# WELLHEAD PROTECTION AREA DELINEATION
# IN
# SOUTHERN ESCAMBIA COUNTY, FLORIDA

**Water Resources Special Report 97-4**

**Prepared for:**

**Escambia County Utilities Authority**
**City of Pensacola**
**Escambia County**
**Florida Department of Environmental Protection**
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# NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

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# TABLE OF CONTENTS

## TABLE OF CONTENTS (continued)

## LIST OF FIGURES

**Figure** | **Page**

## LIST OF FIGURES (continued)

**Figure** **Page**

## LIST OF TABLES

# LIST OF APPENDICES

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# INTRODUCTION

## Purpose and Scope

This report is being submitted to provide the Escambia County Utilities Authority (ECUA), the City of Pensacola, Escambia County, the Florida Department of Environmental Protection and other interested parties with a delineation of wellhead protection areas (WHPAs) for the principal public supply wells in southern Escambia County. It is the intent of this work to lay a solid technical foundation from which the local community can effectively implement wellhead protection. The work was conducted in accordance with Florida Department of Environmental Protection (FDEP) Contract No. WM574. The purpose of this assessment is to:

1) Review pertinent literature on the delineation of wellhead protection areas, with special emphasis on methodologies recommended, developed or utilized by the U.S. Environmental Protection Agency (USEPA).

2) Compile available information on the hydrogeologic and hydraulic characteristics of the surficial, low-permeability and main-producing zones of the Sand-and-Gravel Aquifer in southern Escambia County. Compile available information on the location, pumping rate, casing depth, screen length, casing diameter and other pertinent construction features of the principal public supply wells in the study area.

3) Work with representatives of local government and the ECUA to develop a consensus regarding the technical approach to be applied in delineating wellhead protection areas (WHPAs). Based on this consensus, delineate WHPAs for the identified wells.

4) Prepare a final report describing the technical approach used, numerical models and analytical tools utilized, and the resultant WHPAs for the identified wells.

WHPAs were delineated for wells owned by the following entities: ECUA, U.S. Navy, Peoples Water Service, Farm Hill Utilities, Gonzalez Utilities, Cottage Hill Utilities and Molino Utilities. Delineations were performed for a total of 56 public supply wells. Delineations were not performed for wells with water use classifications other than public supply. This includes the large number of self-supplied industrial use wells located in the area (i.e. wells owned by Champion International, Monsanto Corporation, Gulf Power and others). In addition, delineations were not performed for the smaller, minor public supply wells.

This project and the preparation of this report were funded in part by a Section 319 Nonpoint Source Management Program grant from the USEPA. The grant was awarded through a contract with the Stormwater/Nonpoint Source Management Section of the FDEP. The total cost of the project was approximately $150,000, of which $75,000 (approximately 50 percent) was provided by the USEPA. The ECUA, the City of Pensacola, Escambia County and the Northwest Florida Water Management District provided the remainder of the project funds.

## Study Area Location

The area described in the report consists of the southern portion of Escambia County (Figure 1). The northern limit of the study area corresponds to the general vicinity of Molino. The study area consists of all of Escambia County south of Molino and includes the principal urban center of the county; specifically the City of Pensacola and the associated urbanized unincorporated portions of Escambia County. The vast majority of Escambia County residents live within the study area. The public supply wells (and associated treatment and distribution systems) which supply water to this population are also located within the study area.

## Previous Investigations

This work builds upon a number of previously conducted investigations of the Sand-and-Gravel Aquifer in southern Escambia County. Those of greatest direct technical relevance were conducted by the NWFWMD on behalf of the ECUA. Beginning in September 1990 and concluding in June 1993, the NWFWMD developed a three-dimensional, finite-element flow and solute transport model of the Sand-and-Gravel Aquifer in Escambia County. The conceptual model upon which the numerical model was based is described in Roaza et al. (1991). The completed numerical model is documented in Roaza et al. (1993).

Subsequent to 1993, the ECUA model was used for several site-specific investigations. In February 1994, the NWFWMD completed an assessment of the feasibility of installing a new production well at a site on Fairfield Drive. In April 1996, the NWFWMD assessed the feasibility of installing additional production capacity near the Pensacola Regional Airport (Roaza et al., 1996). The primary emphasis of the latter work was to examine the potential for saltwater intrusion, which could result from additional pumpage near the airport.

## Ground Water Use in Escambia County

Effectively, all of the water used for public supply, domestic, agriculture and recreation/landscape uses comes from the Sand-and-Gravel Aquifer. Over half of the water used for commercial and industrial uses comes from the aquifer. Only in the case of power generation does a substantial portion of the water use come from surface water. Table 1 summarizes the most recent water use figures for Escambia County by use classification and by source. Table 2 details public water supply use by system. The systems for which WHPAs were delineated constitute about 97 percent of the public water supply of the county.

## Use of ARC/View to Document Results

In order to make this final report more versatile, some data and graphics were prepared in a digital format to be accessed by the Environmental Systems Research Institute, Inc.

(ESRI) ARC/View software, version 3.0. Accordingly, a copy of ARC/View 3.0 is required to access these digital data and to make full use of the information contained therein.

Table 1. Estimated Average Water Use in Escambia County, 1995

| Use Classification | Ground Water (Mgal/d) | Surface Water (Mgal/d) | Total (Mgal/d) |
|---|---|---|---|
| Public Supply | 37.7 | 0.0 | 37.7 |
| Self-supplied Domestic | 3.39 | 0.0 | 3.39 |
| Agriculture | 1.66 | 0.31 | 1.97 |
| Recreation/Landscape | 4.74 | 0.62 | 5.36 |
| Commercial/Industrial* | 37.2 | 22.2 | 59.4 |
| Power Generation | 2.11 | 160 | 162 |
| Total | 86.8 | 183 | 270 |

Source: Marella, in preparation.
* denotes that the commercial/industrial use class includes ground water production from Corry Station that is actually used for public supply at Corry Station and at NAS Pensacola.

Table 2. Estimated Average Public Water Supply by System, 1995

| Public Supply System | Ground Water Use (Mgal/d) | Percent of County Public Supply Total |
|---|---|---|
| ECUA | 32.9 | 87 |
| Peoples Water Service | 2.08 | 5.5 |
| Molino Utilities | 0.58 | 1.5 |
| Century Utilities | 0.51 | 1.4 |
| Gonzalez Utilities | 0.39 | 1.0 |
| Cottage Hill Utilities | 0.33 | 0.9 |
| Farm Hill Utilities | 0.29 | 0.8 |
| Century Water Works | 0.26 | 0.7 |
| Bratt-Davisville Water System | 0.20 | 0.5 |
| Walnut Hill Water Works | 0.19 | 0.5 |
| Total | 37.7 | 100 |

Source: Marella, in preparation.

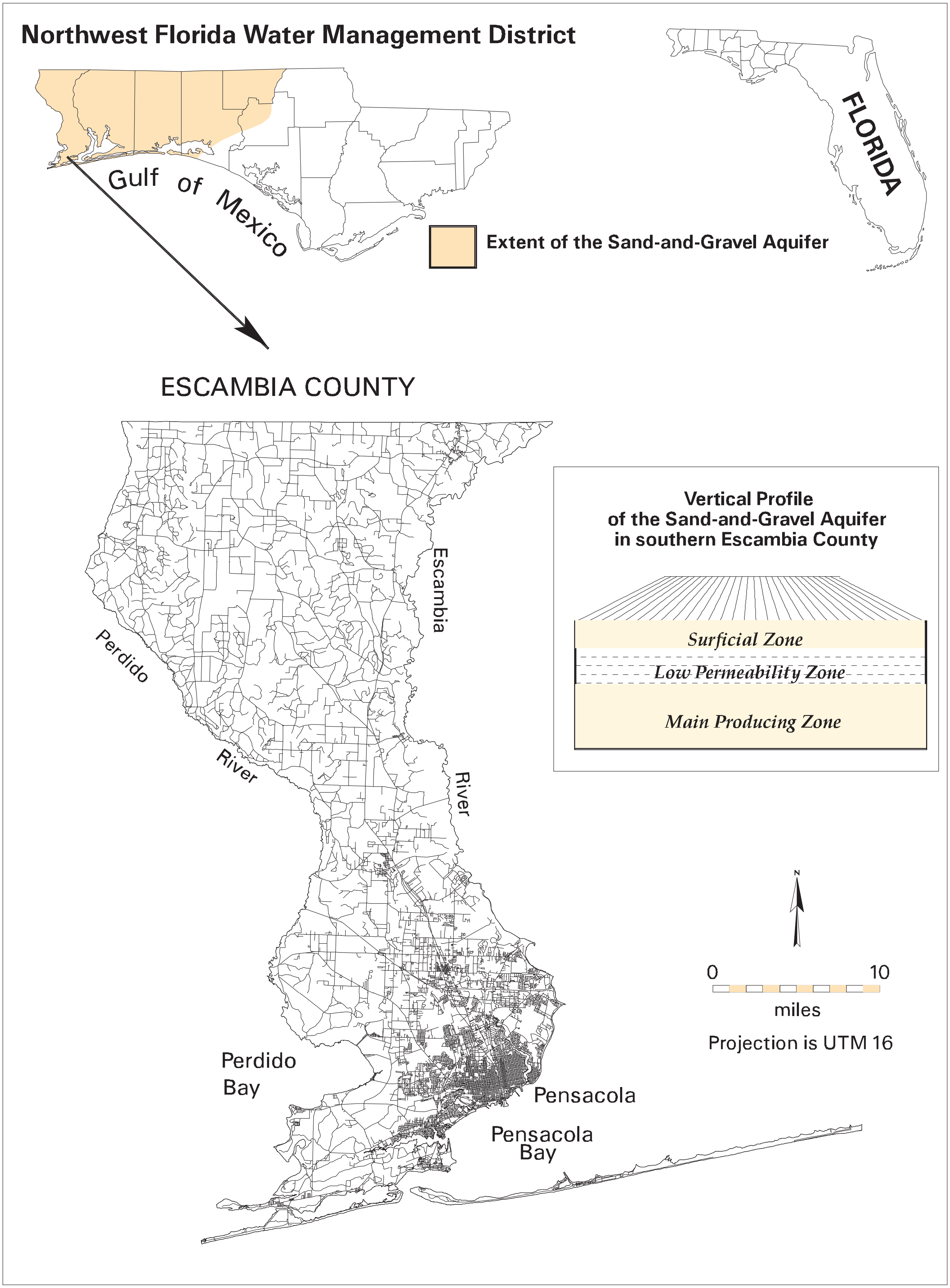



Figure 1. Area of Investigation

## WHPA CONCEPTS

### Definition of a Wellhead Protection Area

In southern Escambia County, all water in the Sand-and-Gravel Aquifer is constantly moving under the influence of gravity, flowing from recharge areas to discharge areas. Most of the southern half of the county is a recharge area. Natural discharge areas are limited to the areas of lowest elevation, including the immediate coastal fringe of the county and major bayous and streams. In addition to naturally occurring discharge, discharge from the aquifer also occurs through well pumpage. Under the influence of pumping, ground water is drawn into a well from the surrounding aquifer and is withdrawn from the ground water flow system. These processes go on more or less continuously.

The source of ground water withdrawn by an individual pumping well is limited to a portion of the aquifer surrounding the well. This "portion" of the aquifer is referred to as the "zone of contribution" for that well. The USEPA (1987) defines the zone of contribution as "the area surrounding a pumping well that encompasses all areas or features that supply ground-water recharge to the well." The actual zone of contribution for a given well is controlled by the physical processes that control the behavior of ground water flow, the hydraulic conditions in the vicinity of the well and the pumping rate. With sufficient information, these physical processes can be simulated to delineate the surface expression of the zone of contribution for each well of interest. This is the goal of the current work.

