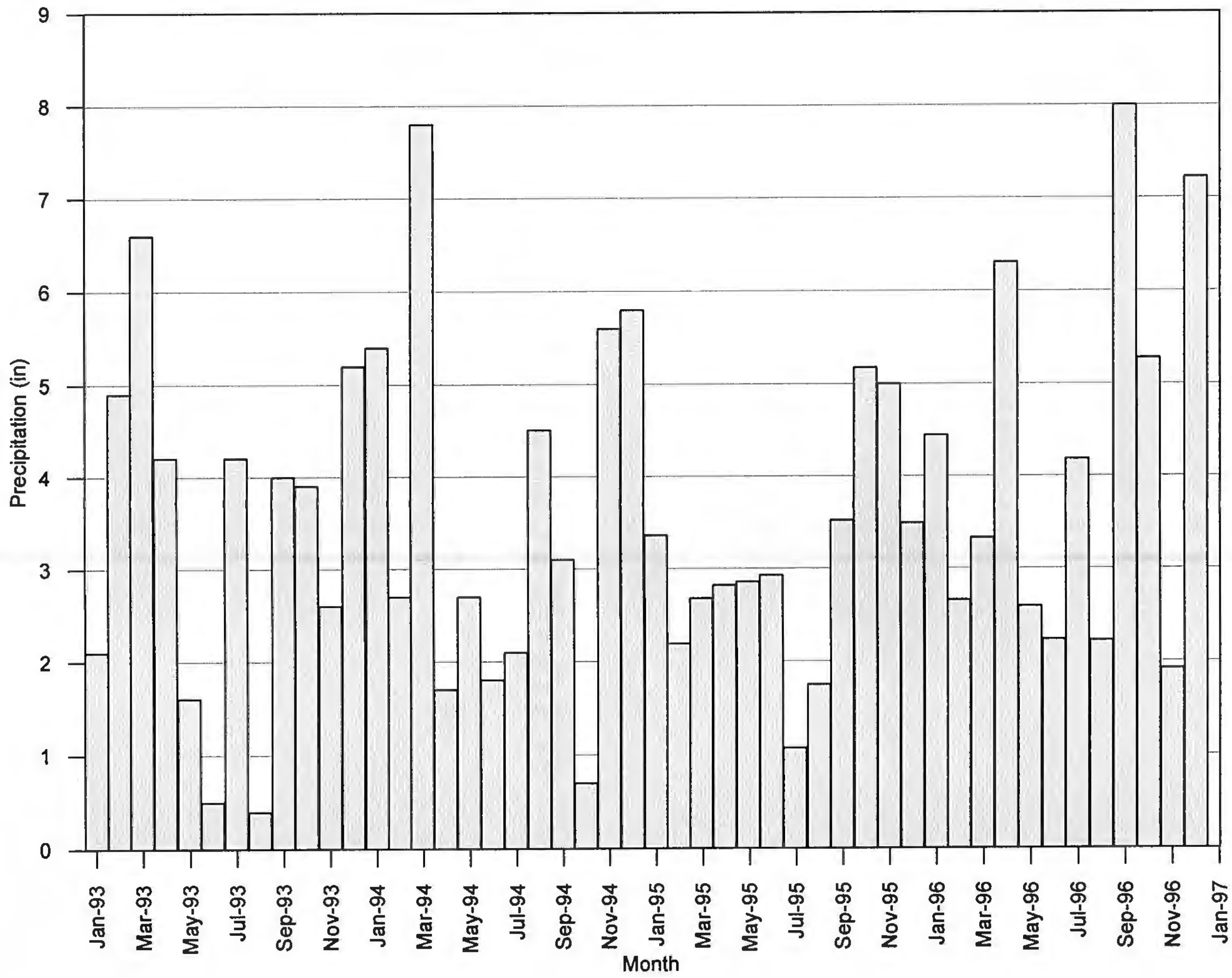


Figure 4 Monthly precipitation for the period 1993-1996

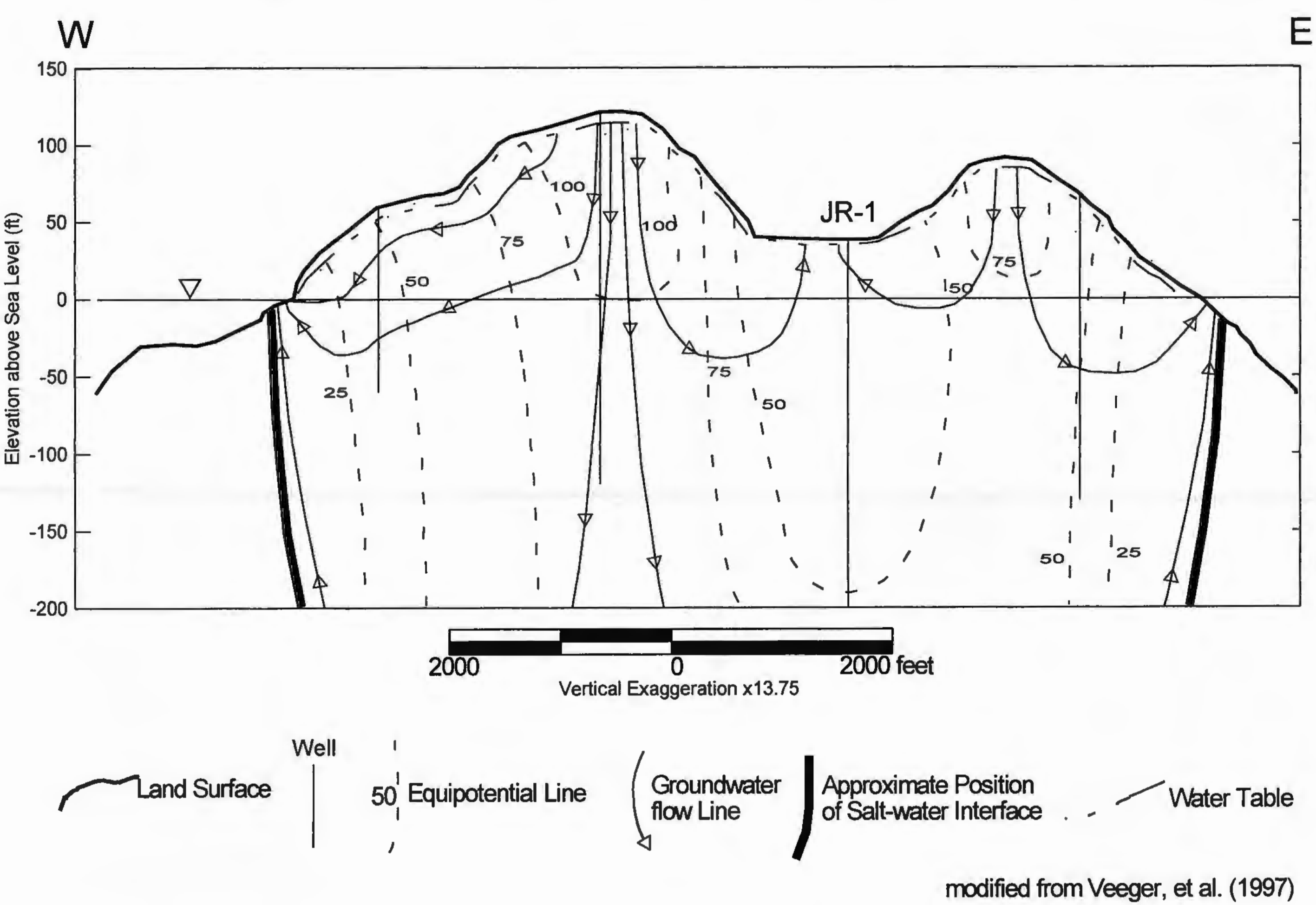


Figure 5 Conceptual cross-section of ground-water flow in the vicinity of JR-1

## Results and Discussion

Long-term drawdown data exist for two wells in the study area, JR-1 and JR-2, a well located approximately 200 feet to the south of JR-1. SR-1, located at the northern edge of the south reservoir, is effectively "dry" over its 250 foot depth. Two additional production wells were drilled in the vicinity of the Route 138 overpass along N.Main Road in 1997 and 1998, however aquifer tests are pending Rhode Island Department of Environmental Management (RIDEM) approval. Figure 6 illustrates time-drawdown data for JR-1 and JR-2 on semi-log axes. The linear segments are suggestive of Darcian behavior, which assumes continuum conditions. The change in slope after 50 hours of pumping indicates that the cone of depression has encountered a less permeable part of the aquifer. Maximum drawdown does not extend below the surface of the bedrock, suggesting that accelerated drawdown in JR-1 is not likely due to fracture dewatering, but to aquifer heterogeneity. Data obtained from nearby observation wells also exhibit linear behavior.

Borehole geophysical data further suggest continuum-like conditions in the vicinity of JR-1 (Figure 7). A suite of borehole geophysical tools was applied to JR-1 by the United States Geophysical Survey (USGS) in 1996, including a acoustic borehole televiewer, heat-pulse flow meter, caliper and resistivity sonde. Acoustic images of the borehole interior were used to map fractures intersecting the borehole and position the flow meter for measurements. The poles of some borehole-intersecting fractures are shown in Figure 3. Orientations of other

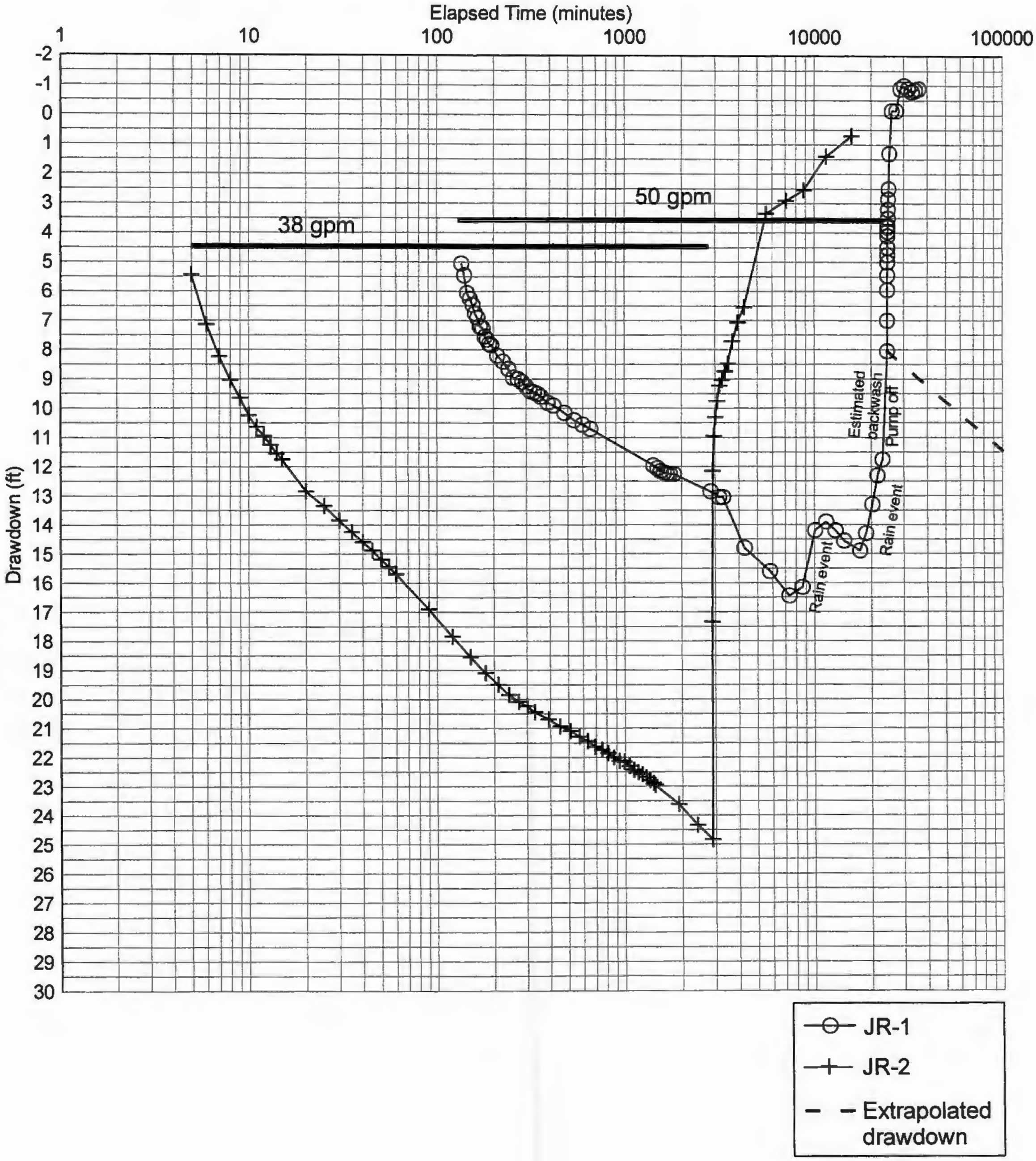


Figure 6 Time-drawdown curves for JR-1 and JR-2

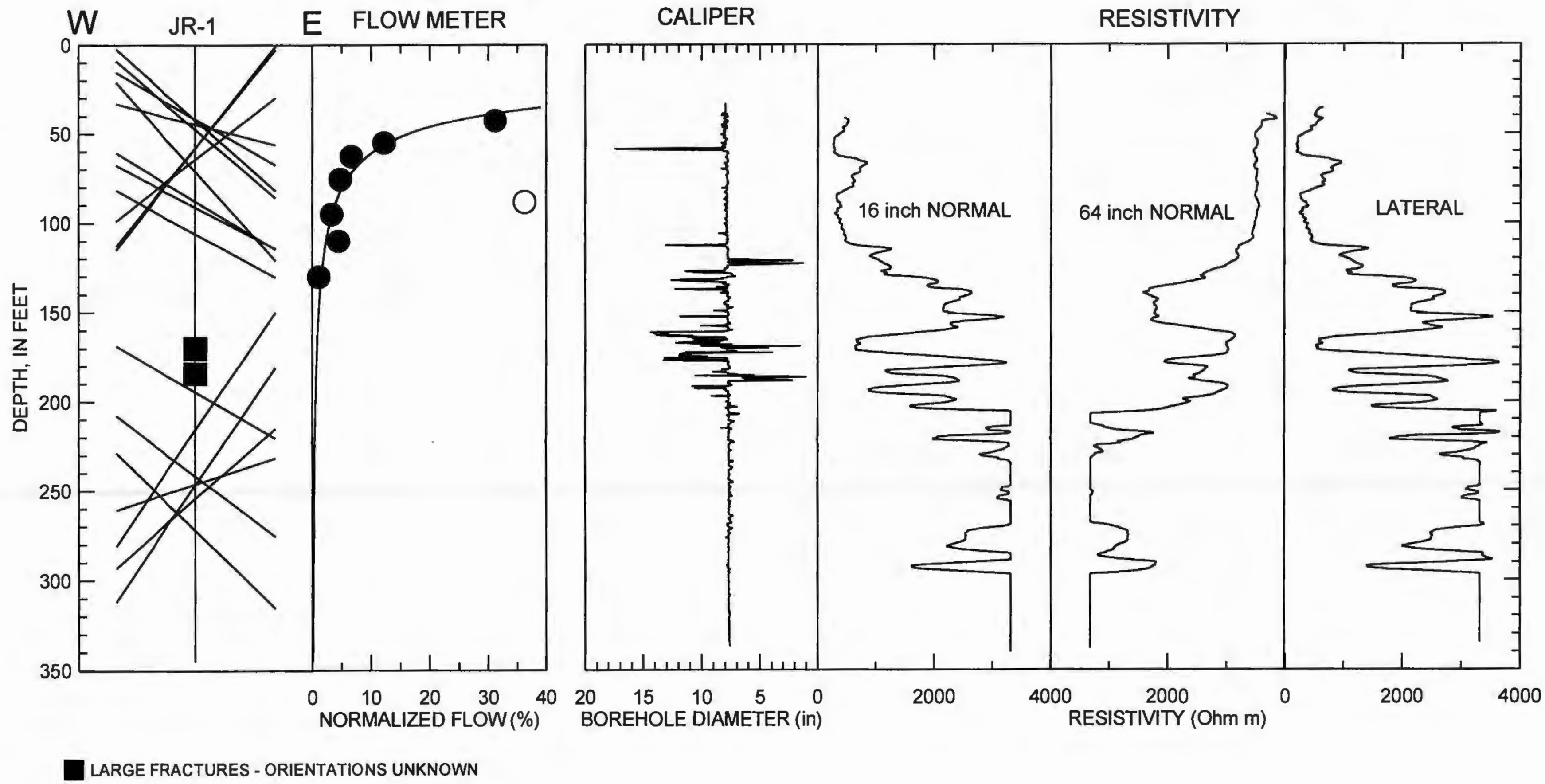


Figure 7 Geophysical logs for JR-1

fractures were not easily measured from televiewer images due to the irregular geometry of the fracture images. Furthermore, near-vertical fractures do not appear in the televiewer images.

Ground-water flow into JR-1 has apparent continuity that can be described using a logarithmic function of depth, with flow into the well decreasing by 2.5 orders of magnitude for every order of magnitude drop in elevation into the well. Assuming horizontal ground-water flow, one may also characterize rock permeability in this way. The anomalous value for flow at a depth of approximately 88 feet underscores the difficulty of working with fractured rock and the importance of fracture interconnectivity or isolation for evaluating continuity. Caliper results are shown to illustrate that the existence of fractures or incompetent rock does not necessarily result in increased ground-water flow to the well.

The flow meter results are supported by the relationship between measured transmissivity estimates and well depth (Figure 8). Transmissivity estimates, obtained from private wells scattered throughout the study area and normalized by well depth, can be seen to decrease relative to well depth. Rock at increasing depth is generally contributing less water to these wells. Some concern has been expressed regarding the validity of this relationship for the evaluation of ground-water availability at depth (Trainer, 1988; Daniel, 1989; Loiselle and Evans, 1995). The potential for statistical interdependence of well yield and well depth should be recognized. This interdependence may play a

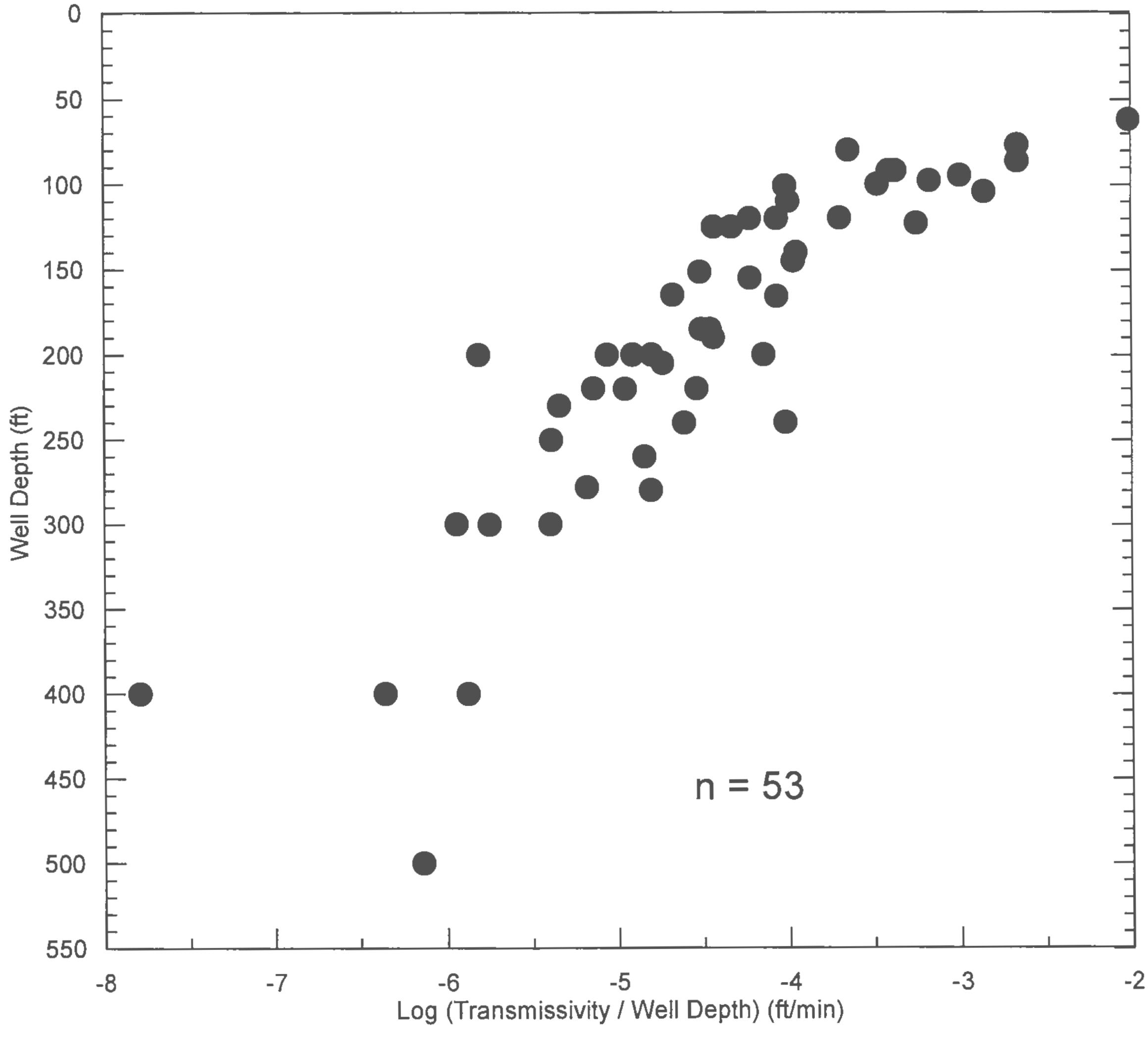


Figure 8 Transmissivity from specific capacity v. well depth for Conanicut Island, RI

role in the apparent inverse correlation between transmissivity and the depth of rock yielding water.