### Technical Alternatives in the Identification of WHPAs

Before a program to protect a well from man-induced contamination can be implemented, it is necessary to delineate the area to be protected. The USEPA has developed a number of publications designed to assist local governments with this task. *Guidelines for Delineation of Wellhead Protection Areas* (USEPA, 1987) summarizes various technical approaches to WHPA delineation. The goal of delineation is simple; to identify an area around a potable water wellhead that, when properly managed, will provide a high degree of protection for the quality of water produced by that well. Ideally, delineation activities incorporate both the physical processes that control ground water flow and transport, and local hydrogeologic information.

A WHPA can be delineated utilizing several different standards or criteria. In USEPA (1987), five criteria that may form the basis of a WHPA delineation are identified. Numerous methods are available to determine WHPA specifications based on chosen criteria. The criteria identified by the USEPA are:

- distance
- drawdown
- time-of-travel (TOT)
- flow boundaries
- assimilative capacity

The distance criterion delineates the WHPA by assigning a radius or other variable dimension from a pumping well. The drawdown criterion establishes the WHPA based on the magnitude of water level drawdown caused by the pumping well. Utilizing the TOT criterion, the WHPA boundary is determined based on time required for water or conservative contaminants to travel through the aquifer and reach the well. The flow boundary criterion incorporates the locations of physical or hydraulic features that control ground water movement such as a ground water divide or known discharge area. The assimilative capacity criterion incorporates the geologic formation's capacity to dilute or attenuate contaminants to acceptable levels before they reach the supply well.

USEPA (1987) also discusses various methodologies that can be used to delineate WHPA "footprints" for a variety of hydrogeologic environments utilizing the criteria listed above. Six general classes of methods used to delineate WHPA boundaries are identified. These methods vary considerably in input data requirements, difficulty of application and cost. Within these general classes, there are many specific technical approaches to identifying WHPAs. In order of increasing technical complexity, the general classes are as follow:

- arbitrary fixed-radius circles
- calculated fixed-radius circles
- simplified variable shapes
- analytical methods
- hydrogeologic mapping
- numerical flow and transport models

Regardless of the method (or methods) used in WHPA delineation, certain basic hydrogeologic data are required to implement delineation (with the exception of the arbitrary fixed-radius method). Actual data requirements are determined by the specific method applied. These data can include the following:

Aquifer properties

- transmissivity
- horizontal hydraulic conductivity
- saturated thickness
- horizontal hydraulic gradient (magnitude and direction)
- location of flow boundaries
- storativity
- porosity

Confining unit properties

- vertical hydraulic conductivity
- thickness

For Escambia County, each of these types of data is available for the Sand-and-Gravel Aquifer. These data were obtained through a process of mapping hydrogeologic units, analyzing aquifer hydraulic data and calibration of a regional ground water flow and solute transport model for Escambia County. These data are presented and documented in Roaza et al., 1991 and Roaza et al., 1993.

## Fixed-Radius Methods

Fixed-radius methods address the distance criterion. One principal advantage of these methods is their ease of application. In the case of the arbitrary radius method, identification of a WHPA simply consists of identifying the WHPA radius and drawing a circle of that radius around a wellhead. The method can be applied with no local knowledge of conditions that control flow and transport in the vicinity of the wellhead. Calculated radius methods are only slightly more complex. They involve application of simple analytical equations that incorporate some of the physical processes taking place in the vicinity of a wellhead. Accordingly, they require some knowledge of local hydrogeologic conditions. Items of information typically required to calculate the radius of the WHPA include well pumpage rate, various aquifer properties (hydraulic conductivity, saturated thickness, storativity and porosity) and a time component. The time component is the time-of-travel, which is generally specified in terms of years.

The disadvantage of fixed-radius methods is that they ignore, or vastly simplify, the hydraulic behavior of wells in their specific hydrogeologic settings. In addition, they do not account for the effects of nearby pumping wells. In a hydrogeologic environment such as the Sand-and-Gravel Aquifer, these methods can identify WHPAs inappropriate for local conditions. WHPAs identified by these methods may be either too large or too small, resulting in wellhead overprotection or underprotection. If the radii are too large, more land use activities may require regulation than necessary to effectively protect the selected wells. In an area of high local recharge, such as Escambia County, little or no real protection will be afforded by protective measures undertaken within radii that are too small.

## Analytical Methods

The simplified, variable shapes and analytical methods address the drawdown and TOT criteria by incorporating generalized aquifer hydraulic conditions and time into WHPA identification. Application of these methods results in WHPAs that reflect the effects of the regional hydraulic gradient, aquifer flow boundaries and the average hydraulic conductivity on well capture zones. Analytical methods involve site-specific application of analytical equations describing flow to a well. They require the site-specific values of the hydraulic conductivity as required for the calculated radii method, as well as information on the magnitude and direction of the regional hydraulic gradient, location of upgradient flow boundaries, and specification of a TOT of interest. Simplified, variable shapes are a derivative of analytical methods. For representative sets of hydrogeologic parameter values, "standardized" WHPA footprints are prepared using analytical methods. These standardized footprints are then applied to wells with similar hydrogeologic parameter values. The advantage of these analytical methods is that they better incorporate local hydrogeologic data and hydraulic behavior than do fixed radii methods. One disadvantage of these methods is that fixed hydraulic parameters (such as hydraulic conductivity and gradient) must be applied uniformly to the vicinity of the well when these parameters may, in fact, vary over the region. Another disadvantage is the inability to incorporate effects of nearby pumping wells. Compared to fixed-radius methods, application of analytical methods is technically more involved.

WHPAs derived by analytical methods are typically asymmetric, having a long and short axis (Figure 4-11, USEPA, 1987). The long axis is oriented parallel to the regional flow gradient, hence the requirement that this gradient direction be known. The pumping well is located near the downgradient end of the WHPA, which extends upgradient toward the nearest flow boundary (in the case of the Sand-and-Gravel Aquifer, this would be a regional ground water divide). The length of the WHPA is a function of the specified TOT; the longer the TOT, the longer the WHPA. If the TOT is sufficient, the WHPA will extend to the nearest upgradient ground water divide.

### Hydrogeologic Mapping

The hydrogeologic mapping method addresses the flow boundary criterion by incorporating local hydrogeologic information. In a hydrogeologic setting such as the Sand-and-Gravel Aquifer, application of this method would rely on identification of the aquifer potentiometric surface, regional flow gradient, upgradient ground water divides, downgradient discharge boundaries and flow paths between upgradient and downgradient boundaries in the identification of capture zones.

### Numerical Methods

Numerical methods are the most sophisticated of the six classes of methods. These methods can incorporate the effects of complex flow fields, complex hydraulic property zonation, boundary conditions and well interference through the use of numerical computer codes which model ground water flow. Computer models, which also simulate solute transport, can typically also address the assimilation criterion. The benefit of these methods is their ability to better incorporate spatial variability in hydrogeologic parameters, multiple well locations and irregular boundary conditions than analytical methods. Because of the complexity of codes used to simulate flow and transport, WHPA delineation with this method requires a high degree of technical expertise. This approach will tend to be the most expensive but, if properly implemented, will yield the most realistic and precise representation of a WHPA, especially in the more complex hydrogeologic settings.

## Current Escambia County Wellhead Protection Ordinance

The current Escambia County wellhead protection ordinance (7.12.00) was developed utilizing the fixed-radius method. It defines a WHPA as "all land within a 500-ft radius of an existing or designated protected wellhead." The ordinance also defines a zone of contribution as "all land within a 200-ft radius of an existing or designated protected wellhead." A "protected wellhead" is defined as "those wellheads with a permitted capacity of 100,000 GPD or more."

Within the 200-ft radius zone of contribution, the ordinance prohibits all "development activities." Within the 500-ft radius WHPA, a number of land uses are prohibited, including the items on the following excerpted list.

- Landfills

- Facilities for the bulk storage, handling or processing of materials on the Florida Substance List.

- Activities that require the storage, use, handling, production or transport of restricted substances: agricultural chemicals, petroleum products, hazardous/toxic wastes, industrial chemicals, medical wastes, etc.

- Wastewater treatment plants, percolation ponds and similar facilities.

- New aboveground and underground tankage of hazardous waste.

Appendix A contains maps showing the 200-ft radius zone of contribution and the 500-ft radius WHPA for all major public supply wells located in southern and central Escambia County. The areas designated by the current Escambia County wellhead protection ordinance are presented on maps with a digital orthophotoquadrangle (DOQ) as a base image.

# HYDROGEOLOGY OF THE SAND-AND-GRAVEL AQUIFER IN SOUTHERN ESCAMBIA COUNTY

## Regional Setting of the Sand-and-Gravel Aquifer

The Sand-and-Gravel Aquifer is a surficial aquifer system unique to the western portion of the Florida panhandle. It constitutes a major aquifer system in Florida and consists of a complex sequence of sand, gravel, silt and clay. Separating this surficial aquifer from the underlying Floridan Aquifer is a thick, effective confining unit known as the Intermediate System. The Floridan Aquifer is deeply buried in this region. Although it is an important source of ground water in much of northwest Florida, in Escambia and much of Santa Rosa counties, the Floridan Aquifer is highly mineralized and is not suitable as a potable supply source. For this reason, the Sand-and-Gravel Aquifer is the sole source for fresh ground water in all of Escambia County.

The base of the Sand-and-Gravel Aquifer is marked by the thick Intermediate System. The Intermediate System is a competent confining unit that effectively separates the Sand-and-Gravel Aquifer from the underlying Floridan Aquifer System. The Intermediate System is composed of thick beds of clays and other low-permeability sediments. It includes the Miocene age Pensacola Clay and the lower portion of the Miocene Coarse Clastics. In Escambia County its thickness ranges between 300 and 1,200 ft. It is thinnest in the northern part of the county and thickest in the south. Beneath urbanized Pensacola, its thickness exceeds 1,000 ft. No significant water bearing zones exist within this system in Escambia County. Because of its thickness and low permeability, the top of the Intermediate System forms the base of the Sand-and-Gravel Aquifer flow system.

The Sand-and-Gravel Aquifer is essentially a vast but thin veneer of sand underlying all of Escambia County. The thickness of the Sand-and-Gravel Aquifer ranges between 150 ft near Bayou Texar to 450 ft around Cantonment.

## Hydrostratigraphic Zonation of the Sand-and-Gravel Aquifer

The Sand-and-Gravel Aquifer includes the Pleistocene terrace deposits, the Pliocene Citronelle Formation and the upper portion of the Pliocene/Miocene Coarse Clastics. Locally, where clay, silt and fine sand dominate the sediments, low-permeability zones exist which may partially confine the underlying sands. These semi-confining zones, however, are discontinuous and lithologically variable and function as leaky confining layers. Intervals dominated by sand and gravel form the highly permeable, productive portions of the aquifer.

At any given site in Escambia County, a vertical profile of the Sand-and-Gravel Aquifer consists of layers of sand and gravel interbedded with layers of lower permeability silt, clay and fine sand sediments. This interbedded nature of the aquifer allows the Sand-and-Gravel Aquifer to be subdivided into three major zones. The designation of these zones is based on permeability contrasts. These major zones are the surficial zone, the low-permeability zone and the main-producing zone.

The surficial zone consists of the uppermost layers of saturated sand and gravel. The surficial zone is composed primarily of sand and gravel, but layers of silt and clay also occur. Beneath the surficial zone is the low-permeability zone. The low-permeability zone is composed of various mixtures of clay, silt and sand. Due to the highly discontinuous nature of individual beds within this zone and their variable lithology, the zone does not constitute an areally continuous confining bed. Thus, the low-permeability zone is very leaky and hydraulically interconnected throughout. Beneath this semi-confining layer lies the main-producing zone. This zone consists of moderate to well-sorted sand and gravel layers, typically interbedded with fine sand and clayey beds. The majority of the ground water withdrawn from the Sand-and-Gravel Aquifer is withdrawn from the main-producing zone.

These three zones vary greatly throughout the county. In addition, individual layers of sand or clay within these zones are highly discontinuous, resulting in considerable heterogeneity within the zones. This sometimes makes it difficult to map the extent of a zone from one area of the county to another. However, despite local variations in lithology, these zones can be generalized and mapped at the county scale.

The zonation of the Sand-and-Gravel Aquifer is best delineated by analysis of lithologic and geophysical logs of deeply penetrating or fully penetrating boreholes. The presence of variable lithology and heterogeneity within the zones make it difficult to delineate the three major zones from well logs that only penetrate a limited portion of the aquifer. The zonation described here and used in the ECUA numerical model application is based on analysis of approximately 180 geophysical logs (Roaza et al., 1991).

## Surficial Zone

The surficial zone consists of the uppermost layer of saturated sediments. It includes the interval of sediments between the water table and the first substantial, regionally continuous, low-permeability layer which marks the top of the low-permeability zone. Within the surficial zone, ground water exists under unconfined conditions. The surficial zone is a hydrogeologic unit and is not associated with any single stratigraphic unit. Locally, higher topographic areas generally exhibit a thicker surficial zone than adjacent areas of lower elevations. In some areas adjacent to the Perdido and Escambia rivers and some other major streams, the surficial zone has been completely eroded away, leaving the low-permeability zone exposed at the surface. Hydraulic property data for the surficial zone is virtually non-existent.

The surficial zone consists primarily of quartz grains, with grain size ranging from sand to gravel. Thin streaks of limonite-cemented sandstones also occur. The amount of gravel generally increases in the northern portion of the county. In addition to sand and gravel, the surficial zone also contains relatively thin and extremely discontinuous layers of clay and silt. These low-permeability layers occur within both the surficial zone and in the overlying unsaturated materials. Where present, these layers can create a perched water table considerably higher than that of the true water table of the surficial zone. The presence of perched water levels is most common in the middle portion of the county. For example, in the vicinity of the intersection of Interstate 10 and Highway 29, there is a continuous drainage of perched ground water into the interstate drainage system. The land surface elevation at this site is approximately 120 ft above sea level. The underlying surficial zone potentiometric surface lies at an elevation of about 65 ft above sea level.

The surficial zone is dissected by the Perdido and Escambia rivers as well as by many smaller streams. Where the streams and rivers have eroded into the water table, discharge takes place. This has resulted in the development of numerous independent flow systems within the surficial zone. These local flow systems each consist of an upland recharge area and adjacent lowland (perennial stream) discharge area. This localized flow system development is particularly prevalent in the northern half of the county. In the southern half of the county, much of the surface discharge from the surficial zone occurs as discharge to the bays and bayous.

## Low-Permeability Zone

The low-permeability zone is the first substantial, regionally continuous low-permeability layer encountered within the Sand-and-Gravel Aquifer. It forms a semi-confining layer, which acts to restrict the vertical flow of ground water between the overlying surficial zone and the underlying main-producing zone. The low-permeability zone is present throughout Escambia County and generally consists of a poorly sorted mixture of sand, silt and clay. The actual lithology of this unit is variable, ranging from poorly sorted sand and silt to sandy clay to clay. Locally, well-sorted, productive sands can also occur within this zone. The distinction between the low-permeability zone and the overlying and underlying materials can be quite subtle and difficult to detect.

In the southern portion of the county, the low-permeability zone consists of poorly sorted sand with some clay and gravel. Poor sorting with grain sizes ranging from fine sand to gravel, along with relatively minor amounts of clay and silt, distinguish this zone from the better-sorted surficial and main-producing zones. In the central and northern portions of the county, clay and silt content increase considerably. In these areas, this zone predominately consists of sandy clay and clay. This results in a more competent semi-confining layer in the central and northern portions of Escambia County. Throughout the county, the thickness of the low-permeability zone ranges between 20 ft and 100 ft.

The key significance of the low-permeability zone lies in its ability to restrict the flow of water between the surficial zone and the main-producing zone. This arises from the contrasts in vertical hydraulic conductivity among the three zones. Typically, the vertical hydraulic conductivity of the low-permeability zone is lower than that of the overlying and underlying zones. For example, at an aquifer test site in the central portion of the southern half of the county (ECUA OLF4A site), the vertical hydraulic conductivity of the low-permeability zone was determined to be 0.24 ft/d. For the underlying main-producing zone, the vertical hydraulic conductivity was determined to be 5.8 ft/d, or about 24 times that of the low-permeability zone.

This contrast in hydraulic conductivity is sufficient to generate a head difference between the surficial and main-producing zones, with the higher heads occurring in the surficial zone over much of the study area. Over most of this area, head differences range from a few feet up to about 10 ft. The maximum head difference between the surficial zone and the main-producing zone in the southern half of the county is on the order of 20 ft.

Typically, heads in the surficial zone are higher than in the main-producing zone. Only in the low areas in the immediate proximity of major discharge boundaries are heads in the main-producing zone higher. For example, along the Pensacola Bay shoreline in downtown Pensacola, heads in the main-producing zone are about five feet above sea level while heads in the surficial zone are only slightly above sea level.

## Main-Producing Zone

The main-producing zone is the most productive portion of the Sand-and-Gravel Aquifer and is the zone tapped by most of the major wells in the county. It includes the interval of the Sand-and-Gravel Aquifer situated below the low-permeability zone. The ground water within this zone exists under semi-confined conditions. The top of the Intermediate System marks the base of the main-producing zone. The thickness of the main-producing zone ranges between 90 ft and 290 ft in southern Escambia County.

The main-producing zone consists of moderate to well-sorted sand and gravel along with interbedded layers of sandy clay and clay. Thin streaks of limonite cemented sandstone, frequently referred to as hardpan, also occur. The clay content within the main-producing zone is, for the most part, limited to the clayey layers. The sand and gravel intervals of the main-producing zone typically contain very little clay. It is these clay-free intervals of sand and gravel which form the productive portion of the main-producing zone.

In southern Escambia County, the productive intervals consist primarily of medium to coarse sand. Local changes in lithology include areal variations as well as variations with depth at any given location. Changes in lithology are frequently subtle and include varying grain size distribution and significant changes in the degree of sorting. Changes in the lithology of the clayey layers involve the sand content, and can range from clayey sand to clay. In general, it appears as though these clayey layers tend to be sandier in the southern portion of the county.

The main-producing zone is primarily composed of productive intervals of sand and gravel. The clayey layers interbedded within the sand and gravel generally constitute from 10 percent to 40 percent of the thickness of the main-producing zone. In some areas, the productive intervals and the clayey layers can be correlated and appear to be continuous over distances of miles. In the Pensacola vicinity, numerous well logs show the productive sand intervals and a clayey layer (located within the bottom third of the main-producing zone) to be continuous throughout most of the area. Elsewhere in the county, a sufficient density of well log data is not available to determine if individual layers within the main-producing zone are indeed continuous over larger areas or if they exist as discontinuous lithologic units within the main-producing zone.

## Recharge, Discharge and Movement of Ground Water

Southern Escambia County receives, on average, about 60 inches of rainfall per year. Most of this rainfall either returns to the atmosphere via evapotranspiration or runs off overland to rivers or bays. However, some of it recharges the Sand-and-Gravel Aquifer. Recharge takes place over most of the study area. Infiltrated rainfall that escapes being recycled to the atmosphere via evapotranspiration moves downward through the unsaturated soils under the influence of gravity and encounters the water table. When this occurs, the infiltrated rainfall becomes part of the saturated ground water flow system.

Over most of the study area, heads in the surficial zone are higher than the heads in the underlying main-producing zone. The difference ranges from a few feet to a maximum of about 40 ft. This results in a downward hydraulic gradient, a downward flow component, and attendant recharge to the main-producing zone (Figure 2). Once water enters the main-producing zone, it moves horizontally to points of discharge. Natural discharge occurs in the low-lying areas where the head in the main-producing zone is greater than the head in the surficial zone, producing an upward flow component. Accordingly, in these areas, ground water moves from the main-producing zone through the low-permeability zone to discharge into the surficial zone and the bays, bayous and rivers. Discharge also occurs via pumping wells. Figure 3 shows the principal horizontal flow directions within the main-producing zone of the aquifer.

Both the Escambia River and the Perdido River form significant discharge boundaries for the Sand-and-Gravel Aquifer. Because these discharge boundaries are relatively close together near Cantonment, essentially no ground water flows from the northern portion of the county to the southern portion of the county. Ground water in northern Escambia County naturally discharges to either the Escambia River or the Perdido River, or is discharged through wells, many of which are located in the Cantonment area. The area south of Cantonment is effectively hydraulically isolated from the northern portion of the county. All ground water in the southern half of the county is derived from local recharge.

Recharge within the study area is substantial. In spite of pumpage in excess of 80 Mgal/d, there is still about 50 ft of hydraulic head (referenced to sea level) in the main-producing zone in the center of the southern half of the county. Ground water flows radially away from the potentiometric high and discharges to adjacent bays and bayous. Additional discharge occurs via pumping wells.

Results of the regional model of the Sand-and-Gravel Aquifer (Roaza et al., 1993) provided an estimate of the recharge to the main-producing zone in the southern half of the county. Over this area, the steady-state recharge to the main-producing zone was estimated to be 124 Mgal/d (12.5 inches per year over the 209 $mi^2$ recharge area generally south of Molino). Of this quantity, pumpage accounted for 75 Mgal/d and discharge to natural boundaries accounted for the balance.

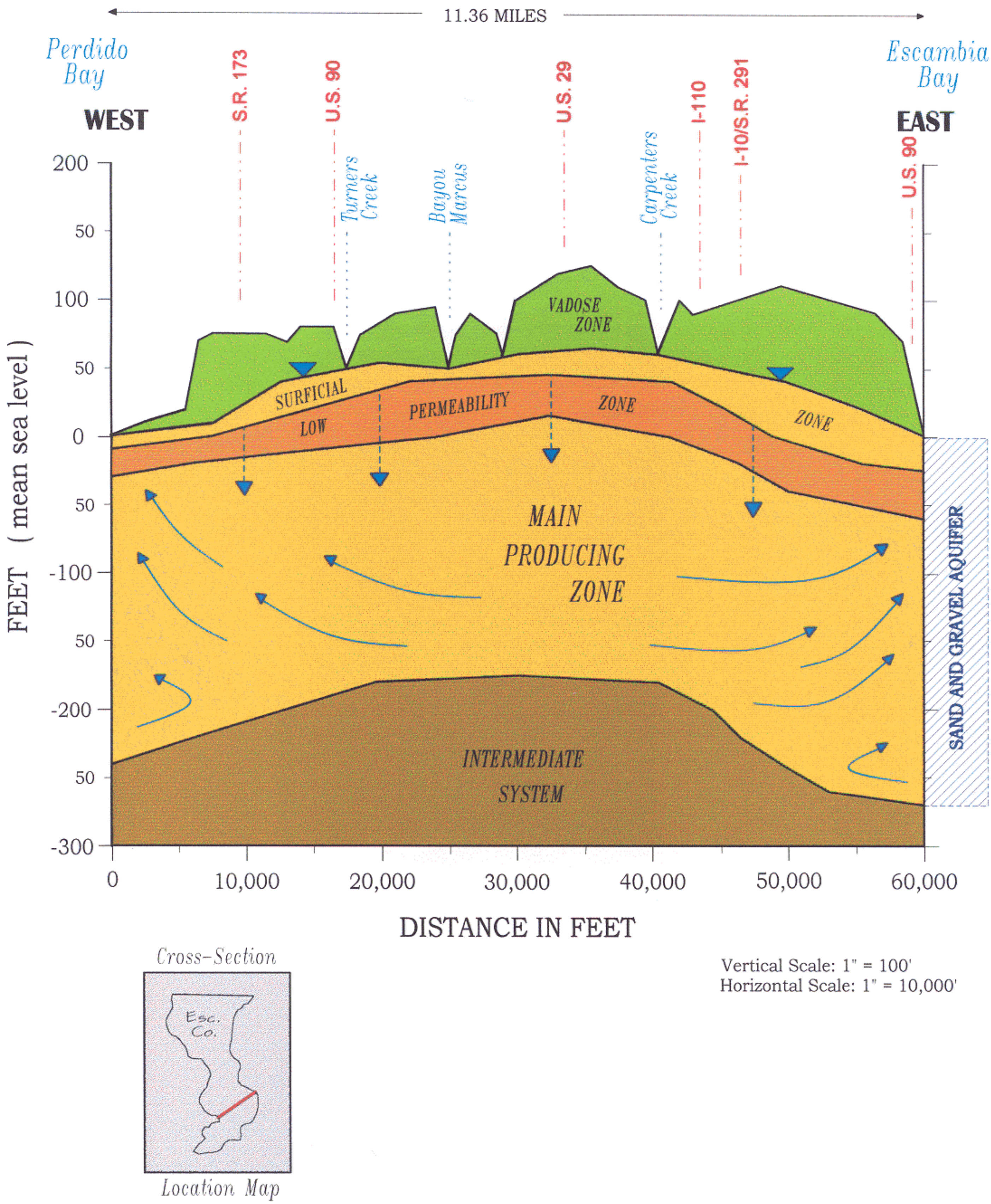



Figure 2. Principal Vertical Flow Directions in the Sand-and-Gravel Aquifer.