The apparent vertical continuity of flow observed in JR-1 is important for this study because it suggests that hydraulic conductivity may have an effectively smooth or near-continuous vertical distribution at some scale. This is useful for defining a REV; however, the isolated water-bearing fracture responsible for a break in the distribution suggests the need to describe flow through individual fractures if solute transport is to be accurately predicted. Linear behavior of municipal well drawdown over time, expected with Darcian flow, also suggests that continuum conditions exist at the drawdown scale. These results are important for a finite-difference description of the aquifer because the aquifer's hydraulic properties may be quantified and applied to model cells representing volumes of rock. Expansion of the investigation of aquifer properties is required however, to test the feasibility of a continuum approach beyond JR-1 and JR-2. VLF geophysics provide an efficient means for the collection of data over a large area. Prior to VLF data collection, USGS quadrangle sheets, a Rhode Island state bedrock map (Hermes et al., 1994), aerial photographs and bedrock structural data obtained on site were evaluated. VLF measurement transects were chosen based on geomorphology (Figure 9). A lineament was identified along the western shoreline (Figure 10), potentially associated with a fault delineated on the state bedrock map. Another lineament corresponds to the valley containing Jamestown Brook. The trend of each of these features is

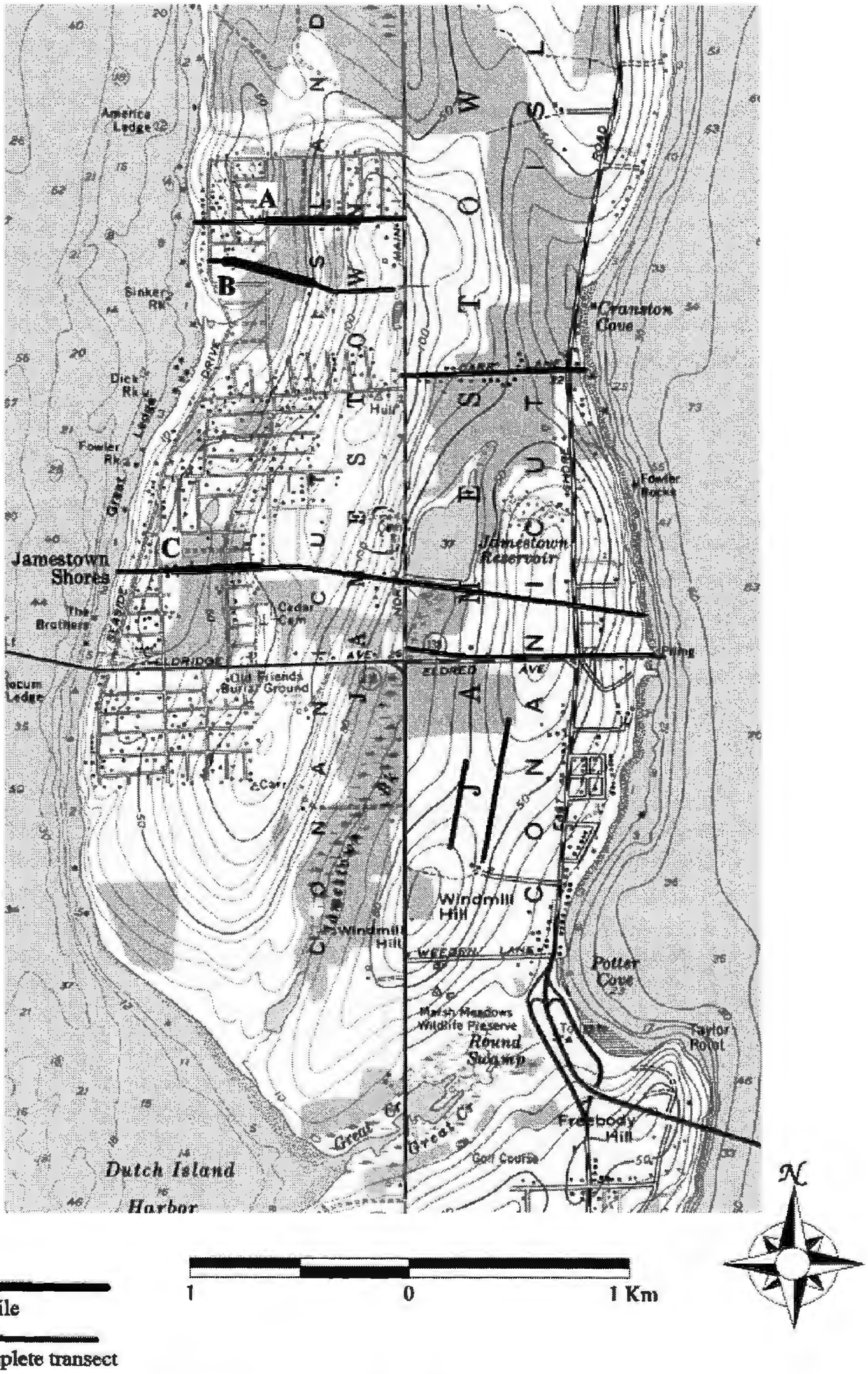


Figure 9 VLF survey transects and current density profile locations

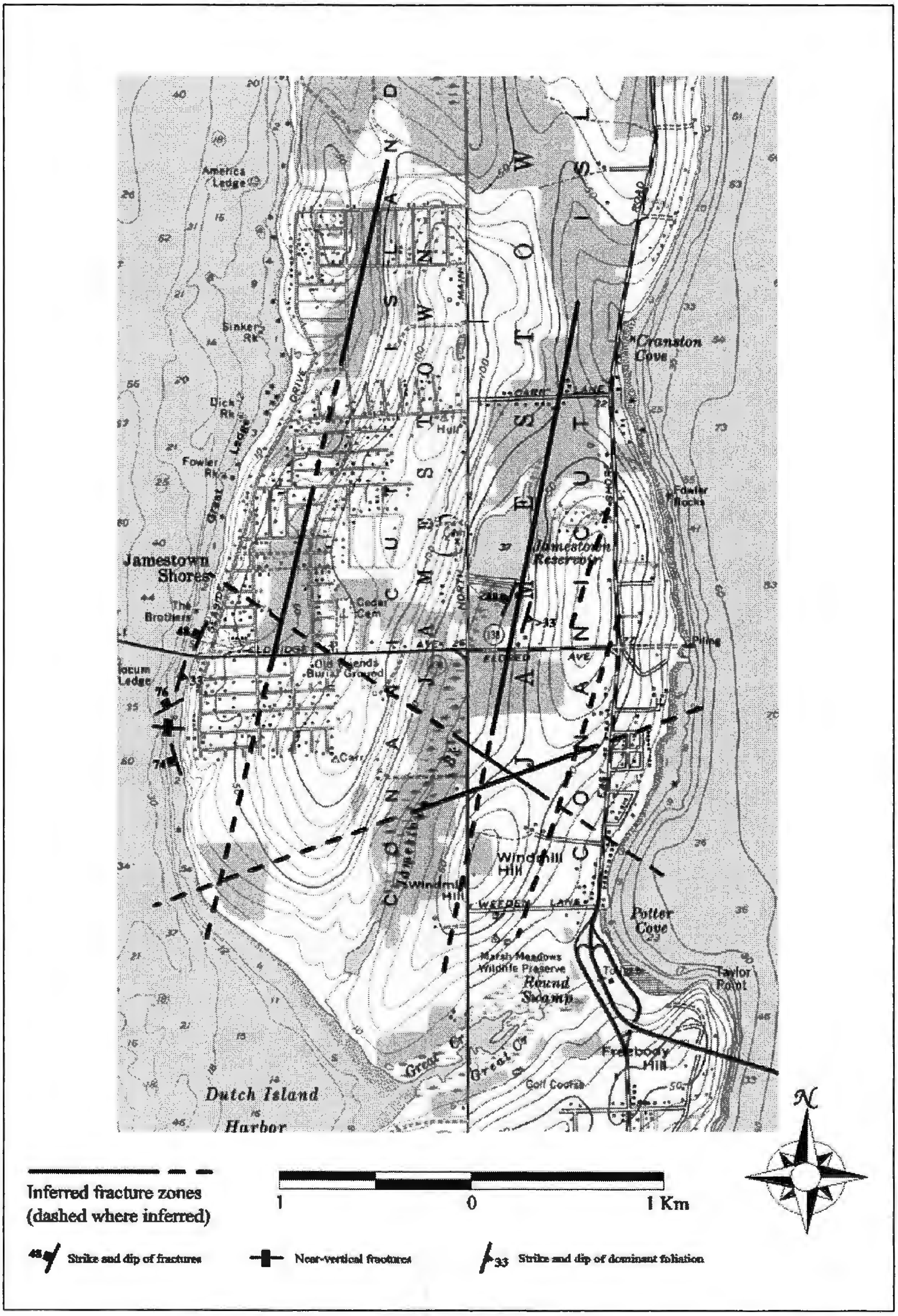


Figure 10 Fracture zone locations inferred from geomorphology and VLF surveys

coincident with the trend of the dominant bedrock foliation. A third target for VLF investigation was a topographic saddle just north of Windmill Hill. ABEM WADI™ instrumentation was used for the collection of VLF data along three transects across each lineament using a 24 kHz signal emitted from Washington state and two transects parallel to the axis of the ridge defining the topographic saddle using a 24.8 kHz signal from Maine.

Data interpretation is based on output generated by ABEM's SECTOR™ and VLFMOD™ inversion software. Current density models, or profiles, shown in this report represent subsections of extensive measurement transects where remarkable features are identified (Figure 10). Modeling VLF current densities to a depth of 100 meters is reasonable. Generally, formation resistivities in excess of 1000 Ω·m were measured in JR-1 during the borehole geophysical investigation (Figure 7). This translates to a minimum VLF skin depth, $\delta$, of 100 meters using

$$\delta = 503\sqrt{\rho / \upsilon} \qquad (1)$$

where $\rho$ is the resistivity of competent rock in Ω·m and $\upsilon$ is the frequency in Hz (ABEM, 1987). Modeled data in Profile A indicates a strong current density in the vicinity of measurement station 70W, i.e. 70 meters west of the base station, 0E (Figure 11). Station 70W is located at the topographic low within a swale corresponding to the identified lineament, through which a stream flows to the south. The current density signature has an apparent east dip assumed to correspond to the dominant foliation, S1a. There is also a signature suggestive

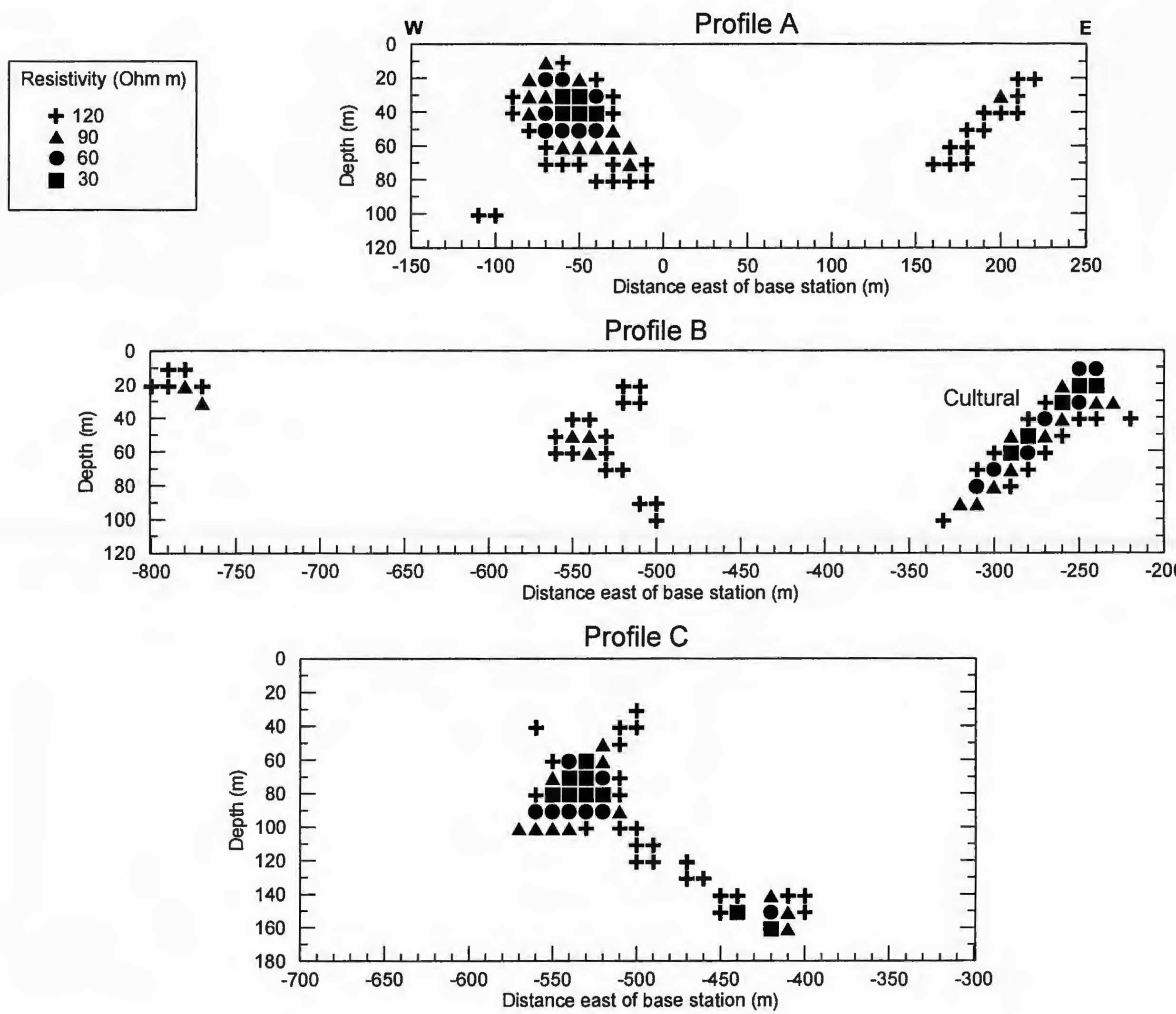


Figure 11 VLF current density Profiles A, B and C

of a west-dipping feature in the vicinity of station 70W, perhaps concordant with the fracture system orthogonal to S1a. A much more defined west-dipping feature is modeled in the vicinity of station 200E. Figure 11, Profile B, shows modeled current density approximately 400 meters south and down strike from Profile A. The current density interpretation includes a strong east-dipping and a west-dipping feature in the vicinity of measurement station 540W, an area of significant ground-water discharge as observed in the field during data collection. Note the decreased resistivity at the center of the cross-pattern, suggesting a juncture of two fractured zones. This type of signature is repeatedly expressed in the filtered VLF data, for example in the vicinity of station 540W, Profile C (Figure 11). Manifestations of a potentially continuous fracture zone related to the dominant bedrock foliation and the fracture system orthogonal to that foliation are interpreted from anomalous VLF measurements along transects corresponding to profiles A, B and C. Other current density profiles are found in Appendix V.

Resistivities as low as 30 Ω·m (330 μS/cm) are inferred by the VLFMOD™ model along Transect A (Figure 11). This translates to electrical conductivities that are higher, on average, than Conanicut Island ground-water measured by Veeger, et al. (1997), suggesting the existence of mineralized water coincident with the fracture zones and/or high fracture-surface electrical conductance. The areas outside those exhibiting strong current densities are expected to have resistivities comparable to competent rock due to the low measured signal strength. This has serious implications for the hypothesis being tested. A change in resistivity in excess of an order of magnitude may translate into a comparable variance in rock permeability. This results in a significant restriction on an attempt to model flow using continuum precepts. Uncertainty regarding the effect of the identified fracture zones on rock permeability results in a lack of confidence in describing the aquifer's hydraulic properties.

Fracture permeability, $k$, has been estimated as a function of the rock's formation factor ($F = \frac{\rho_R}{\rho_{pw}}$) and fracture aperture, $d$:

$$k = \frac{\rho_{pw}}{\mathrm{b}\rho_R} d^2 \qquad (2)$$

where $\rho_R$ is formation resistivity, $\rho_{pw}$ equals pore-water resistivity, coefficient b equals 12 for sheet-like pores and fracture aperture, $d$, is measured in meters (Katsube and Hume, 1987). Formation factor has been inversely related to the product of individual fracture aperture and fracture density. Estimates of permeability from resistivity are therefore dependent not only on the width of the conductive zone, but also on individual fracture aperture within the fracture zone. Implications are for a *minimum* permeability variance in excess of an order of magnitude (i.e. $\frac{1000\Omega \cdot \mathrm{m}}{30\Omega \cdot \mathrm{m}}$) in the vicinity of the observed conductive zones along Transect A, without explicitly recognizing the impact of individual fracture aperture in these zones.

Unlike the long-term drawdown and borehole geophysical results, interpretations of VLF data collected over a broad scale reveal what may be sharp gradients in bedrock permeability. Furthermore, the hydraulic properties of the rock where VLF anomalies occurred are difficult to quantify. VLF geophysical results, therefore, bring into question the feasibility of a continuum approach for quantitatively describing the aquifer at a scale incorporating the identified fracture zones. Required REV's would be small such that variability of fracture-zone hydraulic properties could be described, requiring large amounts of data. Nevertheless, VLF results reveal aquifer characteristics that can be incorporated into a finite-difference model. Such a model serves as a final approach for the evaluation of the workability of Darcian principles.

The computer program MODFLOW (McDonald and Harbaugh, 1988) was used to numerically solve for hydraulic head values such that governing equations for flow are satisfied for specified parameters and boundary conditions under steady-state conditions. For purposes of finite-difference simulation, the aquifer is discretized into a rectangular grid consisting of a maximum 32 columns, 47 rows and 10 layers, allowing flexibility for shoreface discharge area (Figure 12). The horizontal extents of the cones of depression around JR-1 and JR-2 were used to establish a grid spacing (Figure 13). Grid spacing is 250 feet in the vicinity of JR-1. A lateral discretization of 500 feet is adopted beyond the drainage divide delineating the Jamestown Brook watershed.

A no-flow, or Neumann, boundary is used at the northern extent of the modeled area to simulate inferred ground-water divides and streamline boundaries. The potential for subsurface recharge across the boundary is

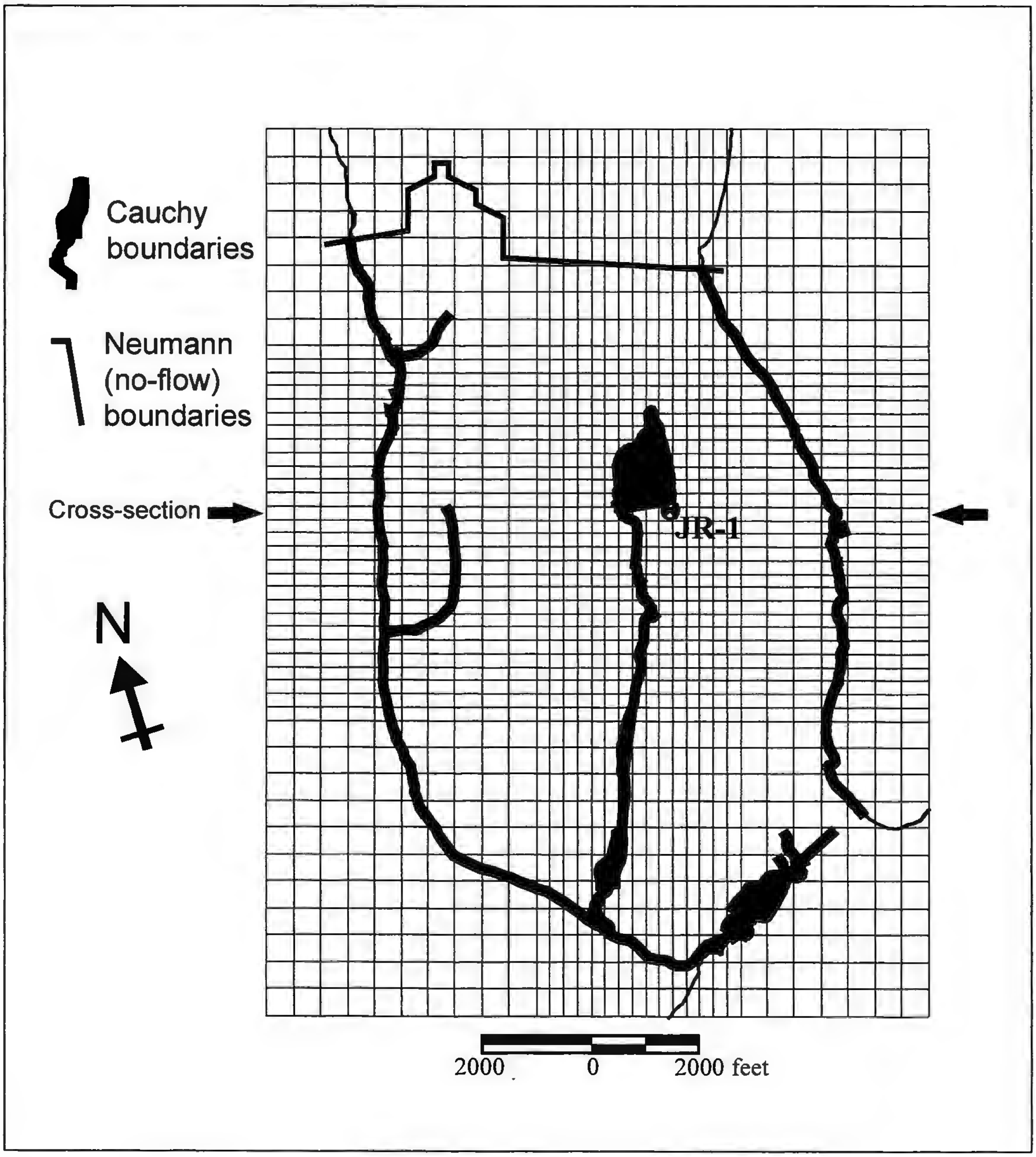


Figure 12 Finite-difference model grid

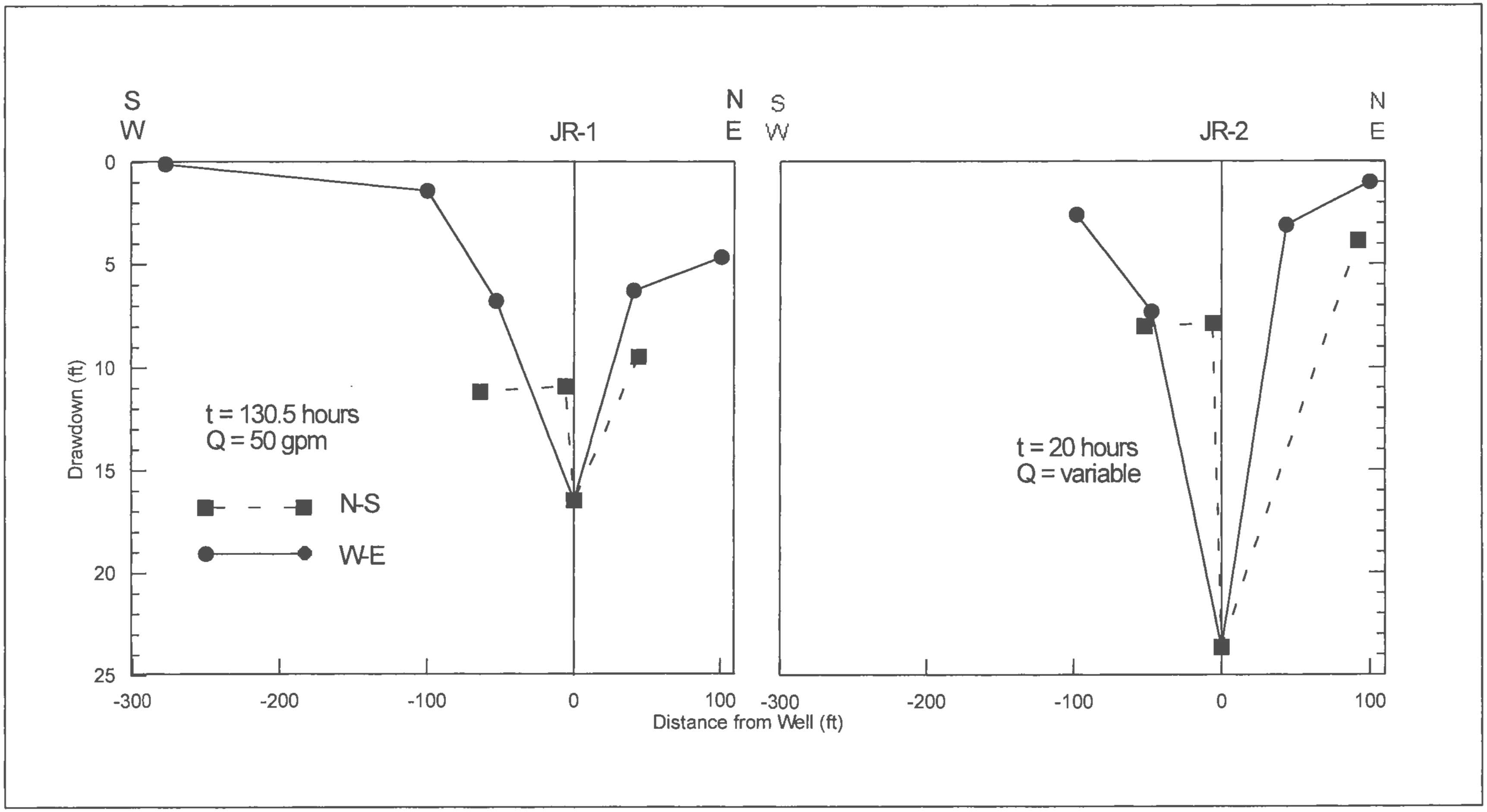


Figure 13 Maximum drawdown profiles in JR-1 and JR-2

ignored. Inactive cells below layers 6, 8, 9 and 10 are used to simulate the no-flow boundary associated with the fresh water-salt water interface at depth. Due to the lack of data available for calibration of this boundary, constraints on model parameters and the balance of hydraulic potential across the boundary drive the location of this boundary.