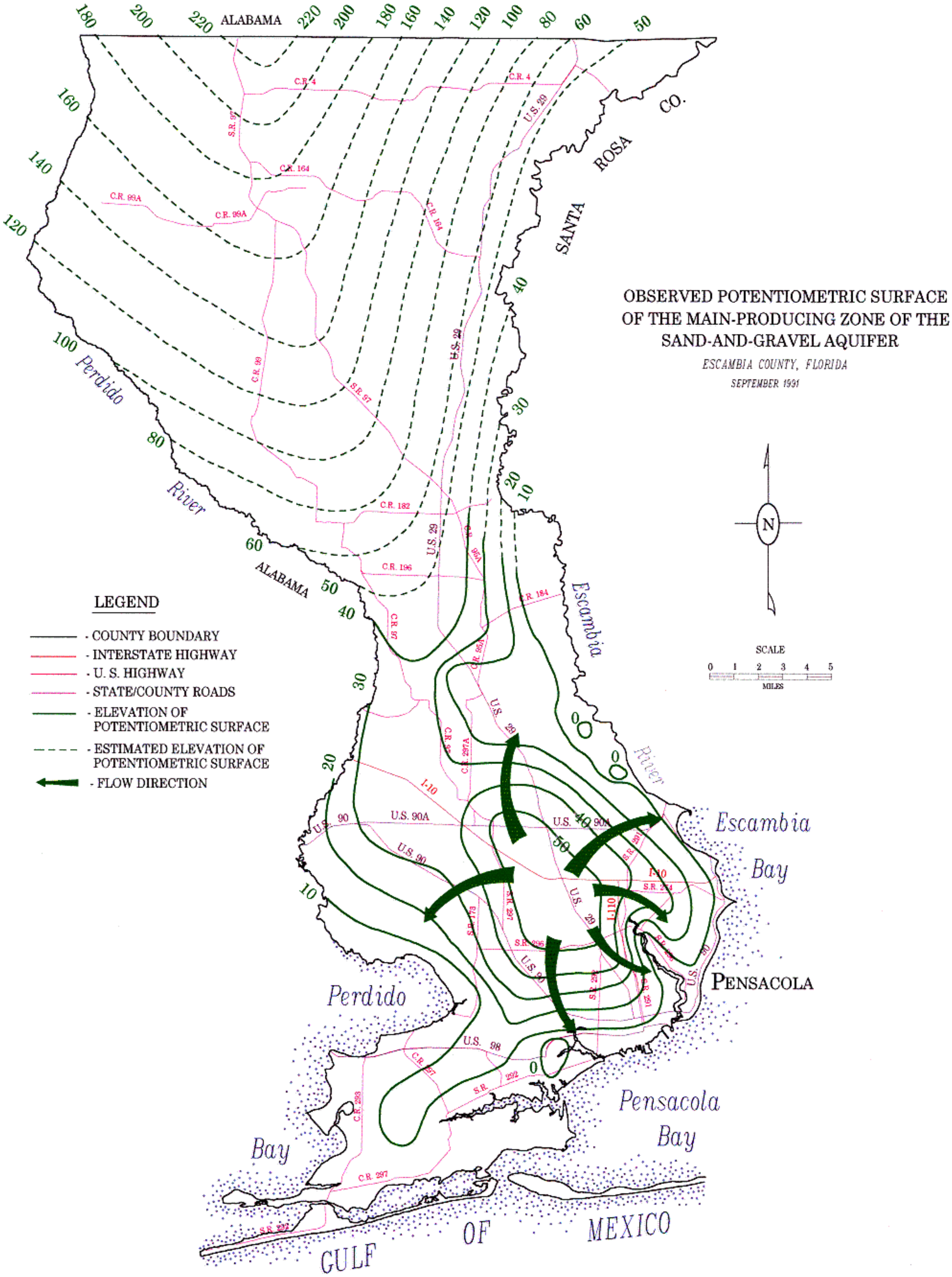



Figure 3. Principal Horizontal Flow Direction in the Sand-and-Gravel Aquifer.

## METHODOLOGY AND PROCEDURES APPLIED TO WHPA DELINEATION

### Local Community Input to Selection of WHPA Delineation Methodology

As a prerequisite to WHPA delineation, local community input was obtained on the issue of a reasonable technical approach to delineation in Escambia County. As outlined above, there are at least six methodologies which can be used to define a WHPA footprint. Given that the local community will ultimately be responsible for implementation, input from local governments and the ECUA was sought regarding which technical approach should be employed for this project. To this end, a series of meetings was held among the NWFWMD, the ECUA and planning staffs of the City of Pensacola and Escambia County to discuss the six methodologies and specific local concerns. At the conclusion of these meetings, the parties mutually agreed to the criteria and methodology that guided the technical work performed by the NWFWMD and described in this report. The specific issues and decisions are outlined below.

- Of the five criteria that may form the technical basis of WHPA delineation (distance, drawdown, TOT, flow boundaries and assimilative capacity), which is the most appropriate for the study area?

It was agreed that, given the existence of the ECUA flow and transport model, the best approach would be to utilize a TOT-based methodology.

- What TOT (in years) is appropriate for this situation?

Following some discussion, 7- and 20-year TOTs were deemed to be most appropriate in southern Escambia County. It was decided that a 5-year TOT provided too little time in which to initiate corrective action. In addition to the 7- and 20-year TOTs, the NWFWMD agreed to describe the TOT associated with a circle of 500-ft radius. This is the radial distance associated with the current Escambia County wellhead protection ordinance. It was further agreed that the technical approach would incorporate both the vertical travel time through the low-permeability zone and the horizontal travel time through the main-producing zone.

- What methodology will be used to define the shape, size and location of the WHPA footprints?

Given the existence of the Escambia County numerical model (Roaza et al., 1993) and the desire to include the vertical TOT through the low-permeability zone, it was agreed to use a combination of numerical and WHPA general particle tracking (GPTRAC) methods (Blandford and Huyakorn, 1991) to define the shape, size and location of the WHPA footprints.

- What value(s) of low-permeability zone vertical hydraulic conductivity (k') should be used?

One component of the ECUA numerical model is a map depicting the calibration-derived zones of vertical hydraulic conductivity (k') used in the model. This map depicts, in plan view, the various k' zones. Within each zone, k' is constant; between adjacent zones, k' values vary. During the course of discussions, it was recognized that use of the model-calibrated zone map could yield undesirable artifacts in the WHPA footprints. This arises in the circumstance where a k' zone boundary lies near a pumping well (within the WHPA). Accordingly, the decision was made to modify the k' zone polygons to minimize this problem. It was further agreed to modify the zone polygons such that the upgradient k' polygon value would be used in the vicinity of the pumped well.

- What pumpage rates should be simulated?

The ECUA agreed to calculate an expected (forward-in-time projection) annual pumping rate for each of its wells. These rates were used in the delineation calculations. The same methodology was used to estimate pumpage for the other systems simulated and is presented later in this report.

- Does the technical approach treat contaminants as conservative, or does it attempt to account for the effects of retardation or assimilation?

WHPA delineations will be predicated on the assumption that contaminants behave in a conservative manner.

**These decisions guided the subsequent technical analysis, which lead to the WHPA delineations documented in this report.**

## General Delineation Procedure

Based on the agreed-upon methodology outlined above, a procedure for WHPA delineation was established. The following outlines the general procedures applied to all WHPA delineations included in this report. The Environmental Systems Research Institute, Inc. (ESRI) ARC/INFO geographic information systems software (Version 7.0) was utilized extensively throughout the WHPA delineation process.

- Identify all significant ground water withdrawal wells within the study area.

- Update well locations utilizing differential GPS techniques.

- Review and update water use data for these wells.

- Establish pumpage rates to be utilized for WHPA determinations.

- For the purposes of verification, re-run steady-state regional model (Roaza et al., 1993) with original calibration pumpage (75.2 Mgal/d), and with revised WHPA pumpage (98.9 Mgal/d).

- Modify low-permeability zone vertical hydraulic conductivity (k') distribution to facilitate WHPA delineations. Run steady-state regional model with 75.2 Mgal/d pumpage and revised k' distribution. Compare heads obtained from this model with heads from the original regional model. Re-compute calibration statistics.

- Run steady-state regional model with WHPA pumpage (98.9 Mgal/d) and revised k' distribution. Heads obtained from this model are used to interpolate boundary heads for local models.

- Using local model steady-state head distributions and Darcy's Law, calculate vertical TOT across the low-permeability zone. This calculation is based on surficial zone boundary heads, modified k' distribution, porosity, low-permeability zone (model slice 6) thickness and simulated main-producing zone heads. Perform this calculation at each model node. Develop a field of nodal values of vertical TOT. Convert this field of values to a surface model with ARC/INFO.

- Execute the GPTRAC module (component of USEPA WHPA model [Blandford and Huyakorn, 1991]) to determine horizontal times-of-travel through the main-producing zone. GPTRAC module uses main-producing zone hydraulic heads obtained from local-scale models. Execute this model for numerous times-of-travel. Convert horizontal TOT hulls to surface model with ARC/INFO.

- Combine the vertical TOT and the horizontal TOT to determine the 7-year and 20-year WHPAs. Also determine the TOT associated with the currently delineated WHPAs (500-ft radial distance from well).

## **Regional Water Use**

Water use statistics were collated for the 12 principal water systems in the southern half of the county. These systems (Molino Utilities, Peoples Water Service, University of West Florida, ECUA, Gonzalez Utilities, Monsanto Chemical Company, U.S. Navy, Champion International Corporation, Gulf Power Corporation, Farm Hill Utilities, Reichold Chemicals, Inc. and Cottage Hills Utilities) accounted for 87 percent of all ground water use in Escambia County in 1995 (Marella, in preparation). Table 3 lists (for these 12 systems) the pumpage simulated in the Escambia County regional ground water model (Roaza et al., 1993), the average water use over two recent years (1995 and 1996), the current permitted average daily ground water withdrawal rate (ADR), and the consumptive use permit expiration date.

## **Wells and Pumpage Incorporated Into WHPA Simulations**

The Escambia County regional ground water flow model (Roaza et al., 1993) simulated pumpage impacts from 94 wells. The simulated pumpage associated with these wells was 75.2 Mgal/d. This figure represents the 1991 average daily withdrawal from these wells. Simulated pumpage of 75.2 Mgal/d and the August/September 1991 main-producing zone and surficial zone potentiometric surfaces constituted the original calibration data set.

In order to complete the WHPA delineations, it was necessary to incorporate updated pumpage into the calibrated regional model. This included identifying additions and deletions to the set of simulated wells and updating pumpage figures. Examining consumptive use permitting records for the 12 major systems within the study area identified additions and deletions. Review of these records identified 107 wells presently on the consumptive use permits of these systems (Appendix B).

From this list of 107 wells, a total of 102 wells were included in the regional model used for WHPA delineations. Five wells (Peoples #7, ECUA Bronson #2, ECUA #2-(#8), NAS Pensacola #1 and NAS Pensacola #2) were excluded due to long-term lack of use. For the remaining 102 wells, updated pumpage figures were collected and used to establish pumpage rates utilized for WHPA delineations.