The thickness of the top layer (layer 1) is constrained by the gradient of the land surface such that, for any particular layer, cell tops do not occur below the bottoms of adjacent cells. In order to simulate various distributions of hydraulic conductivity as a function of depth, elevations of cells within each layer are equidistant from the land surface elevation for each cell column (Appendix II). Land-surface elevations are estimated directly from United States Geological Survey quadrangle sheets (USGS, 1955; USGS, 1957). Layer thickness increases linearly with depth such that more resolution can be obtained for shallow layers, where the greatest amount of flow is shown to occur in JR-1. The no-flow boundary representing the salt water-fresh water interface at depth, is placed at an elevation, $z$, relative to mean high water, such that equilibrium of hydraulic potential across the boundary is reasonably approximated. $z$ is approximated by $\frac{\rho_f}{\rho_f - \rho_s} h_f$, where $\rho_f$ equals fresh-water density, $\rho_s$ equals salt water density and $h_f$ equals fresh-water head at the boundary. The configuration of active cells appears in Appendix II. The impact of changing finite-difference model parameters on the interface position is limited to evaluating the relationship between hydraulic potential across a stationary no-flow boundary. Small adjustments to the vertical distribution of hydraulic conductivity have a negligible impact on model generated head.

The MODFLOW River Package simulates ground-water discharge to surface water bodies with head-dependent, or Cauchy, boundary conditions. To simulate shoreface discharge, the area factor of conductance is expanded or contracted from the shoreline for various discharge area simulations. The vertical components of hydraulic conductivity for cells beneath these Cauchy boundaries are similarly treated. Specified-head values for shoreface Cauchy boundaries are estimated as equivalent fresh-water head based on bathymetric and salinity data (Pilson 1996; USGS, 1955; USGS, 1957).

Aquifer discharge via private and municipal wells is simulated based on best available data (Johnston and Baer, 1987; Goslee, 1995 and personal communication; RIGIS, 1988). Private wells are assumed to remove 180 gpd per housing unit with a 90% return via individual septic disposal systems (ISDS). Unit density is estimated by dividing respective cell-top area by estimated area-weighted mid-range lot size. 15 gpm is drawn from cells in column 20, row 21 to simulate average daily pumping of JR-1. The vertical distribution of well discharge is assumed to be identical to the vertical distribution of hydraulic conductivity. An average well depth of 230 feet, obtained from RIDEM driller logs, is assumed for private wells. JR-1 is simulated to a depth of 385 feet.

Recharge for the finite-difference simulation is estimated at 3.5 inches per month and is intended to represent conditions during the seasonal periods for which water levels are available for model calibration. Average monthly precipitation for the January through April periods in years 1993 through 1996 is adjusted down from 3.9 inches per month to account for a lower average annual precipitation in 1987, the year most commonly represented in the available water-level data. For comparable hydrologic conditions on Block Island, Rhode Island, Veeger and Johnston (1996) estimate direct runoff and evapotranspiration to be approximately 2% and 50% of precipitation, respectively. Base flow measured in May, 1995 by Wingate (1995) provides a minimum estimate of effective recharge as a percent of precipitation, $R$, calculated as

$$R = \frac{B}{A \cdot P}\text{, or 35\%,} \tag{3}$$

where $B$ equals the base flow into South Reservoir, $A$ equals the area of the South Reservoir drainage basin and $P$ is the average precipitation for the month preceding base flow measurements. Evapotranspiration from the phreatic zone and gaining streams is not accounted for and would be expected to account for additional recharge. The MODFLOW evapotranspiration package removes 3.5 inches per month at the land surface with a linear extinction depth of 6 feet.

Analysis of aquifer properties follows careful consideration of available data (Appendix III). Transmissivity values used to calibrate the finite-difference model may be compared with transmissivity values derived in the field. Transmissivity was estimated using long-term drawdown and recovery data from municipal wells and specific capacity calculated from driller logs. Specific capacity is corrected for evacuated borehole storage. For fractured rock, transmissivity from specific capacity can be expected to be overstated (Huntley et al. 1992). Furthermore, due to dewatering, transmissivity estimates from specific capacity are dependent on the vertical interval of bedrock one assumes the measurement characterizes. Assuming that the interval spanning the saturated open borehole interval (during static conditions) is characterized, a minimum value can be established. Transmissivity values from drawdown can be standardized, i.e. normalized by a weighted standard vertical thickness of rock. Weighting is a function of inferred vertical distribution of hydraulic conductivity such that transmissivity for the bedrock interval defined by depths $d_1$ and $d_2$ is expressed as

$$T_{d_1,d_2} = T_{D_1,D_2}\left(\frac{\int_{d_1}^{d_2}\mathrm{K}(d)\,\partial d}{\int_{D_1}^{D_2}\mathrm{K}(d)\,\partial d}\right), \qquad (4)$$

where $T_{D_1,D_2}$ equals transmissivity determined from drawdown analysis and $D_1$ and $D_2$ are the depths defining the domain of flow into the well. $\mathrm{K}(d)$ is the assumed vertical distribution of hydraulic conductivity, $\mathrm{K}(d) = Cd^{u}$, such that $C$ is a well-specific coefficient defining the magnitude of transmissivity for the well in question (approximately equal to 112 for JR-1, with $T$ reported in ft$^2$/min) and $u$ is inferred from heat-pulse flow meter results ($u$ = -2.5). Distributions of normalized transmissivity from specific capacity for the top 150 feet of bedrock appear in Figure 14, assuming 1% storativity. The illustrated distributions may be considered as an upper limit based on assumed storativity. Considering the tendency for hydraulic conductivity to assume a lognormal distribution, the linear

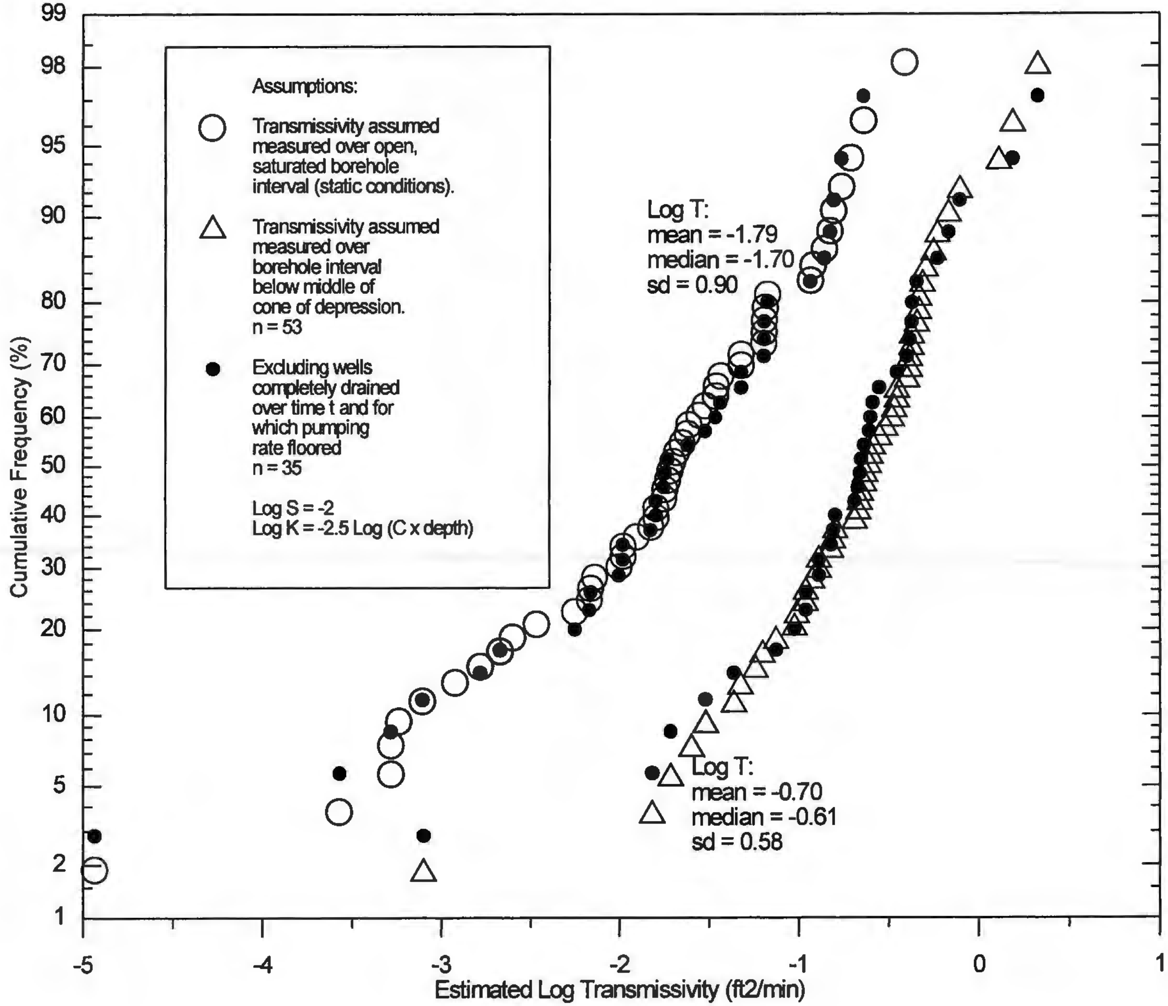


Figure 14 Distributions of transmissivity from specific capacity for the top 150 ft of bedrock

appearance of the distributions in Figure 14 suggests that the sampling of specific capacity is representative of the aquifer. Transmissivity estimates from analyses of time-drawdown and recovery data obtained at JR-1 are at the upper limit of the transmissivity distribution derived from specific capacity. An attempt to describe the spatial distribution of normalized transmissivity is shown in Figure 15, however incomplete driller logs allow only a limited number of sites to be located. The distribution illustrates that hydraulic conductivity varies considerably over a few hundred feet. With the exception of inferences made from surface geophysical results, spatial trends in the lateral distribution of permeability are not apparent and areas of relatively high yield do not correspond with fracture zones delineated in Figure 9.

Equation 4 is also used to calculate transmissivity for finite-difference model layers, defined by depths $d_1$ and $d_2$, by treating $T_{D_1,D_2}$ as a standardized transmissivity value, for example, for the top 150 feet of bedrock (with $D_2$-$D_1$=150). The standardized transmissivity is applied uniformly across the aquifer and varied until calibration is achieved. The effect of overburden is simulated by adding the term $K_{sed}b$ to equation 4 for Layer 1, where $K_{sed}$ equals the assumed hydraulic conductivity of sediment and $b$ equals the saturated sediment thickness in layer 1.

The model free-surface simulating the water table is used to calibrate the model against water levels measured during the January through April periods between 1977 and 1995 (Appendix I). Water levels were obtained from RIDEM

# Estimated Transmissivity (top 150 ft of bedrock)

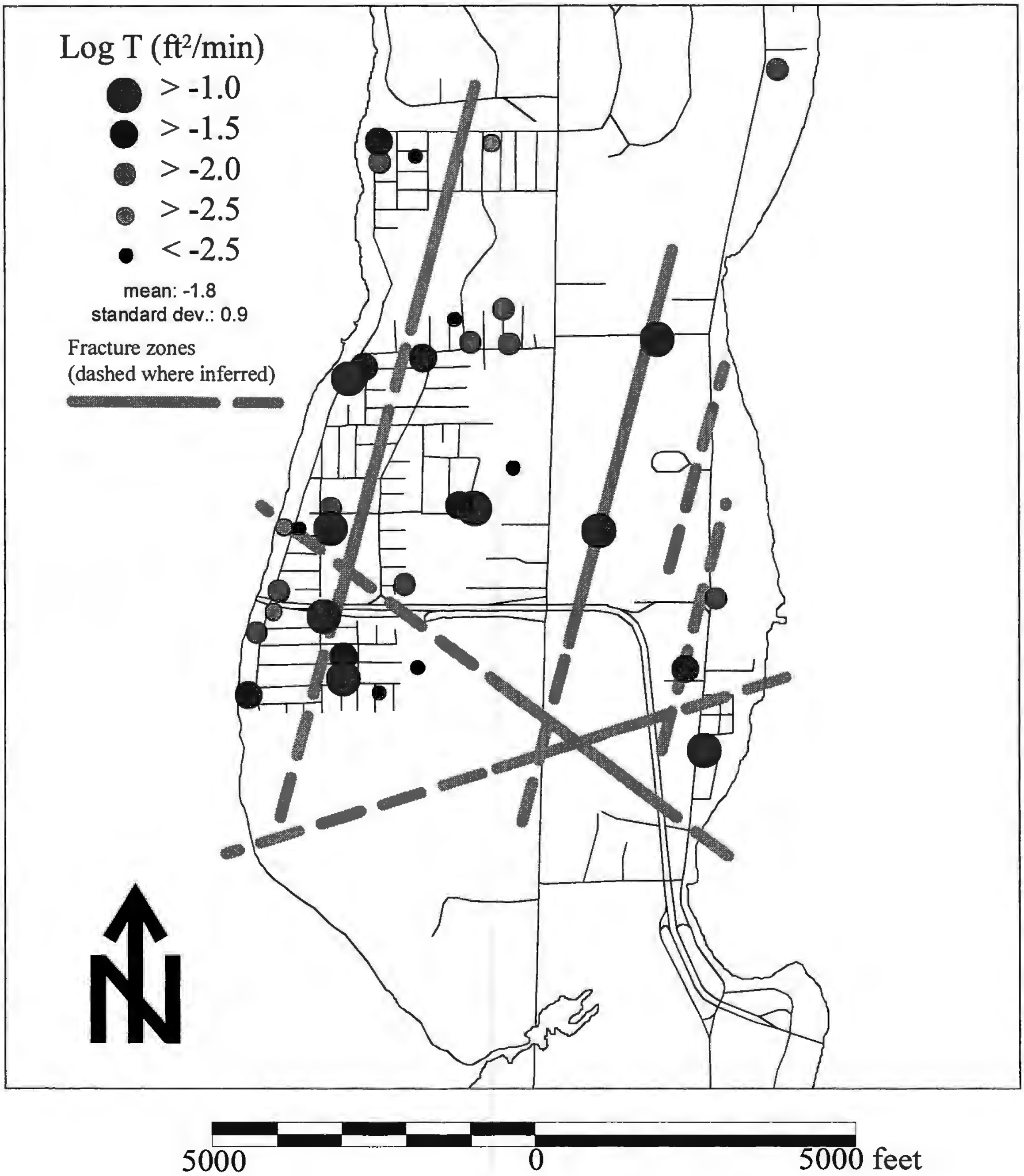


Figure 15 Spatial variation of transmissivity estimated from specific capacity

ISDS percolation test logs. Three criteria are used to evaluate model calibration in Layer 1:

$$\frac{1}{n\cdot m}\sum_{i=1}^{n}\sum_{j=1}^{m}\left(h_{ij}-\hat{h}_{ij}\right) \qquad \frac{1}{n\cdot m}\sqrt{\sum_{i=1}^{n}\sum_{j=1}^{m}\left(h_i-\hat{h}_i\right)^2} \qquad \frac{1}{n\cdot m}\sum_{i=1}^{n}\sum_{j=1}^{m}\left|h_i-\hat{h}_i\right|$$

MEAN SUM    ROOT MEAN SQUARE    MEAN ABSOLUTE SUM

where $\hat{h}_{ij}$ is model-generated head for cell $i,j$ in Layer 1 and $h_{ij}$ is estimated field head corresponding to cell $i,j$, against which model calibration is measured. Parameters used for flow simulations are shown in Table 1. The sequence of parameter variation, together with respective calibration criteria, can be followed from left to right in Table 2. Mean sums decrease from left to right across Table 2 as a specific parameter was changed until root mean square and mean absolute sum began to increase. Following the minimization of transmissivity while assuming isotropic conditions, anisotropy was adjusted to minimize root mean square and mean absolute sum. Further adjustments were made to transmissivity to minimize root mean square and mean absolute sum, resulting in Run I. Each stress period, or Run, reflects a laterally uniform distribution of transmissivity across each layer, expressed as a percentage of the proposed "minimum" transmissivity of $10^{-1.8}$ ft$^2$/min (Figure 14). The distribution of $h_{ij}-\hat{h}_{ij}$ for Run I is shown in Figure 16.

Hydraulic conductivity values for cells corresponding to fracture zones delineated in Figure 9 and Appendix II are increased for Run K by factors

**Table 1 Finite-difference Model Parameters**

| Parameter | Description | Unit | Value |
|---|---|---|---|
| Bedrock Transmissivity, $T$ | Log $T$ for top 150 ft of bedrock. | $ft^2/min$ | -1.36 to -1.24 |
| Distribution of Bedrock Transmissivity | Standard deviation of log $T$ for top 150 ft of bedrock. | $ft^2/min$ | 0 |
| Vertical Distribution of Bedrock Hydraulic Conductivity ($K$), $u$ | $K$ changes by $u$ orders of magnitude per order of magnitude drop in elevation. | dimensionless | -2.5 |
| Layer thickness' | Sequential layer thickness increase with depth. Layer 1 is 65 feet thick. | % | 31.6 |
| Anisotropy | Ratio of column $T$ to row. | dimensionless | 1.4 to 2.2 |
| Fracture zone simulation | Factor by which hydraulic conductivity increased<br>250 ft wide cells<br>500 ft wide cells | dimensionless<br>layer 1, layer 2<br>layer 1, layer 2 | <br>2, 22<br>1.5, 12 |
| Shoreface Hydraulic Conductivity, $K$ | Log $K$ for Shoreface (equal to Layer 1 $K$) with conductance calculated to reflect discharging shoreface with width $d$. | ft/min<br>$d$ (ft) | -3.2 to -3.07<br>250 to 300 |
| Precipitation (based on January-April, 1993-1996 data) | Uniform, excluding Route 138, surface water bodies and shoreface cells. | in/mo.<br>Std. Dev. | 3.5<br>±1.75 |
| Evapotranspiration | Max evapotranspiration from phreatic zone with 6 ft linear extinction depth. | ft/min | 6.7E-6 |
| Municipal Production Well | JR-1; finite-difference grid column 20, row 21. | $ft^3/min$ | 2.0 |
| Private wells | 90% of this amount assumed returned via ISDS | $ft^3/min/unit$ | 1.67E-2 |
| Bay salinity/ water density* | Bay salinity ranges from 28-31 in the vicinity of Conanicut Island. | g/cc (13°C) | 1.022 |
| Stream Head | Elevation above stream bottom (land elevation) | feet | 0.5 |
| Open water depth | minimum | feet | 4 |
| Streambed Hydraulic Conductivity | Log $K$ for 6 inch thick streambed. | ft/min | -1.2 |
| Sediment Hydraulic Conductivity (distribution in Appendix II) | Log $K$ for estimated 22 ft of saturated stratified sediment overlying the bedrock below Jamestown Brook. | ft/min | -1.2 |
| | Log $K$ for estimated 4 ft of saturated till overlying the bedrock. | ft/min | -4.7 |

* Pilson (1996), Clesceri et al. (1989).

**Table 2** **Calibration Criteria**

| Error statistic | Run A* | Run B* | Run C* | Run D* | Run E* | Run F* | Run G* | Run H* | Run I* | Run J* | Run K* | Run L** | Run M* | Run N*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mean sum | -2.430 | -2.491 | -2.551 | **-2.611** | -2.671 | -2.696 | -2.522 | -2.426 | **-2.229** | -2.020 | **-1.580** | **-7.807** | **-1.567** | **-2.400** |
| root mean square | 5.002 | 4.983 | 4.972 | **4.971** | 4.979 | 4.996 | 4.949 | 4.931 | **4.912** | 4.914 | **4.811** | **12.122** | **4.816** | **4.777** |
| mean absolute sum | 3.424 | 3.402 | 3.385 | **3.377** | 3.375 | 3.399 | 3.363 | 3.354 | **3.352** | 3.369 | **3.371** | **8.175** | **3.376** | **3.324** |
| **Parameter** | | | | | | | | | | | | | | |
| T as % of $10^{-1.8}ft^2$/min. | 300 | 300 | 300 | 300 | 300 | **290** | **310** | **320** | **340** | **360** | 340 | 340 | 340 | **270** |
| anisotropy ratio (*i* to *j*) | **2.2** | **2.0** | **1.8** | **1.6** | **1.4** | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| fracture zones simulated | no | no | no | no | no | no | no | no | no | no | **yes** | yes | yes | yes |
| recharge (in./mo.) | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 | 3.50 | **5.25** | 3.50 | 3.50 |
| shoreface width (ft) | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | 300 | **250** | 300 |

* Evapotranspiration inactive for cell 10,6 (column, row, layer 1).
** Evapotranspiration inactive for cells 10,6 and 5,5 (column, row, layer 1).
*** Evapotranspiration inactive for cells 10,6 and 5,6 (column, row, layer 1).

approaching $\left(\left(\frac{R_f}{R_a}-1\right)\cdot\frac{z_{(i,j)}}{\Delta(i,j)}\right)+1$, where $R_f$ is the assumed formation or background resistivity (1000 Ω·m), $R_a$ is the the inferred anomalous resistivity from the VLFMOD model (120 Ω·m for Layer 1 and 30 Ω·m for Layer 2), $z_{(i,j)}$ equals the width of the inferred fracture zone across column $i$ or row $j$ (10 m for Layer 1 and 50 m for Layer 2) and $\Delta(i,j)$ equals cell width perpendicular to the strike of the fracture zone. The resulting root mean square decreases, largely due to decreases in $\left|h_{ij}-\hat{h}_{ij}\right|$ in the vicinity of column 8, row 11 and column 25, row 14 (Figure 17), however mean absolute sum increases slightly. Similarly, $\left|h_{ij}-\hat{h}_{ij}\right|$ is reduced in the vicinity of the southern boundary, a complicated area incorporating no-flow boundaries simulating a drainage divide, the underlying interface and Cauchy conditions; model head however is still too high. Model generated head for Run K (Figure 18) can be compared directly with the water-table map modified from Veeger et al. (1997) (Figure 19).