Table 3. Water System Pumpage Information

| System Name | 1991 Regional Model Pumpage (Mgal/d) | Mean 95/96 Water Use (Mgal/d) | Permitted Average Daily Withdrawal Rate (Mgal/d) | Consumptive Use Permit Expiration Date |
|---|---|---|---|---|
| Molino | 0 | 0.584 | 0.599 | Mar 2003 |
| Peoples | 1.54 | 2.12 | 2.36 | Jan 1998 |
| UWF | 0.246 | 0.35* | 0.310 | Mar 2003 |
| ECUA | 33.6 | 33.5 | 44.7 | Sep 2013 |
| Gonzalez | 0.349 | 0.408 | 0.485 | Jul 2002 |
| Monsanto | 9.92 | 9.98 | 8.37 | Jan 1999 |
| U.S. Navy (Corry only) | 5.73 | 2.67 | 5.60 | Apr 2000 |
| Champion | 21.5 | 24.7 | 27.5 | Oct 1999 |
| Gulf Power Crist Plant | 2.20 | 2.11* | 2.20 | Dec 1999 |
| Farm Hill | 0.328 | 0.316 | 0.389 | Mar 2000 |
| Reichold | 0.200 | 0.43* | 0.600 | Aug 2004 |
| Cottage Hills | 0.266 | 0.340 | 0.356 | Jul 2004 |
| **TOTAL** | **75.8** | **77.5** | **93.5** | |

Note: * denotes that only USGS 1995 water use is available (Marella, in preparation). Pumpage at Saufley Field (0.12 Mgal/d) was included in Roaza et al. (1993) and is deleted from the above table due to the fact that pumpage at Saufley has ceased.

Although WHPAs were delineated for major public supply wells only, water use by significant industrial, irrigation and power-generation wells was accounted for and included in the regional model. This derives from the influence of this non-public supply pumping on the regional flow field and associated ground water velocities. Appendix C provides a summary of the recent pumpage history for the 12 systems of interest and the pumpage rates used for WHPA delineation. Also included in this appendix is a description of the data source or methodology used to establish the WHPA pumping rates for individual systems.

ECUA is by far the largest provider of potable water in the county. Consistent with discussions among the ECUA, Escambia County and the City of Pensacola, the ECUA established WHPA delineation pumpage rates to be used for its wells. The methodology thus established was used as a guide for developing estimates for the other public supply wells in the county.

For each of its wells, the ECUA calculated the average daily pumpage for the five highest use months of the year (May through September). This "mean summer pumpage" was calculated for both 1995 and 1996. The higher of the two mean summer pumpage rates was established as the minimum average annual rate for WHPA delineation. For some wells, the ECUA determined that the pumping rate so calculated clearly indicated an under-utilization of the well in question. For these wells, the ECUA upwardly adjusted the WHPA pumping rate by a factor it deemed to be representative of the likely long-term use of the well.

For ECUA, the aggregate pumpage used for WHPA delineation was 1.54 times their annual average withdrawal rate for the years 1995 and 1996 (averaged over two years). This 1.54 factor was applied to all other public water supply systems to determine their simulated withdrawal rates for WHPA delineation. Other water uses (industrial, irrigation and power supply) were generally set at their 1995/1996 mean annual withdrawal rate. Appendix C provides details on individual water production systems. The simulated regional WHPA delineation pumpage of 98.9 Mgal/d is 31.5 percent higher than the 1991 calibrated regional model pumpage and 5.8 percent higher that the currently permitted ADR for these systems.

## Regional Water Budget

The regional model was used to assess water budget changes due to increasing pumpage from 75.2 to 98.9 Mgal/d. Three steady-state regional simulations were run (zero pumpage, 75.2 Mgal/d and 98.9 Mgal/d), each using the calibrated hydraulic parameters of the original regional model (Roaza et al., 1993) and the observed August 1991 surficial zone potentiometric surface. This potentiometric surface served as a constant head boundary. The 75.2 Mgal/d simulation incorporated the 94 wells of the original regional model and the actual 1991 pumping rates. The regional model was calibrated by simulating this pumpage and matching model output to observed August 1991 main-producing zone heads.

The 98.9 Mgal/d simulation incorporated the 102 wells identified as being of significance to the regional WHPA model. Table 4 contains the components of the modeled regional water budget, which apply to the entire model domain (all of Escambia County and approximately 700 square miles in area). Based on the zero pumpage simulation, Table 5 describes the sources of well discharge in terms of induced recharge from the surficial zone and reduced discharge to the surficial zone (streams, rivers and bays).

Well pumpage comes from two sources, induced downward leakage from the surficial zone, and reduced upward leakage to surface water boundaries (streams, rivers and bays). As indicated in Table 5, most of the well pumpage (83 percent) is derived from induced recharge from the overlying surficial zone. This high percentage is attributable to the relatively high k' values used to simulate the low-permeability zone. Model-calibrated k' values in southern Escambia County (where the majority of pumpage occurs) ranged between $5x10^{-3}$ ft/d and $2x10^{-1}$ ft/d. K' values in this range are consistent with the conceptualization of the low-permeability zone as a sandy, leaky, ineffective "confining" unit. In support of values in this range, the measured k' value obtained from the ECUA OLF4A aquifer test site was $2.5x10^{-1}$ ft/d (Roaza et al., 1993). Given the range of k' values derived from the model calibration, the surficial zone is simulated as being relatively well-connected to the underlying, pumped main-producing zone. Accordingly, water is readily supplied to the main-producing zone and this source accounts for a relatively large percentage of the regional water budget.

Table 4. Model-Derived Regional Volumetric Ground Water Budget

| Budget Components | Zero Pumpage Scenario (Mgal/d) | 75.2 Mgal/d Pumpage Scenario (Mgal/d) | 98.9 Mgal/d Pumpage Scenario (Mgal/d) |
|---|---|---|---|
| Recharge to Main-producing Zone from Surficial Zone | 103.7 | 165.8 | 185.6 |
| Discharge to Surficial Zone (streams, rivers and bays) | 103.1 | 89.8 | 86 |
| Discharge to Wells | 0 | 75.2 | 98.9 |
| Percent Discrepancy Between Recharge and Discharge (as a function of discharge) | 0.65 | 0.48 | 0.42 |

Table 5. Well Discharge as a Percent of Water Budget Components

| Budget Components | 75.2 Mgal/d Pumpage Scenario (percent) | 98.9 Mgal/d Pumpage Scenario (percent) |
|---|---|---|
| Well Discharge | 100 | 100 |
| Induced Recharge from Surficial Zone | 82.5 | 82.8 |
| Reduced Discharge to Surficial Zone (streams, rivers and bays) | 17.5 | 17.2 |

## <u>Application of Regional Flow Model for WHPA Delineation</u>

The original regional flow model grid (Roaza et al., 1993) incorporated a variable node spacing scheme and both quadrilateral and triangular elements (the vast majority of elements are quadrilateral). In the southern part of the county, the nodal spacing for the quadrilateral elements was 2,250 ft by 2,250 ft. In the region of Bayou Texar, the spacing was reduced to 1,125 ft by 1,125 ft. This was done to accommodate the steeper hydraulic gradient in the vicinity of the bayou. In the central part of the county, where pumpage was concentrated, a 1,125 ft by 1,125 ft spacing was also employed. In the northern half of the county, nodal spacings varied between 2,250 ft by 2,250 ft and 2,250 ft by 9,840 ft. A spatial multiplier that did not exceed 1.5 governed the variable spacing transition.

In order to accurately simulate ground-water velocities (and associated times-of-travel) in the near vicinity of a pumping well, it is necessary to accurately represent horizontal and vertical hydraulic gradients. This, in turn, requires accurate determination of hydraulic head in the near vicinity of wells for which WHPAs are being delineated. Due to the original regional model's relatively large grid spacing (compared to the anticipated size of a WHPA) and the fact that head calculation accuracy is dependent on nodal spacing, it was necessary to refine the grid spacing in the vicinity of WHPA wells.

The numerical code utilized for the regional model and applied to this work (SWICHA Version 5.05, [GeoTrans, Inc., 1991]) was not capable of executing, in a single simulation, a problem of the size generated by applying a refined grid in the vicinity of all 56 WHPA wells. Therefore, the Telescopic Mesh Refinement (TMR) technique was utilized. This technique allowed the use of multiple meshes; each designed to accommodate a limited number of wells. It also allowed for simulating only the portion of the regional model domain in the general vicinity of the wells of interest. In applying the TMR technique, model boundaries for the detailed, refined grid (local grid) are obtained from a regional model simulation executed using pumping rates equal to the pumpage to be applied in the local model. In this way, head boundaries for the local model are obtained or interpolated from the regional model.

## Regional Model Recalibration

A standard component of the development of any numerical model is calibration. The relevant ASTM standard (ASTM, 1994) defines calibration as "the process of refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the ground-water flow system." Model calibration consists of a series of numerical simulations. The difference between successive simulations is that, prior to performing a new simulation, some aspect of the model (boundary conditions, hydraulic properties, etc.) is modified. The modification is based on review of model output from the previous simulation.

As each simulation is performed, the output is evaluated and used to guide modification of the relevant hydraulic parameters to be used as input to the next simulation. By manipulating model input and evaluating the corresponding output, the goal of calibration is to produce a model which, to an acceptable degree, simulates the natural system of interest. Usually this means minimizing, over the entire model domain, differences between observed and simulated water levels. Through model calibration, water level residuals (differences between observed and simulated water levels) converge to an acceptably low level.

During the original regional model development, a calibration was performed. A total of 25 numerical model simulations were performed before the model was deemed to be calibrated. As a part of the calibration process, a number of statistics were calculated on water level residuals. Roaza et al. (1993) present statistics for the mean error, the mean absolute error, and the root mean square error for the final, calibrated version of the regional model. Those statistics are reiterated in Table 6.

In the context of the present WHPA delineation process, two aspects of the Roaza et al. model indicated the need to undertake a limited recalibration. First, the k' distribution of Roaza et al. imparted undesirable artifacts to WHPAs located near k' zone boundaries. To correct this problem, the regional k' field was modified. Second, review of the main-producing zone head field indicated that, in certain areas, the calculated heads had unacceptably large errors. These head errors were reduced by simultaneously modifying the k' distribution and the source-bed head distribution. Together, these modifications constituted a limited re-calibration of Roaza et al. (1993). Hydraulic conductivities and the source bed head distribution used for WHPA delineation are presented in Appendix D.

The calibrated regional model of Roaza et al. (1993) represented spatial variability in the low-permeability zone k' distribution as a series of polygons (Plate 10). K' over each polygon was assigned a single, uniform value. Over the model domain, k' took the form of a piece-wise discontinuous step function. Accordingly, between polygons there were abrupt changes in k' values. In the most extreme instance, k' varied by two orders of magnitude. Elsewhere, it varied by (approximately) an order of magnitude. While appropriate for the regional flow model, abrupt changes in k' over short distances posed a problem for WHPA delineation.

Roaza (1996) documented the effects of abrupt changes in k' on the shape of delineated WHPAs. These effects derive from inclusion of vertical travel time into delineation. For constant values of gradient and porosity, seepage velocity and k' are linearly correlated (positively). Increasing k' by an order of magnitude increases the corresponding seepage velocity by an equivalent magnitude. For constant values of gradient and porosity, k' and travel time are log-linearly correlated (negatively). Increasing k' by an order of magnitude decreases travel time by an equivalent magnitude. Therefore, order of magnitude k' variations over short distances (polygon-boundary proximity) resulted in similar magnitude vertical travel time variations. This generated undesirable artifacts (sharp angles, odd shapes, etc.) in WHPA hulls prepared for a well lying near k' polygon boundaries.