Analysis of finite-difference model sensitivity to parameter variation is important due to uncertainty inherent in those parameters. Sensitivity testing was limited due to model instability. An increase of 24% in transmissivity from log T = -1.34 to -1.24 $ft^2$/min (Runs F and J) results in a mean sum decrease of 0.68 feet, or 25%. A 25% increase in hydraulic conductivity from log T = -1.37 to -1.27 $ft^2$/min (Runs N and K) results in a mean sum decrease of 0.82 feet, or 34%. In both instances, mean absolute sum and root mean sum decrease by marginal amounts. Based on the finite-difference model results, transmissivity

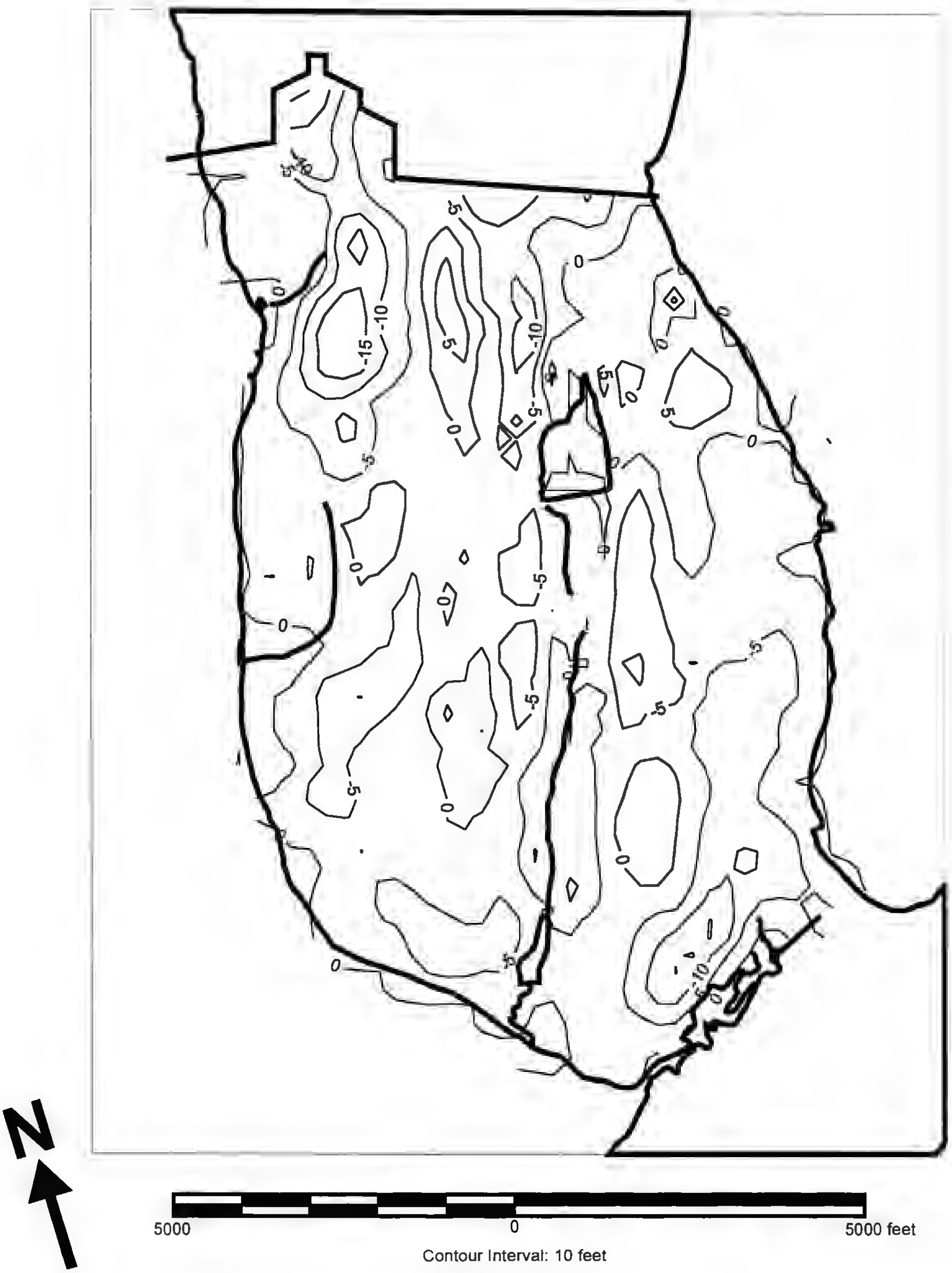


Figure 16 Distribution of $h_{ij} - \hat{h}_{ij}$, Layer 1, Run I

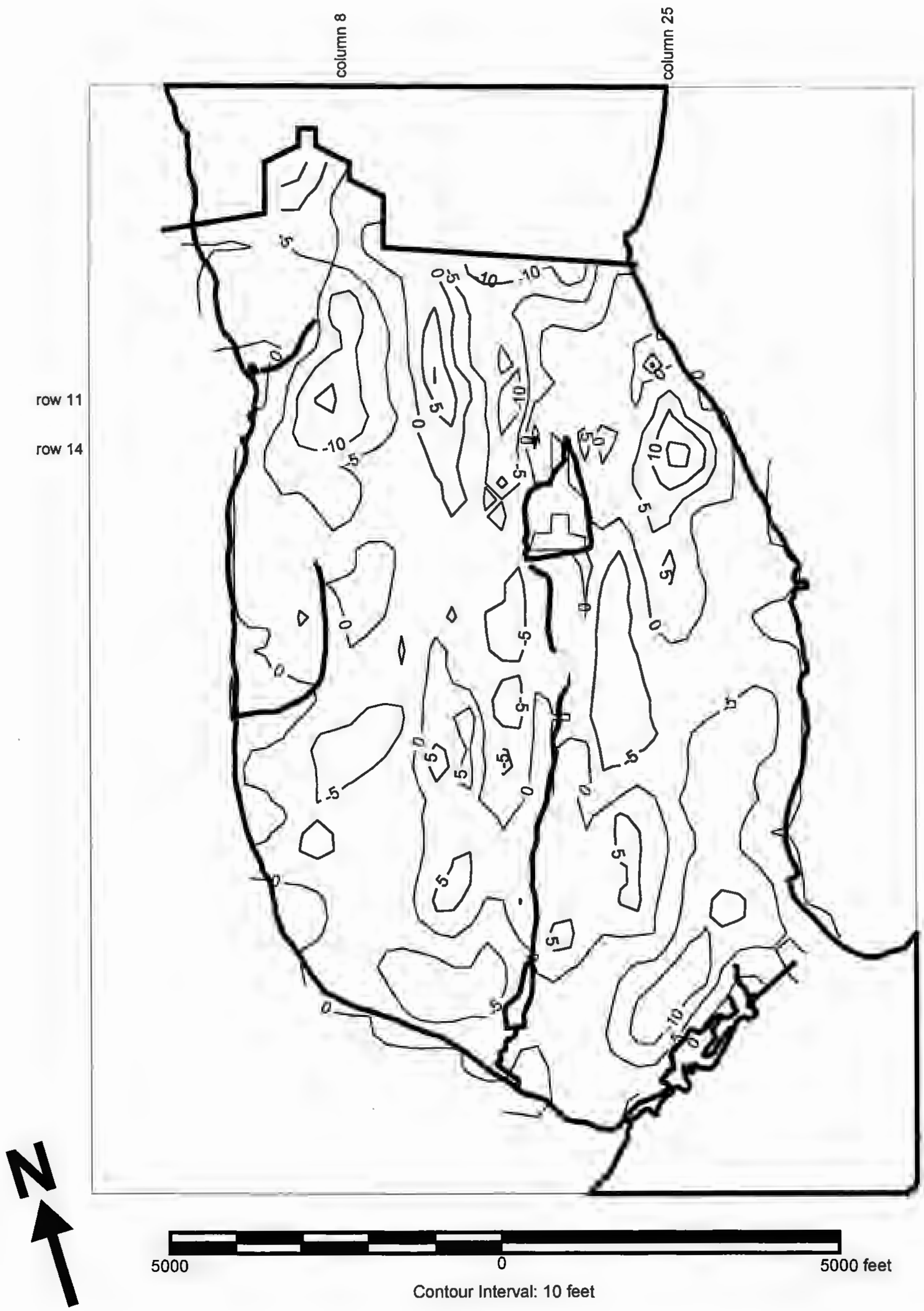


Figure 17  Distribution of $h_{ij} - \hat{h}_{ij}$, Layer 1, Run K

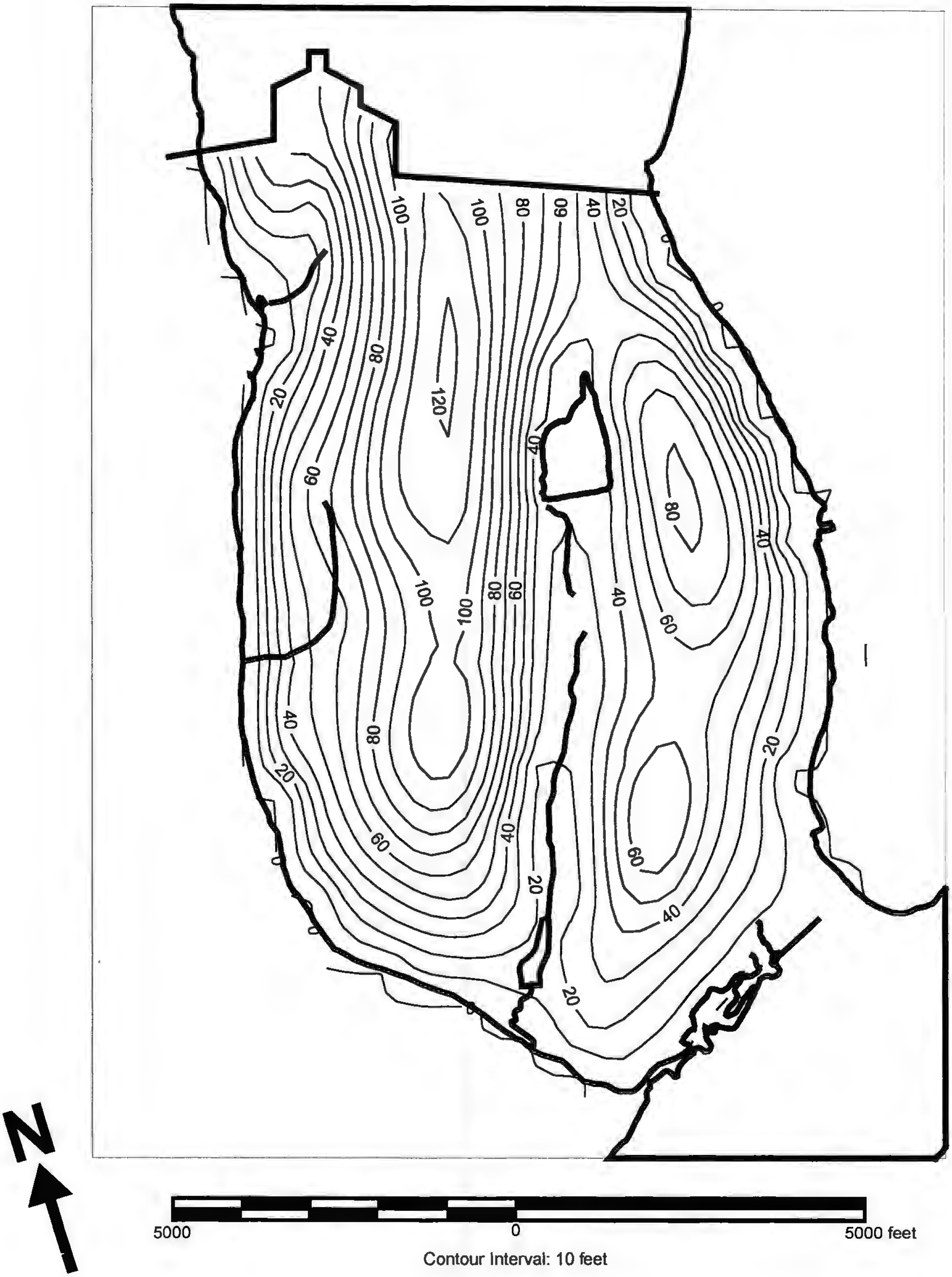


Figure 18 Distribution of model-generated head, Layer 1, Run K

## Generalized Ground-Water Map of Northern Conanicut Island, Jamestown, RI

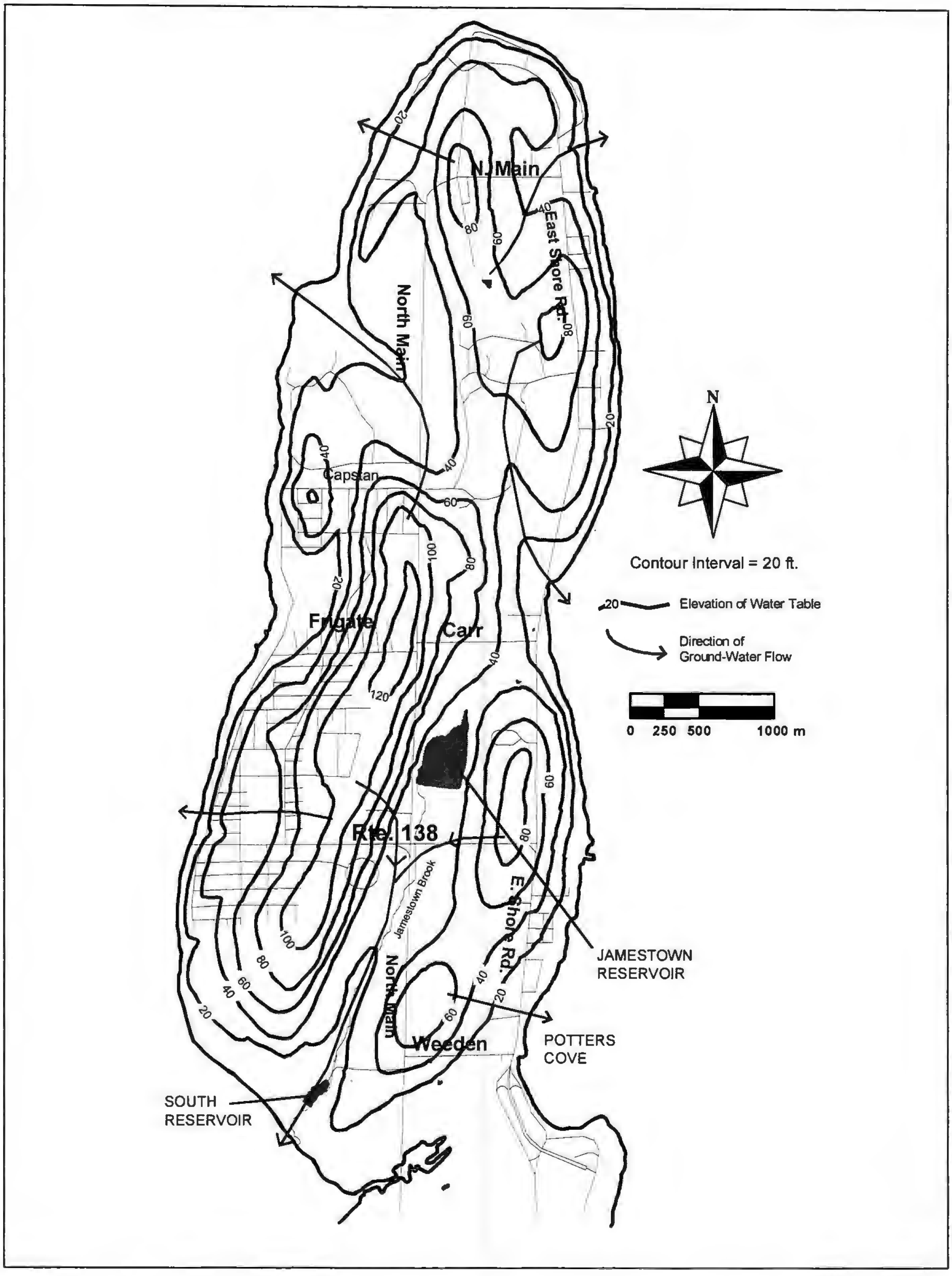


Figure 19 Ground-water map (modified from Veeger et al., 1997)

estimated from specific capacity appears to be understated. The model is relatively sensitive to recharge (Runs K and L) and relatively insensitive to the conductance of rock underlying the discharging shoreface (Runs K and M).

Figure 20 shows the distribution of simulated evapotranspiration for Run K. Potential simulated loss to evapotranspiration is limited to 3.5 inches per month (100% of recharge) due to model instability at higher levels. Realized loss to evapotranspiration of approximately 56% of recharge from the system is simulated by the model (Table 3). Discharge across the shoreface accounts for

| **Table 3** | **Water budget for Run K** | | |
|---|---|---|---|
| **Source/ Sink** | **Flow to system (gpm)** | **Flow from system (gpm)** | **Net Flow to system (gpm)** |
| Recharge | - | - | 4,544 |
| Fresh surface water | 432 | 1,195 | -763 |
| Shoreface Discharge | - | - | -1,211 |
| Evapotranspiration | - | - | -2,544 |
| Net consumptive use | - | - | -26 |

an additional 27% of recharge. The remaining discharge is attributed to net loss to fresh-water bodies and net well pumping, the latter accounting for less than 1%. Model K simulates net ground-water discharge of 1.56 cfs into Jamestown Brook between the dam at Jamestown Reservoir and South Reservoir. This can be compared with an estimated baseflow into South Reservoir of 0.37 cfs, measured by Wingate (1995) in May of 1995. Water loss from Jamestown Brook and other surface-water bodies to evapotranspiration is, however, unaccounted for.

Simulated flow through the system is generally as described in Figure 5, with very little north-south flow (Figure 21). Although the model-generated head

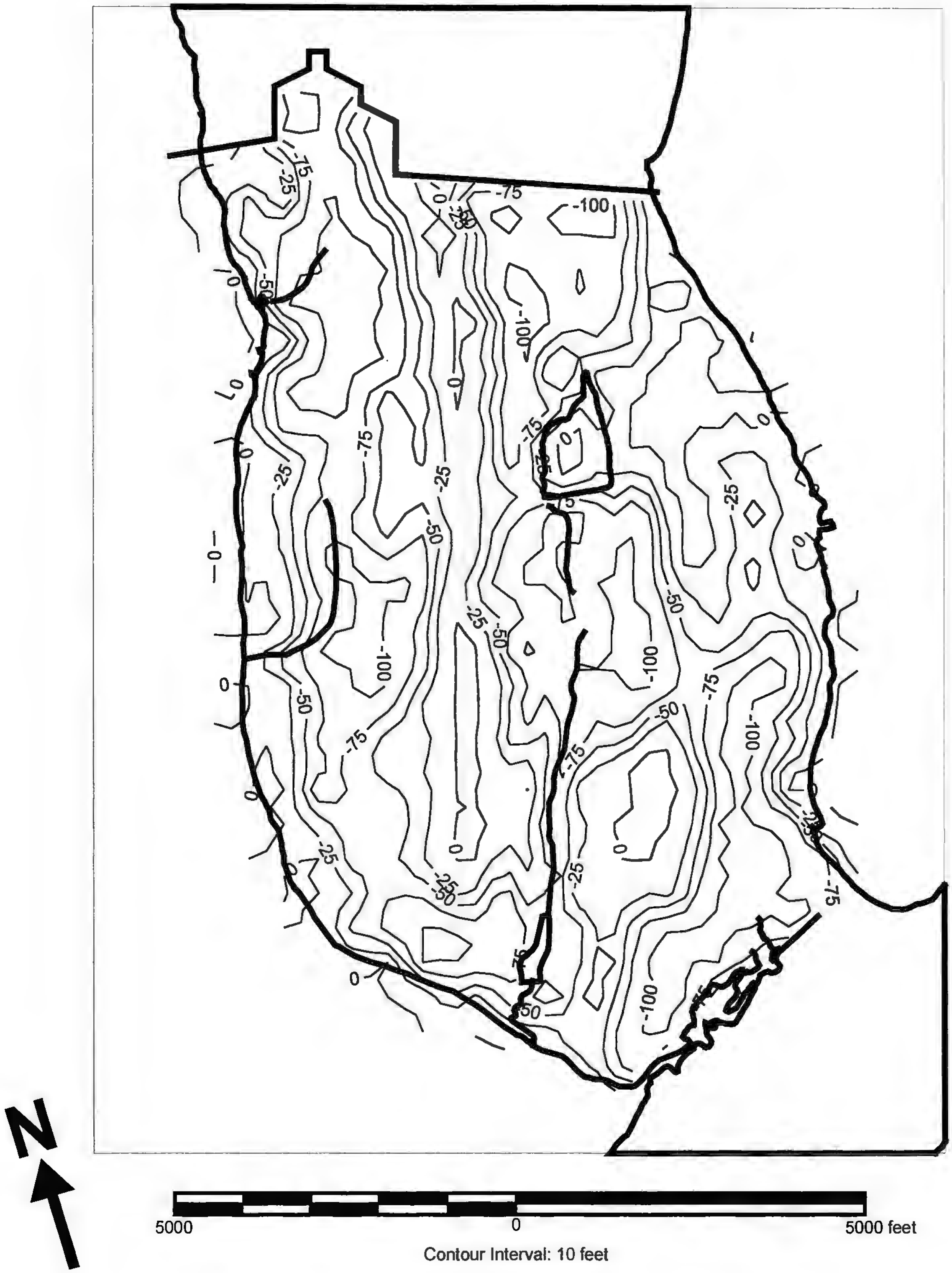


Figure 20 Distribution of evapotranspiration as a percent of recharge, Run K, Layer 1

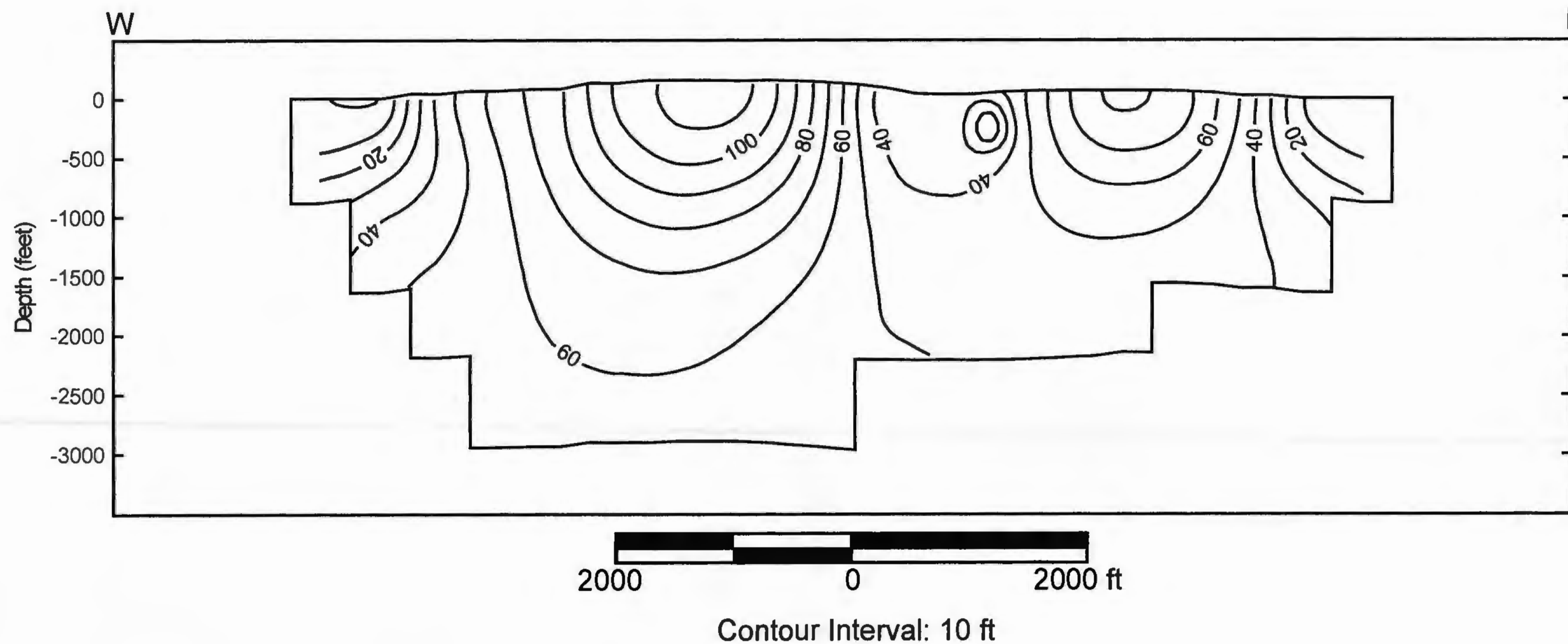


Figure 21 Cross-section along model row 21 showing contoured equipotential lines for Run K

generally mirrors topography, as desired, model parameters result in calibration problem areas. Excessive mounding of model generated head, however, occurs in areas where little is known about aquifer properties and where laterally extensive fracture zones are thought to exist. Current density models of the subsurface, developed from VLF measurements, suggest that these fracture zones are not uniformly distributed, but linked to extensive bedrock structures related to the tectonic history of the area. It appears that distinct bedrock fracture zones may influence ground-water flow, however the ability to accurately characterize the hydraulic properties of these zones is questionable. Appropriate REV's would require a level of detailed description of aquifer properties beyond practicality, particularly where fracture zones occur.

Evaluation of enhanced permeability used to simulate fracture zones is obscured by an inability to validate the parameters used to simulate ground-water flow in adjacent areas. Assumptions made about the vertical distribution of hydraulic conductivity, aquifer heterogeneity and anisotropy and the conductance of melt-water deposits overlying the fracture zone identified in the Jamestown Brook area can have an impact on attempts to simulate the effect of the fracture-zones on ground-water flow. The conductance of unconsolidated sediments in the Jamestown Brook area is not field-tested and is expected contribute significantly to ground-water flow. Hydraulic conductivity in this area is assumed to be 11% and 400% greater than surrounding areas overlain by a thin veneer of till for Layer 1 and Layer 2, respectively. The effect of increasing

hydraulic conductivity by factors ranging from 1.5 to 22 to simulate fracture zones would be obscured
by increases in the assumed conductance of the glacial melt-water deposits.

The vertical distribution of hydraulic conductivity represented by the model assumes horizontal ground-water flow to JR-1 and that JR-1 is generally representative of the aquifer. Although the model is relatively insensitive to small changes in the vertical distribution of hydraulic conductivity, the assumption that hydraulic conductivity decreases with depth is important to the general characterization of flow as predominantly shallow and needs to be evaluated further. On a smaller scale, anisotropy and heterogeneity afforded by individual fractures is also not very well understood. Anisotropy and heterogeneity on smaller scales can be expected to have a significant impact on the path of solutes. The use of finite-difference model calibration to evaluate model parameters is imperfect due to an inability to explain small-scale hydraulic characteristics that can have a profound impact on the transport of these solutes.

## Summary

Time-drawdown analyses and borehole geophysics suggest Darcian continuum precepts may be appropriate for describing ground-water flow on Conanicut Island. This is implied by linear behavior of drawdown over time in Jamestown's municipal wells and an apparent continuous vertical distribution of ground-water flow into JR-1 at the borehole scale. Although time-drawdown and borehole analyses suggest Darcian behavior and suitability of continuum treatment in the vicinity of the wells investigated, detailed borehole data are extremely limited. Surface geophysics and a finite-difference flow model were used to expand the investigation beyond this scale.

Expansion of the scale of observation using surface geophysics and the identification of large-scale fracture zones reveals the complicated nature of the aquifer's physical properties. VLF results suggest that significant fracture zones exist and are laterally extensive, however they do not identify all fracture zones nor do they directly evaluate the magnitude and variability of permeability within those zones. Despite the development of a representative distribution of transmissivity from drawdown analyses, little is known about the spatial scale of variability and the effect fracture zones have on the distribution of permeability. Representation of large fracture zone permeabilities in the data is expected to result in bimodality, provided a large enough sample size were available. This is not observed in the field data.

Consideration was given next to the response of a finite-difference model of the aquifer. The finite-difference model calibration is generally within the margin of error of the criteria against which it is measured. The value of a finite-difference simulation for the purpose of investigating the suitability of imposing continuum conditions on a quantitative description of the aquifer system is limited, however. Due to limitations on available data, the model can not be validated, i.e. cause and effect relationships can not be adequately demonstrated by the model (Konikow and Bredehoeft, 1990). Furthermore, the existence of non-unique numerical solutions to governing flow equations causes model calibration to be inadequate for evaluating model parameters.

Critical to modeling ground-water flow on Conanicut Island is an understanding of the spatial variability of bedrock hydraulic conductivity and the conductance of overlying sediment. A stochastic assignment of hydraulic conductivity values to grid cells was considered, however the resulting spatial distribution of hydraulic conductivity values was inconsistent with known bedrock structural trends. A strategy of using a uniform, horizontal distribution of hydraulic conductivity values decreasing with depth was adopted to reveal areas of model inadequacies. The effect of liberalizing hydraulic conductivity to simulate fracture zones identified from the VLF results improved model calibration, however, calibration problem areas remain, particularly where fracture zones were identified and near complicated boundaries.

**Conclusions**

Often the development of a finite-difference model as a description of ground-water flow in an aquifer is intended as a first step toward modeling transport of chemical species. Modeling of solute transport is based on flow simulation output, therefore flow-model inadequacies and resulting errors are compounded by the addition of schemes and assumptions used to simulate advective and dispersive chemical behavior. For example, porosity assumptions, otherwise unnecessary for steady-state flow simulations, must be made. Simulation of advective behavior using a particle tracking code is dependent upon flow vectors calculated during flow simulation. For fractured rock, adjustments must be made to velocity vectors such that restrictions on particle travel direction imposed by fractures are considered.

It is clear from this study that an effort to simulate solute transport in a fractured-rock environment demands a much more comprehensive understanding of aquifer anisotropy and heterogeneity on both a broad- and small-scale level. A finite-difference flow model, potentially a framework for simulating advective transport, appears to describe ground-water flow at Conanicut Island reasonably well. Substantial model inadequacies exist however, such that it would be difficult to expand the model to describe chemical transport in the Conanicut Island system. It is difficult, therefore, to postulate that the Conanicut Island system can be described using continuums precepts based on available data. The current model configuration must be limited to hypothetical analyses.

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**Internet Sites**

LOT SIZES

*Prudence Island USGS Quadrangle:*

Metadata

http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q25llu93.htm

Data

http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q25llu93.e00

*Wickford USGS Quadrangle:*

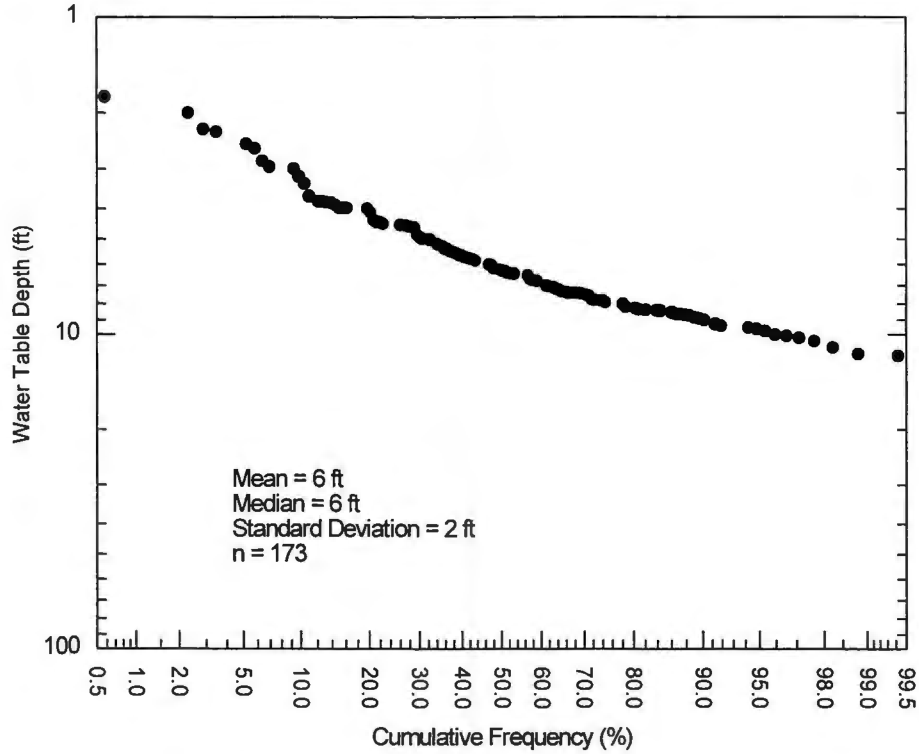
Metadata

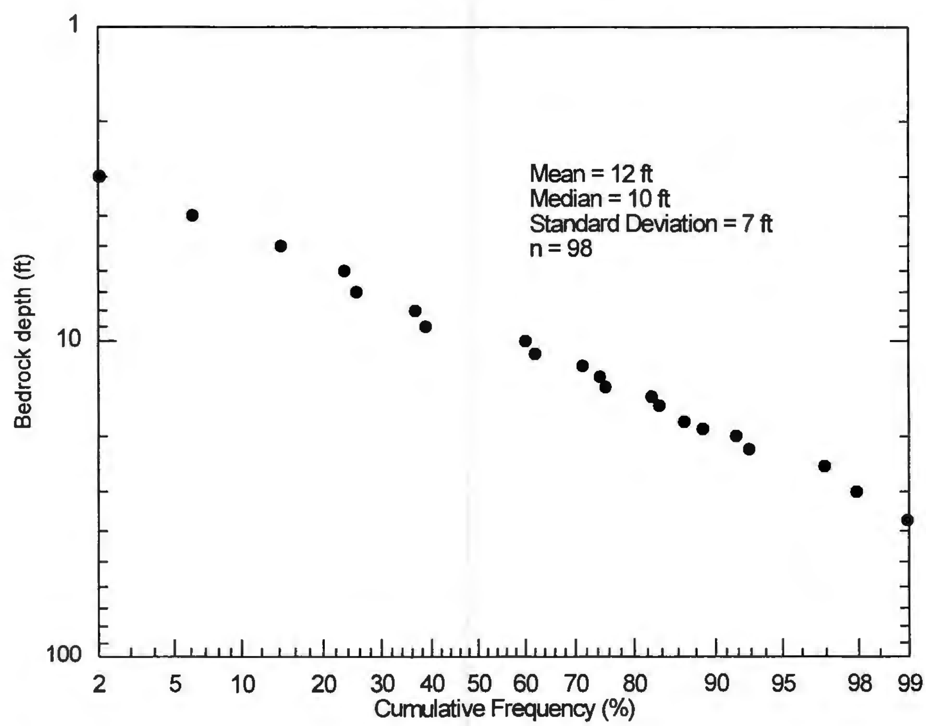
http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q24llu93.htm

Data

http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q24llu93.e00

# Appendices




* RIDEM ISDS percolation test logs
** RIDEM driller logs

*Appendix II   Finite-difference Grid Values*

## Active boundary array for Layers 1-6

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 7 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 8 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 9 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 10 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 11 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 12 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 13 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 14 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 15 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 16 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 17 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 18 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 19 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 20 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 21 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 22 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 23 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 24 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 25 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 26 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 27 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 28 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 29 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 30 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 31 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
| 32 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
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| 36 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 37 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
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| 40 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | |
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| 42 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 43 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 44 | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 45 | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Active boundary array for Layers 7 and 8

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | |
| 7 | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 8 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 9 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 10 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 11 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 12 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 13 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 14 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 15 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 16 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 17 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 18 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 19 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 20 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 21 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 22 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 23 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 24 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 25 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 26 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 27 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 28 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 29 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 30 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 31 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
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| 36 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 37 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | |
| 38 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 39 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 40 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | |
| 41 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | |
| 42 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 43 | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 44 | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 45 | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Active boundary array for Layer 9

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | |
| 7 | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | |
| 8 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | |
| 9 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | |
| 10 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 11 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 12 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 13 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 14 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 15 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 16 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 17 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 18 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 19 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 20 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 21 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 22 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 23 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 24 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 25 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 26 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 27 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 28 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 29 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 30 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 31 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 32 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 33 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 34 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 35 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 36 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 37 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 38 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 39 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | |
| 40 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 41 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 42 | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | |
| 43 | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | |
| 44 | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | |
| 45 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Active boundary array for Layer 10

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 1 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | |
| 13 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |
| 14 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |
| 15 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |
| 16 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |
| 17 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 18 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 19 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 20 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 21 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 22 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 23 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 24 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 25 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 26 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 27 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 28 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 29 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 30 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 31 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 32 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 33 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 34 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 35 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 36 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 37 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| 38 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 39 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| 40 | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | |
| 41 | | | | | | | | | | 1 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | | | |
| 42 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 43 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 44 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 45 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# Estimated land surface elevation (feet above MHW)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 50 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 43 | 49 | 72 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 48 | 47 | 80 | 105 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | -7 | 20 | 42 | 53 | 34 | 70 | 109 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | -9 | 5 | 27 | 43 | 27 | 60 | 98 | 118 | 119 | 103 | 92 | 85 | 76 | 68 | 56 | 46 | 29 | 20 | 14 | 4 | -8 | | | | | | | | | |
| 7 | | | -10 | -1 | 15 | 23 | 19 | 42 | 85 | 116 | 127 | 117 | 102 | 89 | 83 | 76 | 62 | 50 | 42 | 32 | 23 | 18 | 4 | -9 | | | | | | | | |
| 8 | | | | -5 | 8 | 12 | 14 | 46 | 80 | 118 | 135 | 118 | 105 | 90 | 78 | 70 | 63 | 56 | 48 | 42 | 34 | 26 | 18 | 7 | -7 | | | | | | | |
| 9 | | | | -7 | -1 | 7 | 15 | 45 | 83 | 118 | 136 | 124 | 107 | 92 | 76 | 66 | 59 | 53 | 48 | 44 | 41 | 38 | 32 | 10 | 5 | -17 | | | | | | |
| 10 | | | | -8 | -3 | 6 | 17 | 44 | 84 | 115 | 137 | 129 | 114 | 94 | 76 | 62 | 55 | 48 | 46 | 45 | 47 | 47 | 42 | 36 | 23 | -6 | -35 | | | | | |
| 11 | | | | | -5 | 6 | 22 | 47 | 86 | 117 | 133 | 131 | 115 | 94 | 72 | 58 | 51 | 45 | 42 | 46 | 51 | 53 | 52 | 49 | 39 | 12 | -24 | | | | | |
| 12 | | | | | -4 | 8 | 28 | 51 | 84 | 117 | 132 | 131 | 111 | 92 | 69 | 55 | 48 | 42 | 40 | 47 | 55 | 59 | 63 | 60 | 52 | 30 | -15 | | | | | |
| 13 | | | | | -3 | 14 | 30 | 52 | 89 | 119 | 132 | 128 | 111 | 92 | 67 | 53 | 45 | 39 | 41 | 52 | 59 | 68 | 72 | 72 | 65 | 37 | -12 | -50 | | | | |
| 14 | | | | -13 | -3 | 19 | 33 | 57 | 95 | 120 | 129 | 124 | 111 | 90 | 66 | 51 | 43 | 38 | 39 | 53 | 63 | 73 | 79 | 81 | 77 | 55 | 14 | -33 | | | | |
| 15 | | | | -13 | -1 | 24 | 40 | 65 | 104 | 117 | 128 | 124 | 107 | 87 | 66 | 48 | 39 | 36 | 36 | 49 | 65 | 77 | 85 | 88 | 84 | 64 | 14 | -28 | | | | |
| 16 | | | | -14 | 2 | 31 | 51 | 68 | 104 | 120 | 126 | 123 | 108 | 85 | 58 | 45 | 37 | 32 | 34 | 44 | 65 | 78 | 88 | 91 | 87 | 66 | 25 | -18 | | | | |
| 17 | | | | -16 | 9 | 35 | 57 | 71 | 107 | 120 | 125 | 122 | 108 | 83 | 63 | 39 | 31 | 30 | 32 | 41 | 61 | 79 | 88 | 92 | 87 | 67 | 30 | -9 | -48 | | | |
| 18 | | | | -14 | 12 | 45 | 62 | 78 | 108 | 120 | 124 | 120 | 106 | 83 | 60 | 42 | 31 | 30 | 30 | 40 | 59 | 74 | 87 | 93 | 88 | 68 | 38 | -3 | -30 | | | |
| 19 | | | | -9 | 15 | 48 | 63 | 79 | 108 | 120 | 123 | 118 | 104 | 84 | 62 | 38 | 30 | 30 | 30 | 40 | 55 | 70 | 84 | 93 | 90 | 73 | 44 | 9 | -26 | | | |
| 20 | | | | -16 | 18 | 48 | 64 | 78 | 108 | 120 | 122 | 117 | 103 | 85 | 64 | 40 | 33 | 34 | 37 | 40 | 52 | 64 | 82 | 92 | 92 | 78 | 49 | 12 | -23 | | | |
| 21 | | | | -18 | 15 | 48 | 64 | 73 | 107 | 116 | 121 | 116 | 102 | 85 | 65 | 42 | 32 | 29 | 30 | 38 | 49 | 59 | 78 | 91 | 94 | 80 | 51 | 15 | -15 | | | |
| 22 | | | | -19 | 11 | 48 | 62 | 80 | 103 | 112 | 118 | 114 | 101 | 82 | 62 | 41 | 29 | 29 | 29 | 37 | 48 | 58 | 73 | 89 | 93 | 84 | 52 | 17 | -8 | -36 | | |
| 23 | | | | -20 | 7 | 48 | 60 | 72 | 99 | 108 | 114 | 112 | 99 | 79 | 61 | 39 | 29 | 29 | 29 | 36 | 46 | 57 | 71 | 86 | 91 | 83 | 58 | 22 | -5 | | | |
| 24 | | | | -26 | 6 | 46 | 58 | 68 | 93 | 104 | 113 | 111 | 97 | 77 | 57 | 38 | 29 | 28 | 29 | 35 | 44 | 55 | 68 | 83 | 89 | 82 | 56 | 27 | -5 | -27 | | |
| 25 | | | | -28 | 7 | 48 | 56 | 65 | 86 | 101 | 112 | 107 | 93 | 76 | 56 | 37 | 28 | 28 | 28 | 33 | 42 | 53 | 66 | 78 | 84 | 78 | 56 | 32 | -2 | -24 | | |
| 26 | | | | -28 | 9 | 43 | 56 | 63 | 82 | 99 | 113 | 106 | 91 | 76 | 56 | 38 | 28 | 27 | 28 | 32 | 41 | 51 | 62 | 72 | 78 | 76 | 56 | 31 | -1 | -20 | | |
| 27 | | | | -28 | 9 | 42 | 55 | 60 | 78 | 99 | 112 | 105 | 92 | 78 | 59 | 40 | 28 | 26 | 27 | 31 | 39 | 48 | 58 | 69 | 72 | 72 | 54 | 30 | -1 | -16 | | |
| 28 | | | | -24 | 9 | 44 | 54 | 61 | 78 | 99 | 111 | 106 | 94 | 77 | 57 | 38 | 27 | 26 | 27 | 29 | 38 | 46 | 55 | 64 | 69 | 67 | 49 | 27 | -2 | -16 | | |
| 29 | | | | -29 | 9 | 41 | 53 | 63 | 79 | 99 | 111 | 107 | 97 | 75 | 55 | 37 | 27 | 25 | 26 | 28 | 36 | 43 | 52 | 60 | 64 | 62 | 46 | 23 | -1 | -11 | | |
| 30 | | | | -31 | 2 | 30 | 52 | 64 | 79 | 100 | 112 | 108 | 102 | 75 | 55 | 37 | 27 | 25 | 26 | 27 | 35 | 42 | 49 | 58 | 59 | 56 | 42 | 21 | 1 | -11 | | |
| 31 | | | | -29 | 9 | 44 | 54 | 65 | 83 | 104 | 113 | 110 | 102 | 77 | 55 | 37 | 26 | 24 | 25 | 29 | 37 | 42 | 51 | 55 | 58 | 52 | 37 | 19 | -1 | -14 | | |
| 32 | | | | -29 | 10 | 42 | 54 | 63 | 85 | 108 | 119 | 112 | 102 | 78 | 54 | 36 | 26 | 23 | 26 | 32 | 39 | 45 | 52 | 56 | 57 | 49 | 33 | 17 | -1 | -17 | | |
| 33 | | | | -27 | 10 | 43 | 54 | 66 | 89 | 110 | 121 | 113 | 103 | 79 | 53 | 35 | 26 | 22 | 27 | 34 | 43 | 51 | 58 | 59 | 56 | 48 | 31 | 20 | -5 | -20 | | |
| 34 | | | | -28 | 9 | 41 | 52 | 68 | 92 | 109 | 118 | 112 | 102 | 76 | 52 | 34 | 25 | 21 | 28 | 37 | 48 | 56 | 62 | 62 | 57 | 46 | 27 | 18 | -9 | -28 | | |
| 35 | | | | -29 | -1 | 38 | 49 | 68 | 93 | 107 | 113 | 110 | 96 | 72 | 48 | 32 | 24 | 21 | 29 | 42 | 52 | 62 | 69 | 68 | 58 | 43 | 26 | 11 | -14 | | | |
| 36 | | | | -32 | -6 | 35 | 47 | 67 | 91 | 106 | 111 | 107 | 94 | 74 | 43 | 28 | 19 | 22 | 32 | 44 | 58 | 71 | 75 | 72 | 62 | 44 | 25 | 10 | -12 | | | |
| 37 | | | | | -21 | 30 | 37 | 62 | 84 | 99 | 104 | 101 | 89 | 62 | 41 | 25 | 17 | 23 | 32 | 46 | 65 | 78 | 82 | 76 | 65 | 45 | 26 | 7 | -12 | | | |
| 38 | | | | | -24 | 10 | 36 | 54 | 71 | 87 | 93 | 88 | 75 | 54 | 33 | 22 | 15 | 22 | 28 | 48 | 68 | 77 | 82 | 73 | 61 | 38 | 23 | 8 | -9 | -23 | | |
| 39 | | | | | -38 | -5 | 33 | 43 | 58 | 71 | 78 | 74 | 65 | 49 | 34 | 25 | 14 | 20 | 29 | 46 | 62 | 74 | 77 | 64 | 52 | 33 | 15 | 7 | 1 | -12 | | |
| 40 | | | | | | -2 | 19 | 32 | 40 | 50 | 56 | 57 | 49 | 38 | 32 | 27 | 12 | 22 | 31 | 43 | 54 | 58 | 56 | 54 | 39 | 22 | 9 | 8 | 4 | 3 | | |
| 41 | | | | | | -26 | -2 | 15 | 24 | 29 | 31 | 33 | 32 | 25 | 24 | 22 | 17 | 23 | 32 | 42 | 44 | 41 | 35 | 30 | 20 | 7 | 6 | 3 | 2 | | | |
| 42 | | | | | | | -18 | -1 | 7 | 12 | 13 | 14 | 17 | 17 | 17 | 14 | 17 | 24 | 32 | 39 | 36 | 28 | 21 | 12 | 8 | 6 | 2 | | | | | |
| 43 | | | | | | | | -18 | -10 | -2 | 1 | 3 | 7 | 8 | 11 | 9 | 12 | 23 | 31 | 31 | 26 | 18 | 12 | 7 | 2 | 1 | | | | | | |
| 44 | | | | | | | | | | -14 | -8 | -6 | -3 | -2 | 2 | 5 | 13 | 17 | 23 | 21 | 16 | 11 | 6 | 3 | 1 | | | | | | | |
| 45 | | | | | | | | | | | | | | -8 | -5 | -3 | -2 | 1 | 8 | 9 | 7 | 4 | 2 | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | -8 | -5 | -4 | -2 | -2 | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