In order to minimize undesirable WHPA shape artifacts and overly large head errors, modification of the regional k' distribution and the overlying source-bed head distribution were required. Through a series of regional-model simulations, a modified k' distribution and a modified source-bed head distribution were developed. In order to assess whether or not these changes yielded a substantially different regional head distribution, the calibration statistics were re-computed for the new main-producing zone head field. Those statistics are given in Table 6. Based on a qualitative comparison of the two sets of statistics, the k' and source-bed head changes were deemed to yield a main-producing zone head field not significantly different from the original regional calibration of Roaza et al. (1993).

Table 6. Regional Model Calibration Statistics

| | Roaza et al. (ft) | Modified k' Distribution (ft) |
|---|---|---|
| **Mean Error** | | |
| Minimum | -6.8 | -8.99 |
| 25th percentile | -0.8 | -1.37 |
| Median | 1.1 | 0.78 |
| 75th percentile | 3.1 | 2.3 |
| Maximum | 11.5 | 10.66 |
| Standard Deviation | 3.3 | 3.24 |
| Mean | 1.4 | 0.48 |
| **Mean Absolute Error** | | |
| Minimum | 0.04 | 0.13 |
| 25th percentile | 1.0 | 1.01 |
| Median | 1.7 | 1.97 |
| 75th percentile | 3.8 | 3.24 |
| Maximum | 11.5 | 10.66 |
| Standard Deviation | 2.4 | 2.09 |
| Mean | 2.6 | 2.50 |
| **Root Mean Square Error** | | |
| RMS | 3.3 | 3.25 |

note: The number of residuals for Roaza et al. (1993) was 61.
The number of residuals for the revised k' distribution was 64.

## Application of Local Flow Model for WHPA Delineation

It was important to utilize accurate well locations and to accurately locate wells within the numerical model domain. To this end, all wells selected for WHPA delineation were located using differentially corrected Global Positioning System (GPS) equipment (Appendix B). Based on the GPS well locations, eight local (sub-regional) model grids were generated. Each of these meshes (point and polygon topology) was geo-referenced to NAD83. Eight meshes were required to limit the number of nodes in any one mesh to less than 100,000, while imposing a fine node spacing in the vicinity of WHPA wells. The maximum node number limitation was a software constraint of the SWICHA code. Among the eight meshes, the node number ranged between 38,000 and 96,000. Each mesh was constructed using only quadrilateral elements. Each mesh preserved the seven slice vertical structure of the regional model.

Local meshes were generated from the WHPA wells outward, with a node at the coordinates of each well. Nodal spacings ranged from no more than 66 ft adjacent to WHPA wells to a maximum of 1,903 ft. A nodal spacing multiplier of 1.4 was applied in the mesh design. For those wells that were not delineated, no effort was made to further refine the node spacing at the well. These wells were assigned to the nearest existing node.

## Vertical Time-of-Travel Calculation

One local-community decision regarding WHPA delineation was to incorporate vertical times-of-travel into the delineation process. Since the USEPA's WHPA model (Blandford and Huyakorn, 1991) is not designed to directly incorporate vertical TOT through a semi-confining unit, this activity was performed external to the execution of the WHPA model. Using heads output from the local flow models, these calculations were performed within the ARC/INFO operating environment.

The underlying conceptual assumption is that a finite time is required for contaminants to travel across the low-permeability zone. Assuming the surficial zone head is higher than the head in the underlying main-producing zone, the contaminant travel direction across the semi-confining unit is downward. Over most of southern Escambia County, this assumption is appropriate. Therefore, contaminants reaching the boundary between the surficial zone and the low-permeability zone will be advected across the low-permeability zone into the main-producing zone. It is the goal of the vertical travel time calculations to approximate the time required for this to occur.

One of the key attributes of both the regional model and the local models is that the hydraulic gradient across the low-permeability zone is oriented either vertically upward or vertically downward. None of the models provide for horizontal hydraulic gradients within this unit. Therefore, in order to approximate the desired steady-state vertical seepage velocity ($v_s$) at any boundary node, it is sufficient to know the following: nodal boundary head ($h_b$), calculated head in the immediately-underlying node ($h_m$), low-permeability zone thickness (b'), low-permeability zone vertical hydraulic conductivity (k'), and low-permeability zone porosity ($\phi$). Hence, the steady-state vertical seepage velocity is approximated as follows:

$$v_s = (1/\phi)*(k'((h_b-h_m)/b')) \qquad [ft/d]$$

The vertical travel time at any boundary node is simply the thickness of the low-permeability zone (b') divided by the seepage velocity ($v_s$). Using this approach, a two-dimensional, areal, steady state vertical TOT field was calculated for each of the local models. Travel times were calculated at each SWICHA mesh node. From these values, an ARC/INFO TIN surface model was prepared. The final step involved preparing a regular grid of point values of travel time. Converting the TIN surface model to a regular, 20-meter grid did this. Output from this final step was combined with the horizontal times-of-travel to produce the desired vertical/horizontal composite delineations.

### Sensitivity of Vertical Travel Times to Low-Permeability Zone K' Values

The final calibrated k' distribution is an artifact of the regional model calibration. This particular distribution is but one of a number of possible distributions, all of which would yield essentially the same main-producing zone heads. Any of these k' distributions are appropriate for inclusion in the regional model. At a given point in space, however, k' may (and probably will) vary from the modeled value at that point. What is unknown is by how much local-scale k' values vary from model-calibrated values. Since the model-calibrated values are used for WHPA delineation, questions regarding the impact of k' variability on travel times are appropriate. In order to place this question in context, a travel time sensitivity analysis was performed with the regional model (75.2 Mgal/d pumpage and original k' distribution).

The sensitivity analysis was performed by modifying the regional k' distribution and running the model. The modification consisted of multiplying k' zone values by a series of factors; 0.25, 0.5, 1.0, 1.5, 2 and 3. For each of six steady-state model executions, all k' zone values were increased (or decreased) by the same factor. No other modification of the regional model was performed. Following the zone modification, the regional model was run and head differences determined at selected nodes. Associated nodal travel times were calculated and plotted against values of the multiplier. Results from three selected nodes are given in Figure 4.

The degree of sensitivity of travel time to k' is denoted by the slope of the curve. The steeper the slope, the greater the sensitivity of the dependent variable (travel time) to the independent variable (k'). If the line were flat, travel time would be completely insensitive to regional k' values. As it is, the vertical travel time demonstrates moderate to large sensitivity to k' variability. Among simulations, the k' multiplier varied over about an order of magnitude. For boundary nodes 25306 and 25071, this resulted in vertical travel times that varied by a factor of about 2.5. For boundary node 27254, travel times varied by a factor of seven.

The regional k' distribution has greatest relevance to the regional model. When used for local-scale WHPA delineation, some uncertainty in travel time determination is introduced. The Sand-and-Gravel Aquifer is inherently heterogeneous. This applies to the hydraulic properties of the low-permeability zone as well. Given the shortage of measured k' values, it is difficult to ascertain the extent to which WHPA-scale k' values vary from the model-calibrated values. Nonetheless, the model-calibrated k' distribution represents the best available information on low-permeability zone k' values at the countywide scale. Accordingly, this is what was used for vertical travel time determination. Future ground water data-gathering efforts should include multi-well aquifer tests to allow for wellhead-scale determinations of vertical hydraulic conductivity.

## Horizontal Time-of-Travel Calculation

The GPTRAC module of the USEPA WHPA model was used to approximate horizontal times-of-travel within the main producing zone. GPTRAC is a two-dimensional, particle-tracking code used to identify the volume of aquifer contributing water to a well over a given period of time. It does this by approximating the location of streamlines that converge on a pumping well. Streamline locations are determined by reverse tracking a series of particles along the converging streamlines, up the hydraulic gradient, and away from the pumping well. In particular, each particle is reverse tracked away from the well for the same value of time. The positions of a sufficient number of reverse-tracked particles are used to define an area. That area is the WHPA associated with the specified TOT.

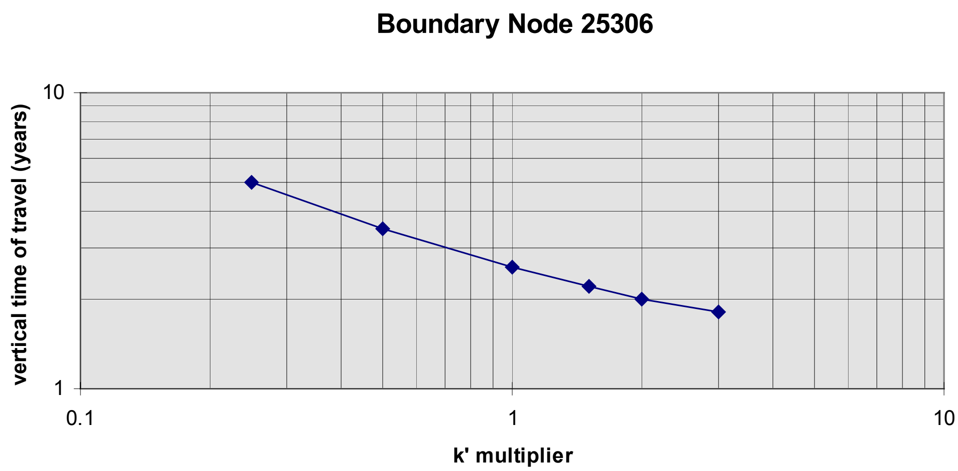
The number of GPTRAC meshes was identical to the number of local-scale SWICHA meshes (eight). Each GPTRAC mesh had the same spatial footprint and used the same node topology, as did the corresponding SWICHA mesh. Hydraulic property zonations, pumping well locations and pumping rates were also identical. Hydraulic heads calculated with the local-scale SWICHA meshes were used as input heads for the particle-tracking simulations. Given the correspondence of the nodal topology between meshes, head values calculated with SWICHA were directly assigned to the corresponding GPTRAC node.

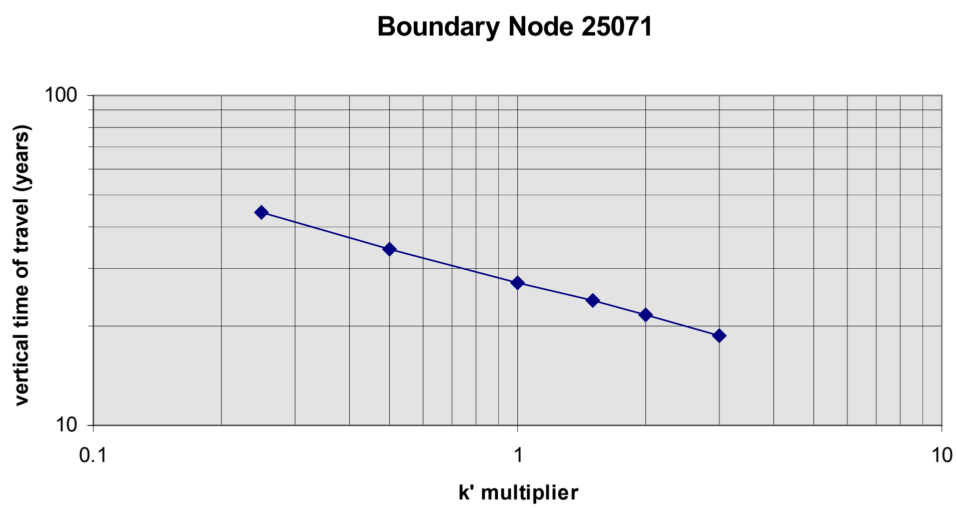
Because of the presence of a fairly extensive, fairly competent confining unit within the main-producing zone in the vicinity of Cantonment, this unit was divided into two separate production zones in the regional model (Roaza et al., 1991). Wells operated by four systems (Champion International, Molino Utilities, Cottage Hill Utilities, and Farm Hill Utilities) tap both production zones. Delineation of WHPAs for Molino, Cottage Hill and Farm Hill necessitated preparation of two separate GPTRAC models for each of the two SWICHA meshes that included these wells (total of four GPTRAC meshes). The distinction between GPTRAC models was that different vertical slices of the SWICHA output heads and hydraulic properties were utilized for the respective meshes. Therefore, the total number of GPTRAC models used for delineation was ten.