| Estimated depth to water (ft) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 6 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 6 | 6 | 6 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 6 | 0 | 6 | 6 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | -7.18 | 19.9 | 6 | 6 | 0 | 6 | 6 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | -9.23 | 4.9 | 6 | 6 | -0.5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | -0.5 | 3.9 | -8.2 | | | | | | | | | |
| 7 | | | -10.3 | -1.03 | 6 | 6 | -0.5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 3.9 | -9.23 | | | | | | | | |
| 8 | | | | -5.13 | 7.9 | 0 | -0.5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 17.9 | 6.9 | -7.18 | | | | | | | |
| 9 | | | | -7.18 | -1.03 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 4.9 | -17.4 | | | | | | |
| 10 | | | | -8.2 | -3.08 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | -6.15 | -35.9 | | | | | |
| 11 | | | | | -5.13 | 5.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 11.9 | -24.6 | | | | | |
| 12 | | | | | -4.1 | 7.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 6 | 29.9 | -15.4 | | | | | |
| 13 | | | | | -3.08 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 2 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | -12.3 | -51.3 | | | | |
| 14 | | | | -13.3 | -3.08 | 6 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 1 | 2 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 13.9 | -33.8 | | | | |
| 15 | | | | -13.3 | -1.03 | 6 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -1 | -1 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 13.9 | -28.7 | | | | |
| 16 | | | | -14.4 | 1.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -5 | -3 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 24.9 | -18.5 | | | | |
| 17 | | | | -16.4 | 8.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 2 | -6 | -7 | -5 | 4 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -9.23 | -49.2 | | | |
| 18 | | | | -14.4 | 11.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 | -6 | -7 | -7 | 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -3.08 | -30.8 | | | |
| 19 | | | | -9.23 | 14.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 1 | -7 | -7 | -7 | 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 8.9 | -26.7 | | | |
| 20 | | | | -16.4 | 17.9 | 6 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 3 | -4 | -3 | 0 | 3 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 11.9 | -23.6 | | | |
| 21 | | | | -18.5 | 14.9 | 6 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | 0 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -15.4 | | | |
| 22 | | | | -19.5 | 10.9 | 6 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -8.2 | -36.9 | | |
| 23 | | | | -20.5 | 6.9 | 6 | 6 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 21.9 | -5.13 | | | |
| 24 | | | | -26.7 | 5.9 | 6 | 6 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -5.13 | -27.7 | | |
| 25 | | | | -28.7 | 6.9 | 6 | 6 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -2.05 | -24.6 | | |
| 26 | | | | -28.7 | 8.9 | 6 | 6 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -1.03 | -20.5 | | |
| 27 | | | | -28.7 | 8.9 | 6 | 6 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -1.03 | -16.4 | | |
| 28 | | | | -24.6 | 8.9 | 6 | 0 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | 0 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -2.05 | -16.4 | | |
| 29 | | | | -29.7 | 8.9 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -1.03 | -11.3 | | |
| 30 | | | | -31.8 | 1.9 | -0.5 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0.9 | -11.3 | | |
| 31 | | | | -29.7 | 8.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -1.03 | -14.4 | | |
| 32 | | | | -29.7 | 9.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -1.03 | -17.4 | | |
| 33 | | | | -27.7 | 9.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -5.13 | -20.5 | | |
| 34 | | | | -28.7 | 8.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -9.23 | -28.7 | | |
| 35 | | | | -29.7 | -1.03 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -14.4 | | | |
| 36 | | | | -32.8 | -6.15 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 9.9 | -12.3 | | | |
| 37 | | | | | -21.5 | 29.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6.9 | -12.3 | | | |
| 38 | | | | | -24.6 | 9.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -9.23 | -23.6 | | |
| 39 | | | | | -39 | -5.13 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 0.9 | -12.3 | | |
| 40 | | | | | | -2.05 | 18.9 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | 0 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | 6 | 6 | 2.9 | | |
| 41 | | | | | | -26.7 | -2.05 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | 0 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | -0.5 | -0.5 | 6 | | | |
| 42 | | | | | | | -18.5 | -1.03 | 6.9 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | -0.5 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | -0.5 | | | | | |
| 43 | | | | | | | | -18.5 | -10.3 | -2.05 | 0.9 | 2.9 | 6.9 | 6 | 6 | -0.5 | -0.5 | 6 | 6 | 6 | 6 | 6 | 6 | -0.5 | -0.5 | -0.5 | | | | | | |
| 44 | | | | | | | | | | -14.4 | -8.2 | -6.15 | -3.08 | -2.05 | 1.9 | 4.9 | 0 | 6 | 6 | 6 | 0 | 0 | -0.5 | -0.5 | -0.5 | | | | | | | |
| 45 | | | | | | | | | | | | | | -8.2 | -5.13 | -3.08 | -2.05 | 0.9 | 7.9 | 6 | -0.5 | -0.5 | -0.5 | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | -8.2 | -5.13 | -4.1 | -2.05 | -2.05 | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Saturated Overburden thickness (feet)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| 13 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 21 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 22 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 23 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 24 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 25 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 26 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 27 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 28 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 29 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 30 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 31 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 32 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 33 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 34 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 35 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 36 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 37 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 38 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 39 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 |
| 40 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 |
| 41 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 |
| 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| 43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 26 | 26 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 45 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 46 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Percent cell area to which Cauchy boundary assigned

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | 52.0 | 8.0 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | 2.5 | 57.5 | | | 0.3 | | | | | | | | | | | | | | 0.4 | 62.5 | 57.5 | | | | | | | | | |
| 7 | | | | 60.0 | | | 0.3 | | | | | | | | | | | | | | | | 72.5 | 47.5 | | | | | | | | |
| 8 | | | | 41.0 | 19.0 | | 0.3 | | | | | | | | | | | | | | | | 100.0 | 47.5 | 72.5 | | | | | | | |
| 9 | | | | 2.5 | 57.5 | 0.4 | | | | | | | | | | | | | | | | | | | 50.0 | 35.0 | | | | | | |
| 10 | | | | | 60.0 | | | | | | | | | | | | | | | | | | | | | 60.0 | | | | | | |
| 11 | | | | | 57.5 | 2.5 | | | | | | | | | | | | | | | | | | | | 45.0 | 15.0 | | | | | |
| 12 | | | | | 58.0 | 2.0 | | | | | | | | | | | | | | | | | | | | 12.5 | 47.5 | | | | | |
| 13 | | | | | 60.0 | | | | | | | | | | | | | 5.0 | | | | | | | | | 60.0 | | | | | |
| 14 | | | | | 60.0 | | | | | | | | | | | | | 20.0 | 25.0 | | | | | | | | 60.0 | | | | | |
| 15 | | | | | 60.0 | | | | | | | | | | | | | 55.0 | 65.0 | | | | | | | | 40.0 | 20.0 | | | | |
| 16 | | | | 7.5 | 52.5 | | | | | | | | | | | | 40.0 | 95.0 | 90.0 | | | | | | | | 15.0 | 45.0 | | | | |
| 17 | | | | 25.0 | 35.0 | | | | | | | | | | | 30.0 | 100.0 | 100.0 | 100.0 | 15.0 | | | | | | | | 60.0 | | | | |
| 18 | | | | 33.0 | 27.0 | | | | | | | | | | | 25.0 | 100.0 | 100.0 | 100.0 | 30.0 | | | | | | | | 60.0 | | | | |
| 19 | | | | 25.0 | 35.0 | | | | | | | | | | | 20.0 | 100.0 | 100.0 | 100.0 | 35.0 | | | | | | | | 40.0 | 20.0 | | | |
| 20 | | | | 25.0 | 35.0 | | 33.3 | | | | | | | | | 10.0 | 95.0 | 80.0 | 50.0 | 15.0 | | | | | | | | 20.0 | 40.0 | | | |
| 21 | | | | 27.5 | 32.5 | | 25.0 | | | | | | | | | | 0.6 | | | | | | | | | | | | 60.0 | | | |
| 22 | | | | 25.0 | 35.0 | | 0.3 | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 23 | | | | 14.0 | 46.0 | | | 0.3 | | | | | | | | | | 0.6 | | | | | | | | | | 2.5 | 57.5 | | | |
| 24 | | | | 10.0 | 50.0 | | | 0.3 | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 25 | | | | 10.0 | 50.0 | | | 0.3 | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 26 | | | | 10.0 | 50.0 | | | 0.3 | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 27 | | | | 7.5 | 52.5 | | | 0.3 | | | | | | | | | | | 0.6 | | | | | | | | | | 60.0 | | | |
| 28 | | | | | 60.0 | | | 0.3 | | | | | | | | | | | 0.6 | | | | | | | | | | 60.0 | | | |
| 29 | | | | | 60.0 | | 0.4 | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 30 | | | | | 60.0 | 0.6 | 0.3 | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 31 | | | | | 60.0 | | | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 32 | | | | | 60.0 | | | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 33 | | | | | 60.0 | | | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 34 | | | | | 60.0 | | | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 35 | | | | | 60.0 | | | | | | | | | | | | | 0.6 | | | | | | | | | | | 60.0 | | | |
| 36 | | | | | 60.0 | | | | | | | | | | | | 0.6 | | | | | | | | | | | 5.0 | 55.0 | | | |
| 37 | | | | | 59.0 | 1.0 | | | | | | | | | | | 0.6 | | | | | | | | | | | 2.5 | 57.5 | | | |
| 38 | | | | | 11.0 | 49.0 | | | | | | | | | | | 0.6 | | | | | | | | | | | | 60.0 | | | |
| 39 | | | | | | 60.0 | | | | | | | | | | | 0.6 | | | | | | | | | | | | 35.0 | 25.0 | | |
| 40 | | | | | | 47.5 | 12.5 | | | | | | | | | | 0.6 | | | | | | | | | | | | | 100.0 | | |
| 41 | | | | | | | 60.0 | | | | | | | | | | 47.5 | | | | | | | | | | 0.3 | 0.3 | | | | |
| 42 | | | | | | | | 60.0 | 24.0 | | | | | | | 57.5 | 40.0 | | | | | | | | | | 5.0 | | | | | |
| 43 | | | | | | | | | 36.0 | 60.0 | 50.0 | 25.0 | 2.5 | | | 15.5 | 4.0 | | | | | | | | | 70.0 | | | | | | |
| 44 | | | | | | | | | | | 10.0 | 35.0 | 57.5 | 60.0 | 60.0 | 10.5 | | | | | | | | | 35.0 | | | | | | | |
| 45 | | | | | | | | | | | | | | | | 49.5 | 60.0 | 50.0 | 7.5 | | 25.0 | | 10.0 | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | | 10.0 | 52.5 | 60.0 | 35.0 | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Factors applied to Layer 1 transmissivities for fracture zone simulation

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 1.5 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 1 | 1.5 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 1 | 1.5 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1.5 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1 | 2 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 7 | | | 1 | 1 | 1 | 1 | 1.5 | 1.5 | 1.5 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 8 | | | | 1.5 | 1.5 | 1.5 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 9 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | | | | | | |
| 10 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | | | | | |
| 11 | | | | | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | | | | | |
| 12 | | | | | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | | | | | |
| 13 | | | | | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | | | | |
| 14 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | | | | |
| 15 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | | | | |
| 16 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | | | | |
| 17 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 18 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 19 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 20 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 21 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 22 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | | |
| 23 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 24 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | | |
| 25 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1.83 | | |
| 26 | | | | 1.99 | 1.99 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1.83 | 1.83 | | |
| 27 | | | | 1 | 1.99 | 1.99 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1.83 | 1.83 | 1 | | |
| 28 | | | | 1 | 1 | 1 | 1.5 | 1.99 | 1.99 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1.83 | 1 | 1 | | |
| 29 | | | | 1 | 1 | 1 | 1.5 | 1 | 1.99 | 1.99 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1.83 | 1.83 | 1 | 1 | | |
| 30 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.83 | 1.83 | 1 | 1 | 1 | | |
| 31 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.83 | 1 | 1 | 1 | 1 | | |
| 32 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1.83 | 1 | 1 | 1 | 1 | | |
| 33 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1.99 | 1 | 1 | 1 | 1 | | |
| 34 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 1.99 | 1.99 | 1.99 | 1 | 1 | | |
| 35 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 1 | 1 | 1 | 1.5 | 1 | 1.99 | 1.99 | | | |
| 36 | | | | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 37 | | | | | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.7 | 1.7 | 1.7 | 1.7 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 38 | | | | | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1.7 | 1.7 | 1.7 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | | |
| 39 | | | | | 1 | 1 | 1.5 | 1 | 1 | 1 | 1.7 | 1.7 | 1.7 | 1.7 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | | |
| 40 | | | | | | 1 | 1.5 | 1 | 1.5 | 1.5 | 1.7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | | |
| 41 | | | | | | 1 | 1.5 | 1.5 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | | | |
| 42 | | | | | | | 1.5 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | | | | | |
| 43 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | | | | | | |
| 44 | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 45 | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# Factors applied to Layer 2 transmissivities for fracture zone simulation

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 12 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 1 | 12 | 1 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 1 | 12 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | 1 | 1 | 1 | 1 | 12 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 12 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 | 13.2 | 1 | 22 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 7 | | | 1 | 1 | 1 | 1 | 12 | 12 | 12 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | | | | | | | | |
| 8 | | | | 12 | 12 | 12 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 9 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | | | | | | |
| 10 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | | | | | |
| 11 | | | | | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | | | | | |
| 12 | | | | | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | | | | | |
| 13 | | | | | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | | | | |
| 14 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | | | | |
| 15 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | | | | |
| 16 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | | | | |
| 17 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 18 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 19 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 20 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 21 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 22 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | | |
| 23 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 24 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | | |
| 25 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 19 | | |
| 26 | | | | 21.9 | 21.9 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 19 | 19 | | |
| 27 | | | | 1 | 21.9 | 21.9 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 19 | 19 | 1 | | |
| 28 | | | | 1 | 1 | 1 | 12 | 21.9 | 21.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 19 | 1 | 1 | | |
| 29 | | | | 1 | 1 | 1 | 12 | 1 | 21.9 | 21.9 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 19 | 19 | 1 | 1 | | |
| 30 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 22 | 22 | 22 | 22 | 22 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 19 | 19 | 1 | 1 | 1 | | |
| 31 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 22 | 22 | 22 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 19 | 1 | 1 | 1 | 1 | | |
| 32 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 22 | 22 | 22 | 22 | 1 | 22 | 19 | 1 | 1 | 1 | 1 | | |
| 33 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 22 | 22 | 22 | 21.9 | 1 | 1 | 1 | 1 | | |
| 34 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 22 | 22 | 1 | 1 | 21.9 | 21.9 | 21.9 | 1 | 1 | | |
| 35 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 22 | 22 | 1 | 1 | 1 | 12 | 1 | 21.9 | 21.9 | | | |
| 36 | | | | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 22 | 22 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 37 | | | | | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 16.3 | 16.3 | 16.3 | 16.3 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 38 | | | | | 1 | 1 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 16.3 | 16.3 | 16.3 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | | |
| 39 | | | | | 1 | 1 | 12 | 1 | 1 | 1 | 16.3 | 16.3 | 16.3 | 16.3 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | | |
| 40 | | | | | | 1 | 12 | 1 | 12 | 12 | 16.3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | 1 | | |
| 41 | | | | | | 1 | 12 | 12 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | 1 | 1 | | | |
| 42 | | | | | | | 12 | 12 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | 1 | | | | | |
| 43 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | 12 | | | | | | |
| 44 | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 22 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | |
| 45 | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

## Estimated housing units per cell

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | 5.9 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | 1.9 | 3.7 | 7.4 | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | 6.4 | 7.4 | 9.2 | 7.8 | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | 4.8 | 9.2 | 8.3 | 5.5 | 7.4 | 0.6 | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | 4.6 | 9.2 | 9.2 | 0.9 | | 2.3 | 0.8 | | 0.2 | 0.1 | | | 0.3 | 0.9 | 1.3 | | | 0.3 | 2.1 | | | | | | | | | | |
| 7 | | | | 1.4 | 9.2 | 1.4 | | | | 2.1 | 0.1 | 0.4 | 0.3 | | | | | 2.1 | 1.5 | 0.1 | 0.8 | 2.5 | 0.8 | | | | | | | | | |
| 8 | | | | | 2.7 | | | | | 2.3 | 0.4 | 0.1 | | | 1.8 | 2.1 | 0.8 | 3.5 | 3.0 | | | 0.8 | 4.4 | 3.2 | 0.1 | | | | | | | |
| 9 | | | | | | | | 0.6 | 2.2 | 4.6 | 2.0 | 2.3 | 0.6 | 1.9 | 1.0 | 0.2 | 0.2 | | | | | | 0.1 | 0.8 | 0.2 | | | | | | | |
| 10 | | | | | | 1.0 | 0.2 | 3.0 | 4.1 | 4.6 | 2.3 | 2.3 | 9.2 | 0.2 | | | | | | | | 0.1 | 0.2 | 0.3 | 0.4 | 0.2 | | | | | | |
| 11 | | | | | | 0.6 | | 4.0 | 4.3 | 4.1 | 2.0 | 1.6 | 0.5 | | | | | | | | | | | 0.2 | 0.3 | 0.4 | | | | | | |
| 12 | | | | | | 2.3 | 2.3 | 4.6 | 4.1 | 1.4 | 1.0 | 0.8 | 0.9 | 0.8 | 0.3 | | | | | | | | | 0.2 | 0.3 | 0.6 | | | | | | |
| 13 | | | | | | 3.2 | 3.9 | 4.5 | 2.9 | 0.1 | | | 0.7 | 0.9 | 0.4 | | | | | | | 1.7 | 5.8 | 6.6 | 0.4 | 0.7 | 0.1 | | | | | |
| 14 | | | | | 0.8 | 3.4 | 1.9 | 3.3 | 4.0 | 0.2 | | 0.5 | 1.0 | 0.2 | | | | | | 3.1 | 7.3 | 7.7 | 7.7 | 7.7 | 1.5 | 0.7 | 0.3 | | | | | |
| 15 | | | | | 1.7 | 4.6 | 1.7 | 3.1 | 4.6 | 0.6 | | 1.0 | 0.6 | | 0.1 | | | | | 1.2 | 7.7 | 7.7 | 6.5 | 5.0 | 1.4 | 0.8 | 0.7 | | | | | |
| 16 | | | | | 2.6 | 3.8 | 2.1 | 4.0 | 4.6 | 2.5 | 0.5 | 1.0 | 0.6 | | | | | | | | 2.7 | 1.1 | | | 0.4 | 1.8 | 1.1 | | | | | |
| 17 | | | | | 3.3 | 4.6 | 2.7 | 4.6 | 4.6 | 2.8 | 0.2 | 0.5 | 0.2 | | | | | | | | | | | | | 1.9 | 1.9 | 0.3 | | | | |
| 18 | | | | | 3.7 | 4.6 | 2.1 | 4.6 | 4.6 | 4.1 | | 0.1 | 1.0 | 0.9 | | | | | | | | | | | 0.7 | 2.3 | 1.9 | 0.3 | | | | |
| 19 | | | | | 3.4 | 3.8 | 3.3 | 4.6 | 4.6 | 4.6 | 1.0 | 0.2 | 0.2 | 0.4 | 0.2 | | | | | | | | | | 0.3 | 2.2 | 1.3 | | | | | |
| 20 | | | | | 3.3 | 3.4 | 0.2 | 4.0 | 4.6 | 4.6 | | 0.3 | 0.1 | 0.5 | 1.0 | 0.2 | | | | | | | | | | 0.1 | 1.4 | | | | | |
| 21 | | | | | 3.6 | 4.4 | 1.0 | 4.1 | 4.6 | 2.9 | | 0.5 | 0.2 | 0.2 | 1.0 | 0.6 | | | | | | | | | | 0.2 | 1.0 | 0.1 | | | | |
| 22 | | | | | 3.3 | 4.6 | 3.0 | 3.2 | 4.6 | 3.8 | 0.5 | 0.6 | 0.8 | 0.6 | 1.0 | 0.2 | | | | | | | | | | 0.1 | 1.4 | 0.4 | | | | |
| 23 | | | | | 3.0 | 4.4 | 0.5 | 3.4 | 4.0 | 0.7 | | 0.2 | | 0.1 | 0.7 | 0.3 | | | 0.1 | 0.3 | | | | | | | 0.1 | | | | | |
| 24 | | | | | 2.6 | 3.7 | 0.6 | 2.5 | 4.3 | | | | | | | | | | | 0.2 | | | | | | | | 2.0 | 0.4 | | | |
| 25 | | | | | 2.4 | 4.4 | 0.5 | 1.2 | 2.6 | | | | | | 0.2 | 0.2 | | | | | | | | | | 0.2 | 0.3 | 4.4 | 0.9 | | | |
| 26 | | | | | 2.3 | 4.0 | | 0.4 | 3.0 | | | 0.1 | 0.4 | 0.5 | 0.8 | 0.3 | | | | | | | | | | | 2.8 | 4.6 | 1.4 | | | |
| 27 | | | | | 2.4 | 4.6 | 0.5 | | 2.3 | | | 0.1 | 0.4 | 0.1 | 0.1 | | | | | | | | | | | 0.2 | 4.5 | 4.6 | 1.7 | | | |
| 28 | | | | | 2.2 | 4.6 | 1.3 | | 0.7 | | | | | | | 0.2 | | | | | | | | | | 2.1 | 3.4 | 4.6 | 1.0 | | | |
| 29 | | | | | 1.2 | 3.2 | 1.6 | 0.6 | 2.2 | | | | | | | | | | | | | | | | | | 1.4 | 4.6 | 1.8 | | | |
| 30 | | | | | | 0.2 | 0.7 | 2.8 | 4.5 | 2.2 | | 0.1 | 0.2 | | | | | | | | | | | | | | 0.6 | 4.3 | 1.6 | | | |
| 31 | | | | | 0.3 | 3.2 | 4.6 | 4.6 | 4.6 | 3.9 | | | | | | | | | | | | | | | | | | 2.9 | 1.0 | | | |
| 32 | | | | | 2.2 | 4.6 | 4.6 | 4.6 | 4.6 | 4.1 | | | | | | | | | | | | | | | | | | 4.1 | 2.0 | | | |
| 33 | | | | | 2.2 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 | 0.5 | | | | | | | | | | | | | | | | | 3.9 | 1.6 | | | |
| 34 | | | | | 2.1 | 4.6 | 4.6 | 4.6 | 4.6 | 4.6 | 1.2 | | | | | | | | | | | | | | | | | 3.3 | 0.6 | | | |
| 35 | | | | | 4.6 | 3.3 | 4.6 | 4.6 | 4.6 | 3.5 | 0.3 | | | | 0.2 | | | | | | | | | | 0.3 | 0.1 | | 2.8 | 0.1 | | | |
| 36 | | | | | 3.4 | 9.5 | 4.6 | 4.6 | 2.3 | | | | | | 0.1 | | | | | | | | | | | | | 2.3 | | | | |
| 37 | | | | | 1.1 | 17.2 | 4.6 | 2.3 | | | | | | | | | | | | | | | | | | | 0.2 | 5.6 | 0.1 | | | |
| 38 | | | | | | | | | | | | | | | | | | | | | | 0.2 | 0.2 | | | | 0.6 | 8.0 | 1.0 | | | |
| 39 | | | | | | | | | | | | | | | | | | | | | | | | | 1.8 | 0.5 | 0.9 | 2.9 | | | | |
| 40 | | | | | | | | | | | | | | | | | | | | 0.3 | 2.2 | | | | | | | | | | | |
| 41 | | | | | | | | | | | | | | | | | | | | | 0.7 | | | | | | | | | | | |
| 42 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 43 | | | | | | | | | | | | | | | | | | | | | | | 0.2 | 0.3 | | | | | | | | |
| 44 | | | | | | | | | | | | | | | | | | | | | | | | 0.1 | | | | | | | | |
| 45 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