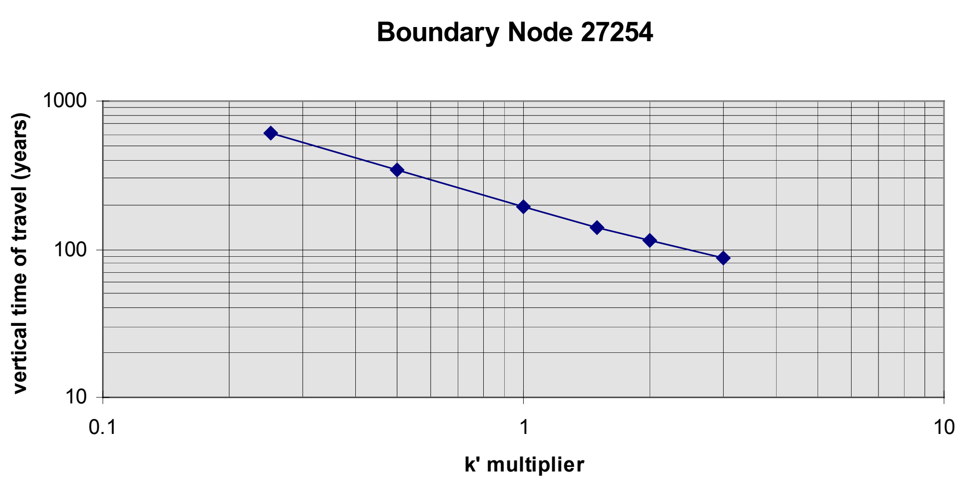
Because SWICHA is three-dimensional and GPTRAC is two-dimensional, it was necessary to select a particular vertical slice of a given SWICHA model to serve as input to the appropriate GPTRAC model. For three of the GPTRAC models (grids 2, 3 and 6) output heads and hydraulic properties from node slice five/element layer five (counting up from the bottom of the seven-layer scheme used in the SWICHA representation) were used as input to GPTRAC. For the mesh which included Corry Station and the Peoples Water Service wells (grid 1), output heads and hydraulic properties from node slice three/element layer three were used.

For the meshes which included the ECUA Montclair and Carriage Hills wells (grid 4) and the East Pensacola/airport vicinity wells (grid 5), output heads and hydraulic properties from node slice four/element layer four were used. In the Cantonment area (grid 7), two

Figure 4. Sensitivity of Vertical Travel Time to K'



GPTRAC models were prepared, one from node slice six/element layer five and one from node slice two/element layer two. In the Molino area (grid 8), two GPTRAC models were prepared, one from node slice five/element layer five and one from node slice two/element layer two.

Using each of the ten GPTRAC models, a series of TOT simulations were performed. For each delineation well, horizontal WHPAs were calculated for the following time series, 0.2, 0.5, 1, 2, 3, 5, 7, 10, 13, 16, 20, 25 and 30 years. GPTRAC output was imported into ARC/INFO and hulls (WHPA perimeter polygons) created for each year of the time series. Hulls from all years were combined into a single surface model, representing horizontal TOT in the vicinity of the WHPA wells. From this surface model, a regular 20-meter grid of times-of-travel was prepared.

## WHPA Delineation

The final step in this process consisted of combining the gridded vertical and horizontal TOT fields into a single composite field. This was done by adding together the gridded values for the two travel directions. The result was a single regular array of composite vertical/horizontal travel times. Using ARC/INFO, this array was contoured and the seven and 20-year contours extracted. These contours became the seven and 20-year composite wellhead protection areas. Delineation results are given in Figures 5 through 24. Two figures are given for each GPTRAC model domain. The first figure gives the composite vertical/horizontal WHPA delineation for seven and 20 years. The second figure gives the seven and 20-year WHPAs based solely on horizontal times-of-travel.

The county-wide composite area associated with each of the four classes of WHPAs is given in Table 7. For each of the four WHPA permutations, the areas of all the respective WHPAs were summed to provide one number for the entire county. Also provided are the area of "southern" Escambia County and the entire county. "Southern" is defined as Escambia County south of Molino.

Table 7. Cumulative Area of WHPAs in Southern Escambia County

| Composite Vertical/Horizontal TOT | | Solely Horizontal TOT | | | |
|---|---|---|---|---|---|
| 7-year (acres) | 20-year (acres) | 7-year (acres) | 20-year (acres) | Southern Escambia County (acres) | Escambia County (acres) |
| 3,400 | 11,000 | 8,300 | 16,600 | 195,000 | 425,000 |

For comparison, the existing 200-ft radius "zones of contribution" for the 56 delineated wells have a composite area of 162 acres. The 500-ft radius WHPAs for the delineated wells in aggregate have an area of 1,010 acres.

Because each delineated well does not have its own distinct WHPA, the concept of the "average" size of a WHPA is of limited usefulness. However, to facilitate comparison of the level of effort necessary to implement various protection options, average areas were calculated for the 56 delineated wells using aggregate areas provided in Table 7. The calculated averages are provided in Table 8.

Table 8. "Average" Area of WHPAs in Southern Escambia County

| Composite Vertical/Horizontal TOT | | Solely Horizontal TOT | | | |
|---|---|---|---|---|---|
| 7-year (acres) | 20-year (acres) | 7-year (acres) | 20-year (acres) | 200-ft radius "zone of contribution" (acres) | 500-ft radius WHPA (acres) |
| 61 | 196 | 148 | 296 | 2.88 | 18 |

Using the current WHPA delineation (500-ft radius circle) as a base case, implementing the seven-year, composite flow direction WHPAs represents about a one-half order-of-magnitude increase in the size of the land area to be protected. The three remaining time/flow-direction permutations each represent about an order-of-magnitude increase in the size of the land area that would require protection.

## Times-of-Travel Associated with Existing Ordinance

As per the technical direction provided by the local community, times-of-travel associated with circles of 200-ft and 500-ft radius were calculated. This was performed by interpolating point TOT values for a series of points located on a circle of the desired radius. As applied here, a total of 37 point travel-time values were interpolated on each circle. Due to the complexities of ground water flow in the vicinity of a well, travel times along a circle are variable. Accordingly, the interpolation yielded a range of travel times for each circle. To approximate the TOT associated with a particular circle the minimum point value was selected to represent the entire circle. Values for each well and for both the 200-ft and 500-ft radius circles are tabulated in Appendix E. The median TOT associated with the 200-ft radius circles is 2.8 years and 4 years for the 500-ft radius circles. A frequency distribution for the 56 individual 200-ft circle times-of-travel is given in Figure 21. Comparable information for the 500-ft circles is given in Figure 22.

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

Figure 18

Figure 19

Figure 20

Figure 21. Frequency Distribution of Times-of-Travel
Associated with 200-ft Radius Circle

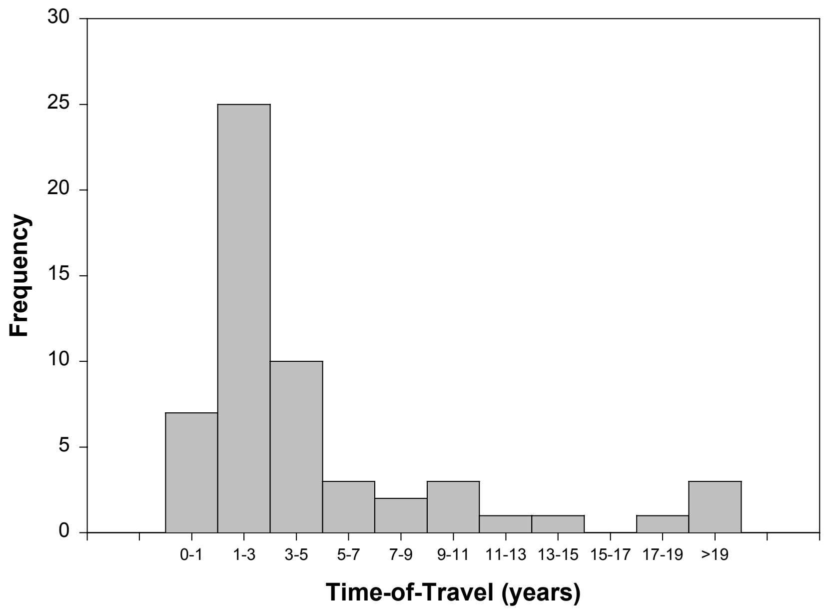
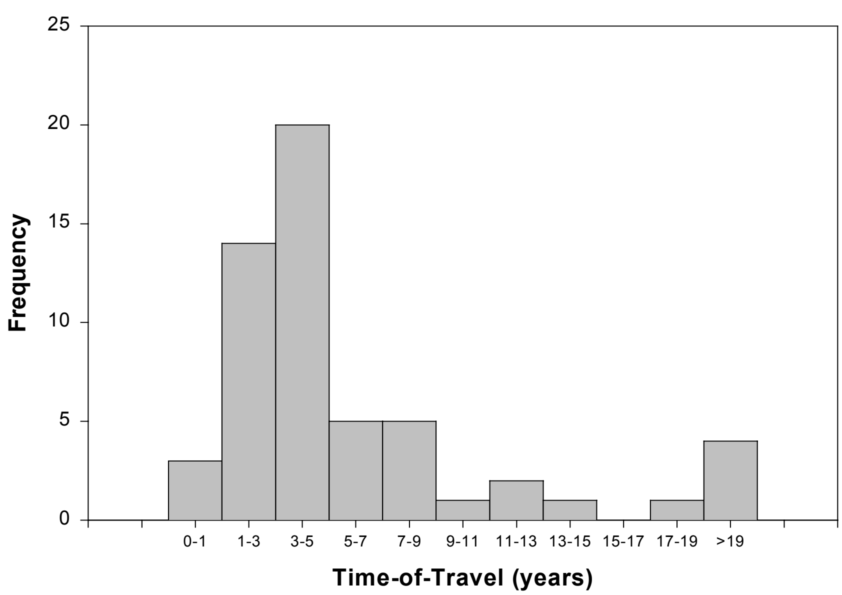



Figure 22. Frequency Distribution of Times-of-Travel
Associated with 500-ft Radius Circle



## CONCLUSIONS AND RECOMMENDATIONS

The wellhead protection area delineations presented here were obtained through the use of a previously developed numerical model (Roaza et al., 1993). As such, the WHPA delineations contained herein are subject to the assumptions and limitations inherent to that previous work. Those assumptions and limitations include the appropriateness of the underlying conceptual model, the appropriateness of the modeled boundary conditions, the appropriateness of the modeled hydraulic properties, and the appropriateness of the original calibration.

The regional model that underlies this work differs from the calibrated regional model of Roaza et al. in two respects. In order to minimize WHPA shape artifacts resulting from the original k' distribution and to further minimize head errors, it was necessary to undertake a limited recalibration. The recalibration entailed modification of both the regional model k' distribution and the source-bed head distribution. Based on a comparison of calibration statistics obtained from both models, the revised model was deemed to be substantially the same as the original regional model. The revised k' and source-bed head distributions were subsequently incorporated into the local-scale models used for the actual delineations.

As pointed out in the text, variability in vertical hydraulic conductivity has a moderate to large impact on associated vertical travel times. The vertical hydraulic conductivities incorporated into the delineations are the result of the regional model calibration. While the k' distribution was deemed to give adequate results in the regional model, it should be recognized that, in the near vicinity of any given well, k' may vary from the values used in delineation. Given the lack of measured k' values in southern Escambia County, it is difficult to predict how much variance there is between model-derived values and reality. Accordingly, there is uncertainty in the attendant WHPA delineations that explicitly incorporate vertical travel times. This uncertainty is unavoidable. At the same time, the calibrated regional model represents the best available information on this property. It was, therefore, deemed appropriate to use this information to delineate the composite WHPAs.