RIGIS, 1988

## Estimated Route 138 area for recharge and evapotranspiration reduction ($ft^2$ x 1000)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 14 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 22 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 24 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | | | | | | | | | | | | | | | | | | 41.6 | 44.8 | 44.8 | 41.6 | 41.6 | 41.6 | 22.4 | | | | | | | | |
| 26 | | | | | | | | | | | | | | | 38.4 | 44.8 | 41.6 | | | | | | | 48.0 | | | | | | | | |
| 27 | | | | | | | | | | | | 44.8 | 38.4 | 44.8 | | | | | | | | | | | 41.6 | | | | | | | |
| 28 | | | | | | | | | 12.8 | 83.2 | 38.4 | | | | | | | | | | | | | | 44.8 | | | | | | | |
| 29 | | | | | | | | 60.8 | 73.6 | | | | | | | | | | | | | | | | | 44.8 | | | | | | |
| 30 | | | | | | 12.8 | 80.0 | 22.4 | | | | | | | | | | | | | | | | | | 41.6 | | | | | | |
| 31 | | | | | 32.0 | 64.0 | | | | | | | | | | | | | | | | | | | | 44.8 | | | | | | |
| 32 | | | | | | | | | | | | | | | | | | | | | | | | | | 41.6 | | | | | | |
| 33 | | | | | | | | | | | | | | | | | | | | | | | | | | 25.6 | 19.2 | | | | | |
| 34 | | | | | | | | | | | | | | | | | | | | | | | | | | | 44.8 | | | | | |
| 35 | | | | | | | | | | | | | | | | | | | | | | | | | | | 44.8 | | | | | |
| 36 | | | | | | | | | | | | | | | | | | | | | | | | | | | 38.4 | | | | | |
| 37 | | | | | | | | | | | | | | | | | | | | | | | | | | | 48.0 | 41.6 | | | | |
| 38 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 89.6 | | | | |
| 39 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 70.4 | 16.0 | | | |
| 40 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 108.8 | | | |
| 41 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 42 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 43 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 44 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 45 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 46 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 47 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Long-term drawdown and recovery

Long-term drawdown data from two municipal production wells, JR-1 and JR-2, are used to extract information about aquifer properties. The data obtained from JR-2 is not quality data considering the unstable pumping rate, however the data can be used, for example, to make inferences about Darcian behavior. The Jacob-Cooper graphical method (Cooper and Jacob, 1946) is used to estimate hydraulic properties in the Jamestown Reservoir area with transmissivity, $T$, and storativity, $S$, calculated from

$$T = \frac{Q}{(h_o - h)} \frac{2.3}{4\pi}, \tag{5}$$

$$S = \frac{2.25 T t_o}{r^2}, \tag{6}$$

where

$Q$ = pumping rate,
$h_o$-$h$ = drawdown per time log cycle,
$r$ = radial distance to observation well and
$t_o$ = time at which fit line intersects the axis at zero drawdown;

and such that the following assumptions are satisfied:

1) $\frac{r^2 S}{4 T t_o} < 0.05$,

2) The aquifer is confined (i.e. $\Delta h \ll$ saturated thickness),

3) Darcy's Law applies,

4) The aquifer is bound below by an impermeable boundary,

5) All geologic structures are horizontal and of infinite horizontal extent; flow to the well is horizontal and radial,

6) The potentiometric surface of the aquifer is horizontal and at steady-state prior to pumping; subsequent changes in surface are due to pumping only,

7) The aquifer is homogeneous and isotropic,

8) Ground-water has a constant density and viscosity,

9) There is no source of aquifer recharge during pumping,

10) Water is released instantaneously from storage, and

11) Water is pumped at a constant rate.

Some of these assumptions are reasonable. Other assumptions, e.g. 3) and a variation of 7), constitute properties not very well understood and which this study attempts to investigate. With respect to assumption 4), it is assumed that the well base, in part, defines the interval of rock being characterized. Furthermore, assumptions 5) and 10) are complicated by observation wells being confined to unconsolidated glacial sediments overlying the bedrock for which estimates are desired. It is difficult to ascertain the influence of the sediments on estimates of transmissivity and storativity, however the effect on the former is assumed to be minimal due to the minor thickness of saturated sediment relative to the interval over which transmissivity is assumed to be measured. Comparison of storage estimates obtained from drawdown analyses with those from recovery analyses are inconclusive.

| Time-drawdown Analyses Results for JR-1 | | | | | | |
|---|---|---|---|---|---|---|
| | Drawdown | | | Recovery | | |
| | early | | late | late | residual drawdown | |
| **observation well** | **Transmissivity ($ft^2$/min.)** | **Storativity** | **Transmissivity ($ft^2$/min.)** | **Transmissivity ($ft^2$/min.)** | **Transmissivity ($ft^2$/min.)** | **Storativity** |
| JR-1 | 0.35 | N/A | 0.19 | 0.40 | 039 | N/A |
| 1 | 0.50 | 0.021 | 0.29 | 0.73 | 0.73 | 0.031 |
| 2 | 0.36 | 0.084 | 0.25 | 0.32 | 0.30 | 0.087 |
| 3 | 0.32 | N/A | 0.078 | 0.41 | 0.29 | N/A |
| 4 | 0.37 | 0.048 | 0.20 | 0.36 | 0.34 | 0.067 |
| 7 | 0.30 | 0.036 | 0.10 | 0.23 | 0.22 | 0.036 |
| 9 | 0.28 | 0.014 | 0.072 | 0.30 | 0.29 | 0.019 |
| **mean** | 0.35 | 0.04 | 0.17 | 0.39 | 0.37 | 0.05 |
| **median** | 0.35 | 0.04 | 0.19 | 0.36 | 0.30 | 0.04 |

For purposes of recovery analyses, $h_O$-$h$ may be treated as recovery from extrapolated drawdown or residual drawdown and intercept elapsed time, $t_O$, may be treated as $t'_O$ or $\frac{t_o}{t'_o}$, respectively, where $t'_O$ is elapsed time since recovery commencement (Driscoll, 1986). Extrapolated drawdown is described by curve slope at $t$ = 15,000 minutes and commences at $t$ = 24,900 minutes, with residual drawdown at 8 feet. Recovery between $t$ = 17,900 and 24,900 minutes is a result of a rain event and loss of water to the well from the pumping apparatus.

Specific Capacity

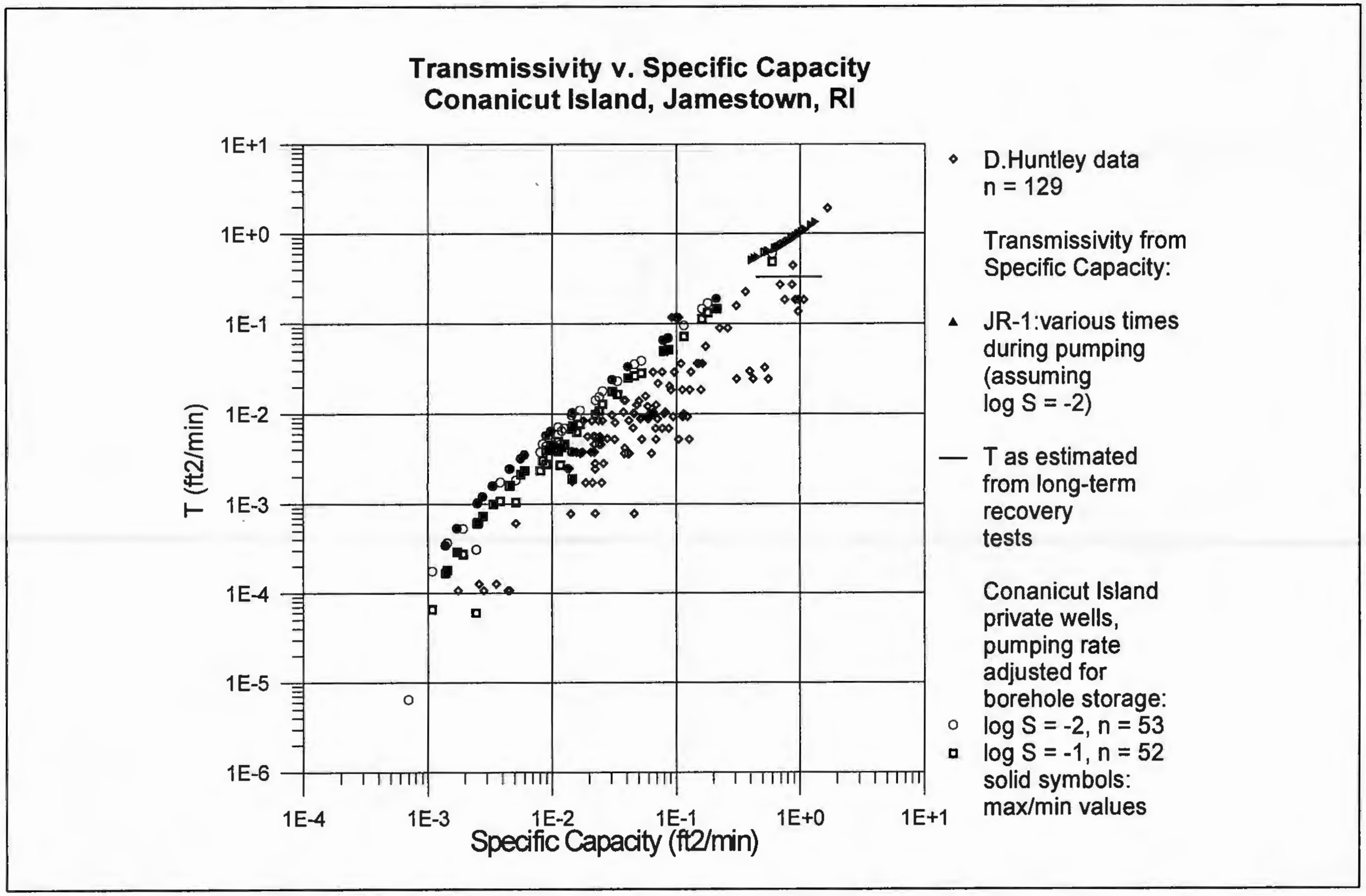
Drawdown, pumping rate and duration data measured at Conanicut Island is available from numerous driller logs obtained from Rhode Island Department of Environmental Management. Driller logs can be expected to yield reasonably good estimates of specific capacity (Paillet and Duncanson, 1994). The data is derived from private wells primarily in the study area, with some data obtained to the north, in comparable rock. Figure 15 shows a distribution of wells located using information provided in well logs, however incomplete reporting results in only partial well location. Furthermore, questionable data pertinent for specific capacity calculation has been noted in the table below and provides for maximum or minimum estimates of transmissivity, as the case may be.

Theis' method (1963) for estimating transmissivity from specific capacity was modified such that the pumping rate factor of specific capacity is reduced to account for borehole storage. Transmissivity is thus calculated as follows, using an iterative procedure developed by Bradbury and Rothschild (1985) and modified by Michaud (below; 1997):

$$T = \frac{2.3\left(Q - \frac{\pi r^2 s}{t}\right)}{4\pi s}\log\frac{2.25Tt}{r^2 S}, \text{ where } Q = \text{pumping rate,} \tag{7}$$

$r$ = radius of the well,
$s$ = drawdown and
$t$ = elapsed time since commencement of pumping.

Due to dewatering in the vicinity of the well being pumping, uncertainty exists regarding the interval for which specific capacity is being measured and for which transmissivity is being calculated (Figure 14). Furthermore, Huntley et al. (1992) looked at the relationship between specific capacity and transmissivity and discovered that using specific capacity to estimate transmissivity in fractured rock can result in overstatement. The theoretical relationship between specific capacity and transmissivity for Conanicut Island data, described by equation 7, is shown below, with Huntley's data for comparison. This is attributed to non-equilibrium, understatement of storativity, anisotropy and/or understatement of effective borehole radius, which is likened to extended effective borehole radius, e.g. as a result of single-fracture flow (Gringarten and Witherspoon 1972). An opposing effect is overstated drawdown due to turbulent flow and well inefficiency (Razack and Huntley, 1991). Calibration criteria suggest transmissivity understatement from specific capacity. If specific capacity-derived




**Transmissivity and Specific Capacity** are theoretically related by Theis (1963), with transmissivity generally found to be overstated for fractured rock (Huntley et al., 1992). Huntley et al. cite non-equilibrium, understatement of storativity, anisotropy and understatement of effective borehole radius as potentially responsible. Specific capacity and transmissivity values derived from time-drawdown analyses of Huntley's data and JR-1 data is shown for comparison. Hunley's data was obtained from the Peninsular Ranges batholith of San Diego County.

transmissivity is overstated, as suggested by Huntley et al., perhaps specific capacity is not describing permeability from the static water level.

## A PROGRAM TO ESTIMATE AQUIFER TRANSMISSIVITY AND HYDRAULIC CONDUCTIVITY FROM SPECIFIC CAPACITY WRITTEN BY K.BRADBURY AND E.ROTHSCHILD, SEPTEMBER 1981; MODIFIED BY SCOTT MICHAUD, MARCH 1997 W/ BOREHOLE STORAGE ADJUSTMENT AND ENHANCED DATA IMPORT: Q-BASIC.

```
20  REM A PROGRAM TO ESTIMATE AQUIFER TRANSMISSIVITY
30  REM AND HYDRAULIC CONDUCTIVITY
40  REM FROM SPECIFIC CAPACITY
60  REM WRITTEN BY K.BRADBURY AND E.ROTHSCHILD, SEPTEMBER 1981
65  REM MODIFIED BY SCOTT MICHAUD, MARCH 1997 W/
75  REM BOREHOLE STORAGE ADJUSTMENT AND ENHANCED DATA IMPORTED
90  REM **************** LIST OF VARIABLES ********************"
110 REM M(Z,1) = INDENTIFICATION NUMBER OF WELL
120 REM M(Z,2) = DIAMETER OF WELL (INCHES)
160 REM M(Z,3) = LENGTH OF TEST (HOURS)
170 REM M(Z,4) = PUMPING RATE DURING TEST (GALLONS/MINUTE)
190 REM M(Z,5) = ESTIMATED OR MEASURED STORAGE COEFFICIENT (UNITLESS)
195 REM M(Z,6) = DRAWDOWN (FEET)
220 REM T = TRANSMISSIVITY (FEET*FEET/SECOND)
240 REM ER = CONVERGENCE CRITERIA FOR T ESTIMATE (FEET*FEET/SECOND)
250 REM ******************************************************"
260 PRINT "HOW MANY WELLS WILL BE ANALYZED?"
270 INPUT XX
290 DIM T(XX)
300 ER = .00000001
315 W = 0
320 TGUESS = .00000001
330 REM ******************************************************
340 REM *  READ IN RAW DATA IN UNITS GIVEN ON DRILLER LOGS   *
350 REM ******************************************************
525 INPUT "ENTER INPUT FILE: "; A$
526 OPEN A$ FOR INPUT AS #1
527 INPUT "ENTER OUTPUT FILE: "; N$
528 OPEN N$ FOR OUTPUT AS #2
530 FOR Z = 1 TO XX
541 REDIM SHARED M(XX, 7)
542 INPUT #1, M(Z, 1), M(Z, 2), M(Z, 3), M(Z, 4), M(Z, 5), M(Z, 6)
560 REM ******************************************************
570 REM *           DO ANALYSIS FOR EACH WELL            *
580 REM ******************************************************
600 ITER = 0
610 REM ******************************************************
620 REM * CHANGE TO CONSISTENT UNITS AND CALCULATE DRAWDOWN  *
630 REM ******************************************************
```

```
645 R = M(Z, 2) / 24
655 TIME = M(Z, 3) * 3600
665 Q = M(Z, 4) / 449
780 REM ************************************************************
790 REM * CALCULATE AQUIFER TRANSMISSIVITY USING THE JACOB EQUATION
800 REM * USING A CORRECTION FOR PARTIAL PENETRATION AS GIVEN BY
810 REM * STERNBERG (1973)
900 REM ************************************************************
910 REM *         NOW SOLVE FOR T USING ITERATIONS         *
920 REM ************************************************************
930 TGUESS = .000001
940 FOR W = 1 TO 25
956 F1 = Q / (4 * 3.1416 * M(Z, 6))
961 F2 = (2.25 * TGUESS * TIME) / (R * R * M(Z, 5))
975 TCALC = F1 * (LOG(F2))
980 TEST = ABS(TCALC - TGUESS)
990 TGUESS = ABS(TCALC)
1000 IF (TEST <= ER) THEN GOTO 1060
1020 NEXT W
1035 IF (W = 25) AND (TEST > ER) THEN GOTO 1050
1040 GOTO 1060
1050 ITER = 1: GOTO 1220
1060 T(Z) = TCALC
1076 WRITE #2, M(Z, 1), T(Z)
1220 IF ITER = 1 GOTO 1390
1305 NEXT Z
1306 CLOSE #1
1307 CLOSE #2
1310 PRINT "THE NUMBER OF WELLS IN THIS RECORD IS "; XX
1320 GOTO 1430
1390 PRINT ""
1405 PRINT "WELL NO. "; M(Z, 1)
1410 PRINT "SOLUTION DID NOT CONVERGE WITHIN 25 ITERATIONS"
1420 GOTO 1305
1430 END
```

| Rhode Island Department of Environmental Management<br>Driller log data used for specific capacity calculations | | | | | | |
|---|---|---|---|---|---|---|
| Static water level (ft) | Pumping rate (gpm) | Pumping duration, t (hours) | Water level after time t (ft) | Depth of Bedrock Surface (ft) | Well depth (ft) | Code* |
| 16.0 | 40.0 | 3 | 25.0 | 10 | 62.3 | |
| 25.0 | 30.0 | 2 | 60.0 | 15 | 95.0 | |
| 13.5 | 22.0 | 2 | 70.0 | 10 | 92.0 | |
| 20.0 | 20.0 | 2 | 140.0 | 4 | 200.0 | |
| 8.0 | 20.0 | 2 | 120.0 | 25 | 145.0 | |
| 8.0 | 20.0 | 2 | 120.0 | 25 | 145.0 | |
| 20.0 | 20.0 | 2 | 100.0 | 6 | 240.0 | |
| 36.0 | 15.0 | 2 | 120.0 | 10 | 140.0 | |
| 30.0 | 15.0 | 2 | 120.0 | 11 | 166.0 | |

| Rhode Island Department of Environmental Management<br>Driller log data used for specific capacity calculations<br>(continued) | | | | | | |
|---|---|---|---|---|---|---|
| Static water level (ft) | Pumping rate (gpm) | Pumping duration, t (hours) | Water level after time t (ft) | Depth of Bedrock Surface (ft) | Well depth (ft) | Code* |
| 20.0 | 15.0 | 2 | 180.0 | 12 | 190.0 | |
| 10.0 | 12.0 | 3 | 20.0 | 12 | 104.5 | |
| 5.0 | 12.0 | 3 | 40.0 | 8 | 92.0 | |
| 5.0 | 10.0 | 4 | 12.5 | 8 | 77.0 | |
| 20.0 | 10.0 | 2 | 140.0 | 4 | 240.0 | |
| 15.0 | 10.0 | 2 | 100.0 | 8 | 155.0 | |
| 10.0 | 10.0 | 1 | 125.0 | 4 | 125.0 | |
| 2.5 | 9.0 | 3 | 50.0 | 8 | 80.0 | |
| 17.0 | 8.5 | 2 | 240.0 | 8 | 278.0 | |
| 16.0 | 8.0 | 3 | 80.0 | 5 | 110.0 | |
| 30.0 | 8.0 | 2 | 150.0 | 6 | 280.0 | |
| 30.0 | 8.0 | 2 | 150.0 | 6 | 280.0 | |
| 30.0 | 8.0 | 2 | 120.0 | 10 | 185.0 | |
| 25.0 | 7.5 | 4 | 115.0 | 10 | 120.0 | |
| 10.0 | 7.5 | 4 | 80.0 | 10 | 101.0 | |
| 35.0 | 6.0 | 4 | 120.0 | 18 | 125.0 | |
| 9.0 | 6.0 | 3 | 105.0 | 7 | 151.5 | |
| 20.0 | 6.0 | 2 | 120.0 | 10 | 260.0 | |
| 20.0 | 6.0 | 2 | 120.0 | 10 | 260.0 | |
| 20.0 | 5.0 | 4 | 195.0 | 8 | 200.0 | |
| 10.0 | 5.0 | 5 | 480.0 | 3 | 500.0 | |
| 25.0 | 4.0 | 5 | 240.0 | 18 | 250.0 | |
| 20.0 | 4.0 | 4 | 300.0 | 20 | 300.0 | |
| 8.0 | 3.0 | 5 | 380.0 | 6 | 400.0 | |
| 15.0 | 3.0 | 2 | 180.0 | 8 | 200.0 | |
| 15.0 | 2.0 | 5 | 400.0 | 10 | 400.0 | |
| 10.0 | 25.0 | 5 | 120.0 | 10 | 120.0 | Max |
| 18.0 | 25.0 | 5 | 100.0 | 12 | 100.0 | Max |
| 15.0 | 15.0 | 5 | 220.0 | 7 | 220.0 | Max |
| 10.0 | 12.0 | 5 | 120.0 | 6 | 120.0 | Max |
| 20.0 | 11.0 | 5 | 185.0 | 6 | 185.0 | Max |
| 20.0 | 7.5 | 5 | 200.0 | 6 | 200.0 | Max |
| 15.0 | 7.0 | 5 | 220.0 | 5 | 220.0 | Max |
| 20.0 | 6.5 | 5 | 165.0 | 5 | 165.0 | Max |
| 10.0 | 6.0 | 5 | 300.0 | 10 | 300.0 | Max |
| 25.0 | 6.0 | 5 | 200.0 | 6 | 200.0 | Max |
| 20.0 | 5.0 | 5 | 220.0 | 12 | 220.0 | Max |
| 10.0 | 5.0 | 5 | 400.0 | 19 | 400.0 | Max |
| 18.0 | 4.0 | 5 | 230.0 | 10 | 230.0 | Max |
| 10.0 | 3.0 | 5 | 300.0 | 7 | 300.0 | Max |
| 20.0 | 20.0 | 0.5 | 205.0 | 13 | 205.0 | Max/Min |
| 6.0 | 30.0 | 2 | 25.0 | 10 | 86.5 | Min |

| Rhode Island Department of Environmental Management<br>Driller log data used for specific capacity calculations<br>(continued) | | | | | | |
|---|---|---|---|---|---|---|
| Static water level (ft) | Pumping rate (gpm) | Pumping duration, t (hours) | Water level after time t (ft) | Depth of Bedrock Surface (ft) | Well depth (ft) | Code* |
| 16.0 | 20.0 | 3 | 50.0 | 5 | 98.0 | Min |
| 17.0 | 20.0 | 2 | 48.0 | 12 | 123.0 | Min |
| 20.0 | 4.0 | 1 | 205.0 | 8 | 205.0 | TO |
| 19.0 | 4.0 | 4 | 285.0 | 10 | ? | TO |
| 20.0 | 3.0 | 2 | 300.0 | 5 | 360.0 | TO |
| 20.0 | 2.0 | 2 | 200.0 | 15 | 280.0 | TO |
| 20.0 | 2.0 | 2 | 200.0 | 15 | 280.0 | TO |
| 15.0 | 1.5 | 5 | 480.0 | 15 | 480.0 | TO |
| 10.0 | 1.0 | 5 | 400.0 | 8 | 400.0 | TO |
| 10.0 | 1.0 | 5 | 500.0 | 5 | 500.0 | TO |

*Codes:

| | |
|---|---|
| Max | complete well drainage suggested; |
| Min | minimum pumping rate noted; |
| TO | thrown out; specific capacity not calculated due to inadequate/ insufficient data |

*Appendix IV Specific Yield from Micro-gravity*

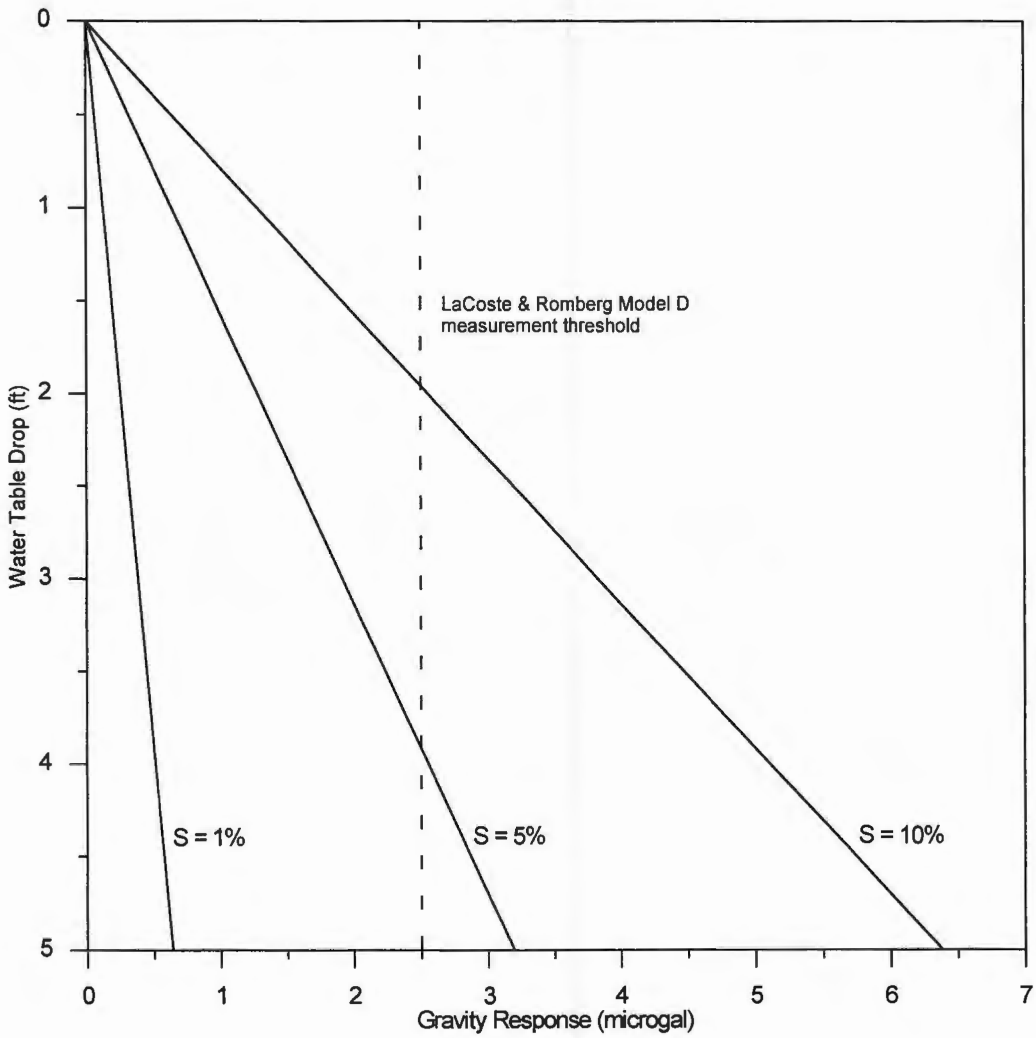
A micro-gravity method was considered for estimation of storativity as a constraint on transmissivity estimates from specific capacity. Micro-gravity techniques can be used to estimate specific yield (Pool and Eychaner, 1995). Specific yield, or more strictly storativity, is a parameter necessary for estimation of transmissivity from specific capacity (Appendix III). The method uses gravity change in response to changes in water table elevation to estimate water storage change. The domain in which gravity change is influenced is treated mathematically as a plate of infinite lateral extent and with thickness equal to the change in water table elevation. Specific yield can be calculated as

$$S_y = \frac{\Delta g}{12.77b} \qquad (8)$$

where $\Delta g$ is gravity change in $\mu$Gal, $b$ is water table elevation change in feet and assuming water density is 1 g/cm$^3$. Pool and Eychaner (1995) show this to be a viable method for an alluvial aquifer where specific yield is significant, however the method was not used for this study because

1) Water table changes in excess of 4 feet are required for specific yields as high as 5% while using the most resolute gravimeters. This is considered unlikely during normal conditions on Conanicut Island. Storage estimates derived from analyses of drawdown data from JR-1 average less than 5% (Appendix III).
2) The residence of the water table in unconsolidated sediments overlying bedrock results in estimates that are meaningless in terms of bedrock.

Storage estimates are limited to those obtained from drawdown and recovery analyses of JR-1data. These estimates are expected to be influenced by overburden.




**Gravity analysis for estimation of storage.** Gravity change in response to water table fluctuation can be used to estimate water storage change over a domain of infinite lateral extent. Water table changes in excess of 4 feet are required for specific yields as high as 5% using the most resolute gravimeters .

## Appendix V Very Low Frequency Electromagnetics (VLF)

VLF geophysics has been used to solve a variety of mining and environmental problems. Karous and Hjelt (1983) applied VLF filtering innovation to data collected in search of ore-bodies. Covel and Robinette (1994) applied VLF geophysics to the investigation of ground-water contamination in fractured bedrock. Covel et al. (1996) used VLF to site monitoring well boreholes in fractured bedrock.

VLF technology exploits very low frequency electromagnetic signals transmitted from submarine communication stations around the world. Frequencies range from roughly 15 to 30 kHz. Signal frequency varies by transmitter such that the appropriate station can be selected by choosing the desired station's frequency at the receiver. Due to the very low frequency of the energy emitted, long distance wave travel can be assured such that these signals are intercepted on site. The selection of a transmitter must be roughly along the strike or trend of the target, i.e. some quasi-planar, subsurface electromagnetically conductive feature. This is necessary for acquisition of maximum signal strength and dip interpretation. The vertical component of the induced magnetic field is measured discretely along a transect perpendicular to the strike of the feature and used to model an equivalent current density for the subsurface. The equivalent current density, $I_j$, for a discrete horizontal layer, discretized into unit cells with dimensions equal to the selected measurement interval, is calculated from

$$H_i = \sum_{j=-n}^{n} I_j \mathrm{K}_{ij} \tag{9}$$

which becomes, by inversion,

$$I_j = \sum_{i=-n}^{n+1} \mathrm{K}_{i0}^{-1} H_{i+j} \tag{10}$$

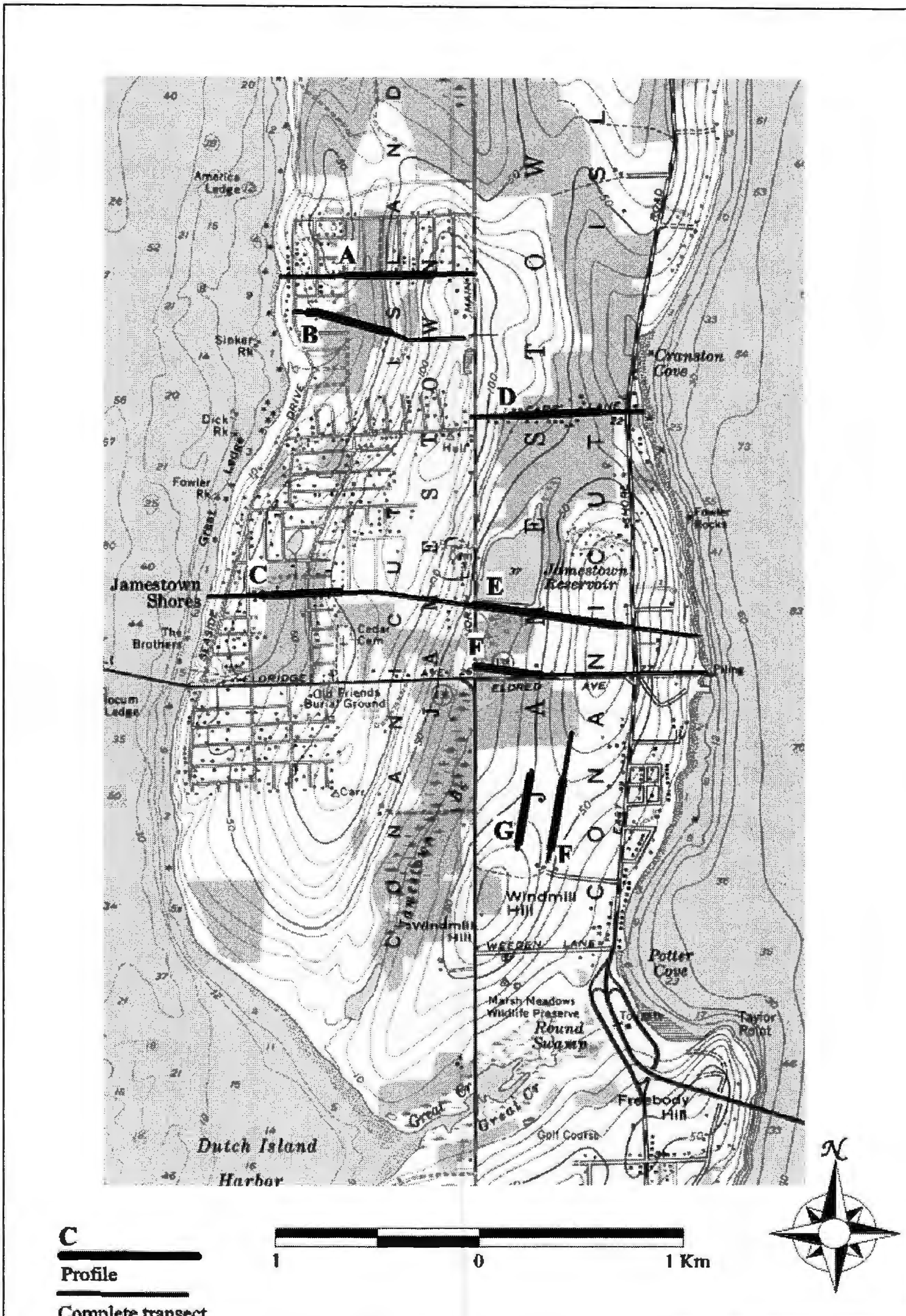
where $H_i$ = vertical component of the measured magnetic field at station $i$,

$I_j$ = the current density for cell $j$,

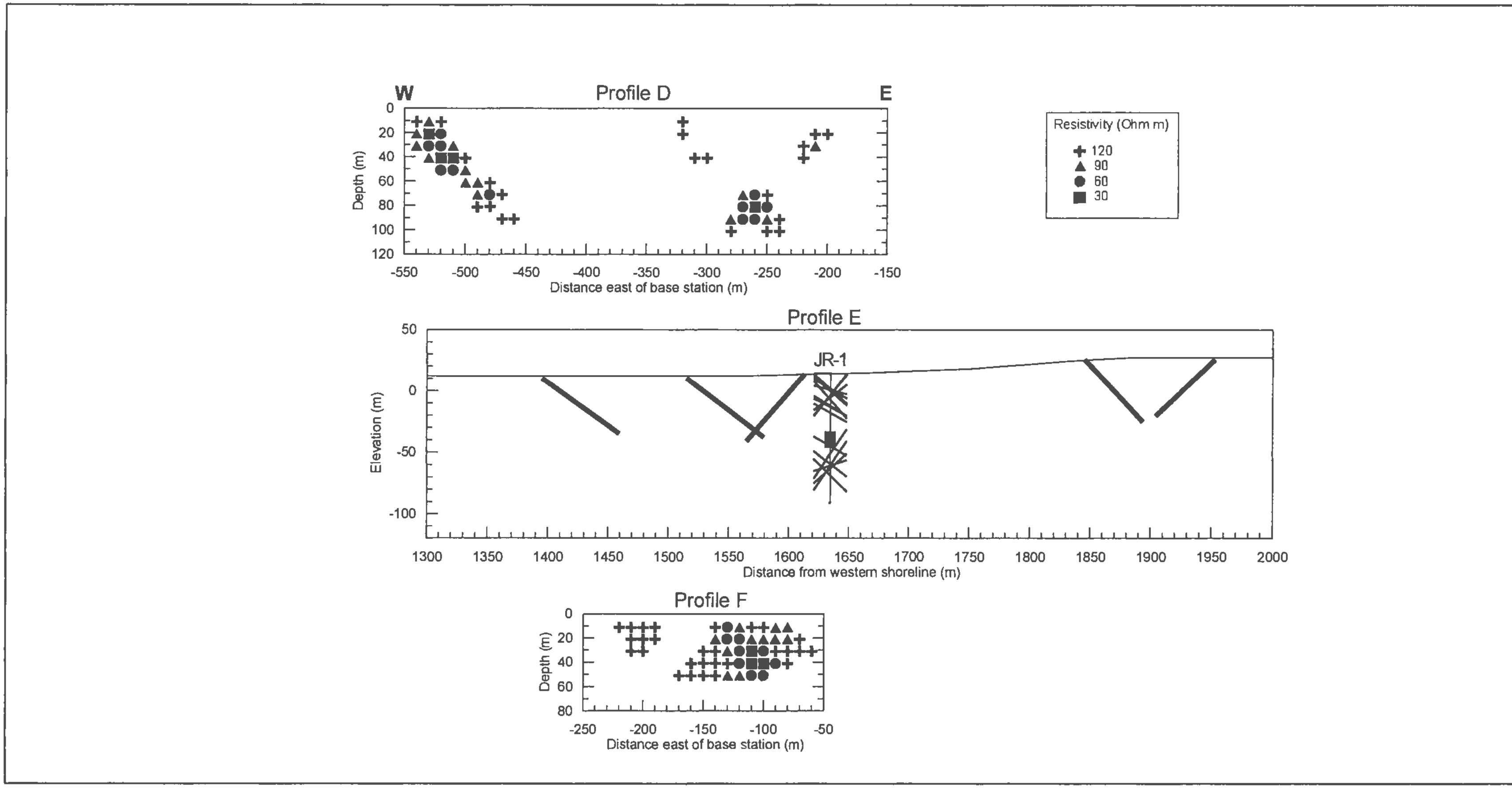
$\mathrm{K}_{ij}$ = weighting factor for effect of $I_j$ on $H_i$, and

$n$ = cell occurring $n$ cell lengths from position $i$ in array of cells assumed to contribute to measured field $H_i$ (Karous and Hjelt, 1983).

Measurements made at the head of the valley containing Jamestown Brook (Profile D, below) suggest a conjugate fracture set or fault system near measurement station 260W. A signature dipping east and suggestive of the dominant bedrock foliation appears in the vicinity of station 520W. Correlative electromagnetic anomalies appear in the data modeled in Profiles E and F. Due to overburden thickness associated with Profile E, the induced electromagnetic signals apparently were not strong enough to model using VLFMOD™, however anomalies were interpreted using SECTOR™ for comparison with fracture orientations measured from the televiewer images (Profile E, below). Note the inferred fracture zone just west of JR-1. Another anomaly in the vicinity of station 110W, Profile F (below) is suggestive of the fracture zone identified in Profiles D and E.




All VLF current density profile locations

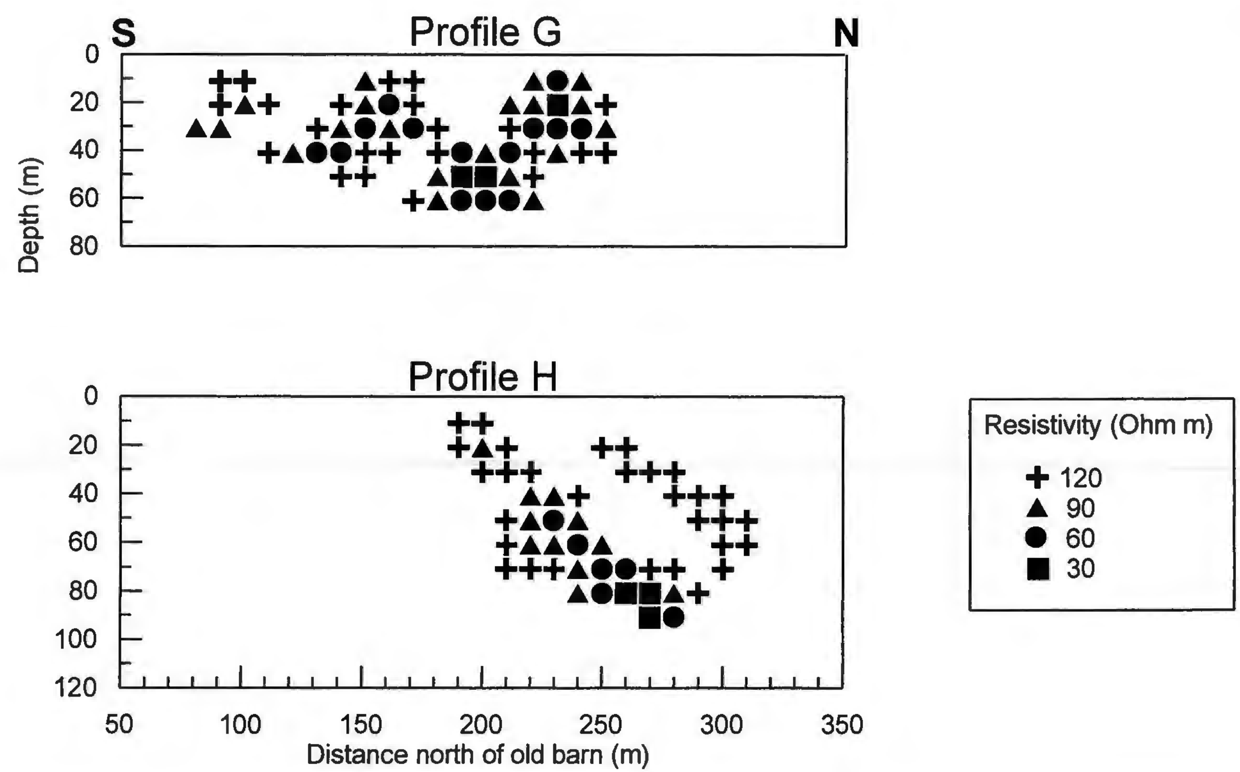



## VLF current density Profiles D, E and F

Current density Profiles D, E and F also show highly conductive subsurface zones lying in a strict linear pattern. Signals along Profile E are not strong enough to model current density using VLFMOD™, perhaps due to overburden thickness, however a cross-section has been constructed with the aid of ABEM's SECTOR™ inversion software, showing fracture zone orientations in the vicinity of JR-1. A cross-pattern signature is also apparent in these profiles.

The strongest anomalies modeled in Profiles A-F are linear along respective lineaments. The anomalies observed in Profiles A-C, where bedrock is inferred to be rather shallow, occur at local topographic lows corresponding to streams and wetland. Relatively thick sediments in the Jamestown Brook area appear to camouflage positions of bedrock features such that high current densities do not directly correspond to topographic lows.

The third focus area of the VLF application is the geomorphologic saddle at Dutra Farm, just north of Windmill Hill. Modeled current density profiles for Transects G & H are shown below, in parallel, separated by a distance of 160 m. Features dipping to the north and to the south are inferred to be fracture sets potentially related to processes described by McMaster's shear model (1980). The trend of these fractures are expected to be NW and SW. Association of the anomalies in each of the current density profiles suggests an approximate trend of N70E. Perhaps the fracture zone is responsible for preferential bedrock erosion resulting in the Dutra Farm saddle and also for the truncation of the ridge separating Area I and Area II to the south. A fracture zone trending NW from Dutra Farm may manifest itself in irregularities in this ridge further to the north, however no VLF data exists for this location.




**VLF current density Profiles G and F**

Current density Profiles G and F, separated by 160 m, are shown in parallel, revealing significant conductive zones with signatures dipping to the north and to the south. Association of the anomalies in each profile suggests a conductive fracture zone oriented approximately N70E, coincident with a fracture system observed in outcrop dipping NW.

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**Internet Sites**

LOT SIZES

Prudence Island USGS Quadrangle:

Metadata

http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q25llu93.htm

Data

http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q25llu93.e00

Wickford USGS Quadrangle:

Metadata

http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q24llu93.htm

Data

http://www.edc.uri.edu/rigisdata/Land_Use/landuse_1988/q24llu93.e00