Certain assumptions were required regarding the pumping rates used for delineation. Based on projections performed by the ECUA, the delineation pumpage rate for public supply was simulated as 1.54 times the actual 1995/1996 water use. Commercial and industrial water use in the delineation model was set to 1995 levels. The composite effect of increasing public supply water use and maintaining commercial/industrial use at present levels is that the delineation pumpage is about 32 percent higher than the 1991 water use. It is also about 6 percent higher than the currently permitted average daily withdrawal rate. Given that the delineation pumpage is only slightly higher than the currently permitted withdrawal rates, pumpage at the rates simulated for delineation is possible in the foreseeable future. Therefore, the delineation pumpage should not be seen as an overly conservative projection of future water use scenarios.

Information presented in this report can be used by the local community to expand the potable supply wellhead protection program in southern Escambia County. Wellhead protection area delineations are provided for the 56 principal public supply wells found in the southern half of the county. These wells produce about 97 percent of the public supply water consumed in the county.

WHPAs were generated for travel times of seven and 20 years. Two sets of delineations were prepared. One set includes the combined effects of both vertical travel through the low-permeability zone and horizontal travel through the main-producing zone. The second set accounts solely for horizontal travel through the main-producing zone. These sets of delineations provide a scientifically based foundation which can be used to increase and standardize the protection afforded to the major public supply wells present in southern Escambia County.

At present, the local community has at least four options regarding wellhead/aquifer protection in Escambia County. The degree of protection afforded by any wellhead protection program is largely based on the size of the designated WHPAs. The larger the WHPA, the greater is the protection afforded the wellhead. The four options are listed below, in order of increasing degree of protection.

- Maintain the current wellhead protection program based on 200-ft and 500-ft fixed-radius wellhead protection areas.
- Implement an expanded wellhead protection program based on the composite vertical and horizontal travel time WHPAs presented in this report.
- Implement an expanded wellhead protection program based on the strictly horizontal travel time WHPAs presented in this report.
- Implement an aquifer protection program for the southern half of the county.

The present 500-ft radius WHPAs equate to a median travel time of four years. Based on the median value of four years, this option provides important, but limited, protection for the potable supply wells in Escambia County. One key limitation of the fixed-radius approach is that it affords vastly different levels of protection for individual wells. Times-of-travel associated with 500-ft fixed-radius WHPAs range from as little as 0.7 years to more than 100 years. The 500-ft radius provides less than four years protection for half of the delineated wells, many of which are protected for only a year or two.

Implementation of WHPAs based on composite vertical and horizontal TOT will significantly increase the protection afforded the existing major public supply wells in southern Escambia County. One advantage of this approach is the standardization it provides. This alternative will provide a similar degree of protection, based on TOT, for all identified wells. Adoption of a 20-year composite TOT WHPA will provide longer-term protection compared to a seven-year composite TOT WHPA. However, while the seven-year WHPA encompasses 3,400 acres, the 20-year WHPA involves protection of 11,000 acres.

Implementation of WHPAs based on solely on horizontal TOT would further increase the protected area, providing longer-term protection for identified wells. As with the composite horizontal and vertical alternative above, the 20-year horizontal TOT WHPA would provide more protection than the seven-year horizontal TOT WHPA. The seven-year horizontal WHPA encompasses 8,300 acres. This compares to the 16,600 acres associated with the 20-year WHPA.

The final listed alternative involves aquifer protection rather than wellhead protection. This alternative involves applying protective strategies to an entire region, rather than to individual wellheads. The advantage of this option is that it provides a very long-term protection program for all existing wells within the designated area. Even more significant is the fact that it also protects areas that will be needed to meet future water supply demands. This includes areas that presently do not have public supply wells in place.

The actual degree of protection afforded the designated WHPAs is dependent on the specific strategies employed to manage selected facilities within these areas. Careful consideration should be given regarding identifying facilities of concern and what protection strategies to employ. A review of WHPA ordinances adopted by other municipalities and counties in Florida (and elsewhere) is highly recommended. This is due to the importance of these decisions and the almost limitless number of possible protection alternatives available.

To conclude, given the vulnerability of the aquifer to anthropogenic impacts and the reliance of the local community on this source of water, additional protection activities are warranted and should be undertaken. It should also be noted that implementation of enhanced wellhead protection activities will not address contamination already in ground water. Most of the contamination issues that the local community is presently dealing with went into the ground years and decades ago. Given the low velocities within the Sand-and-Gravel Aquifer, contamination presently entrained in the ground water flow regime will continue to impact wells into the future, regardless of the degree to which wellheads are protected.

Finally, future application of the model to predict ground water flow and contaminant transport through the aquifer will substantially benefit from additional determinations of k'. K' determinations require multi-well aquifer tests similar to that completed at the ECUA OLF4A well site (Roaza et al., 1993). These determinations are expensive; however, the insights gained into the behavior of this leaky aquifer system are well worth the expense.

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# APPENDIX A

## Principal Water Supply Systems in Southern Escambia County

Appendix A. Principal Water Supply Systems in Southern Escambia County

| WELL NAME | NWF_ID | NAD83 Latitude | NAD83 Longitude | Florida Unique Well ID | WHPA Delineated |
|---|---|---|---|---|---|
| MOLINO #1 | 4710 | 304302.7 | 872048.07 | AAA6441 | yes |
| MOLINO #2 | 4917 | 304608.35 | 872324.89 | AAA6442 | yes |
| MOLINO #3 | 4644 | 304151.15 | 872201.87 | AAA6443 | yes |
| PEOPLES #3A | 1672 | 302335.9 | 871644.8 | AAA6417 | yes |
| PEOPLES #4A | 1660 | 302334.1 | 871541.2 | AAA6413 | yes |
| PEOPLES #5 | 1863 | 302413.5 | 871626.3 | AAA6415 | yes |
| PEOPLES #7 | 1594 | 302319 | 871710 | | no |
| PEOPLES #8 | 1999 | 302434.6 | 871617.4 | AAA6416 | yes |
| PEOPLES #9A | 1684 | 302340.6 | 871626.2 | AAA6414 | yes |
| UWF #1 | 3541 | 303236.38 | 871313.69 | AAA6409 | no |
| UWF #2 | 3603 | 303257.4 | 871257.37 | AAA6410 | no |
| ECUA #1-(#6) | 2142 | 302523.63 | 871255.92 | AAA6574 | yes |
| ECUA #10-LILLIAN | 2105 | 302512.31 | 871907.19 | AAA1116 | yes |
| ECUA #11-BRONSON #1 | 1575 | 302315.86 | 872459.37 | AAA1114 | yes |
| ECUA #12-BRONSON #2 | 1583 | 302317 | 872511 | | no |
| ECUA #13-MONTCLAIR 1 | 2763 | 302725.61 | 871527.02 | AAA6402 | yes |
| ECUA #14-MONTCLAIR 2 | 2784 | 302731.92 | 871604.06 | AAA6403 | yes |
| ECUA #15-MONTCLAIR 3 | 2816 | 302742.08 | 871636.85 | AAA6404 | yes |
| ECUA #17-9TH AVENUE | 3010 | 302900.41 | 871207.27 | AAA6569 | yes |
| ECUA #18-MCALLISTER | 3092 | 302931.19 | 871129.92 | AAA6568 | yes |
| ECUA #19-AIRPORT NOR | 2954 | 302837.28 | 871051.7 | AAA6570 | yes |
| ECUA #2-(#8) | 2205 | 302533.34 | 871257.35 | | no |
| ECUA #20-OLIVE RD | 3248 | 303036.58 | 871236.55 | AAA6566 | yes |
| ECUA #21-DAVIS HWY | 3106 | 302935.35 | 871325.82 | AAA6567 | yes |
| ECUA #22-SWEENEY | 3592 | 303255.62 | 871656.15 | AAA6562 | yes |
| ECUA #23-ENSLEY | 3405 | 303137.65 | 871610.64 | AAA6564 | yes |
| ECUA #24-BROAD ST | 3265 | 303041.58 | 871620.02 | AAA6565 | yes |
| ECUA #25-DUNAWAY | 3194 | 303016.65 | 871920.23 | AAA6408 | yes |
| ECUA #27-UNIVERSITY | 3357 | 303116.46 | 871319.23 | AAA1118 | yes |
| ECUA #28-OLF 4A | 3433 | 303155.38 | 871522.19 | AAA1117 | yes |
| ECUA #29-CARRIAGE HILLS | 2785 | 302730.5 | 871658.65 | AAA6405 | yes |
| ECUA #3-(#9) | 2350 | 302601.9 | 871306.98 | AAA6575 | yes |
| ECUA #30-AVONDALE | 2639 | 302656.97 | 871857.61 | AAA6407 | yes |
| ECUA #37-VILLA | 1859 | 302411.45 | 871900.09 | AAA1115 | yes |
| ECUA #38-ROYCE ST | 2886 | 302807.39 | 871309.27 | AAA0395 | yes |
| ECUA #39-ELLYSON | 3327 | 303103.13 | 871213.89 | AAA6560 | yes |
| ECUA #4-EAST PLANT | 2322 | 302554.35 | 871228.44 | AAA6573 | yes |
| ECUA #40-CANTONMENT | 4157 | 303647.4 | 871857.87 | AAA6563 | yes |
| ECUA #41-TENNANT | 2719 | 302716.94 | 871718.84 | AAA6406 | yes |
| ECUA #42-MCCRORY | 3629 | 303307.46 | 871545.63 | AAA6561 | yes |

Appendix A. Principal Water Supply Systems in Southern Escambia County

| WELL NAME | NWF_ID | NAD83 Latitude | NAD83 Longitude | Florida Unique Well ID | WHPA Delineated |
|---|---|---|---|---|---|
| ECUA #5-WEST PLANT | 2110 | 302514.35 | 871403.75 | AAA6577 | **yes** |
| ECUA #6-HAGLER | 2852 | 302756.47 | 871119.45 | AAA6571 | **yes** |
| ECUA #7-WEST P'COLA | 2194 | 302533.23 | 871605.49 | AAA6579 | **yes** |
| ECUA #8-W & AVERY ST | 2315 | 302551.66 | 871458.41 | AAA6401 | **yes** |
| ECUA #9-F & SCOTT ST | 2427 | 302615.33 | 871347.85 | AAA6576 | **yes** |
| GONZALEZ #1 | 3909 | 303501.88 | 871749.85 | AAA6425 | **yes** |
| GONZALEZ #2 | 3891 | 303456.16 | 871721.99 | AAA6424 | **yes** |
| MONSANTO #10 | 3887 | 303459.82 | 871508.84 | AAA6432 | no |
| MONSANTO #2 | 4052 | 303601 | 871512.16 | AAA6434 | no |
| MONSANTO #5 | 3975 | 303528.48 | 871507.17 | AAA6427 | no |
| MONSANTO #6 | 3937 | 303521.66 | 871515.49 | AAA6426 | no |
| MONSANTO #7A | 3930 | 303514.54 | 871524.48 | AAA6428 | no |
| MONSANTO #8 | 4046 | 303555.35 | 871521.65 | AAA6435 | no |
| MONSANTO #9 | 3906 | 303507 | 871516.61 | AAA6433 | no |
| MONSANTO #A (#11) | 3860 | 303448.42 | 871601.81 | AAA6430 | no |
| MONSANTO #B | 3849 | 303438.37 | 871555.12 | AAA6431 | no |
| MONSANTO #C (#13) | 3899 | 303501 | 871559 | AAA7505 | no |
| MONSANTO #D (#14) | 3888 | 303458.73 | 871614.02 | AAA6429 | no |
| CORRY #10 | 1973 | 302430.67 | 871704.92 | AAA6554 | **yes** |
| CORRY #11 | 1902 | 302421.28 | 871650.69 | AAA6557 | **yes** |
| CORRY #12 | 1864 | 302410.23 | 871646.79 | AAA6559 | **yes** |
| CORRY #13 | 1937 | 302425.91 | 871727.34 | AAA6550 | **yes** |
| CORRY #14 | 1958 | 302428.15 | 871716.08 | AAA6553 | **yes** |
| CORRY #15 | 1920 | 302424.79 | 871740.1 | AAA6551 | **yes** |
| CORRY #16 | 1771 | 302404.08 | 871652.12 | AAA6558 | **yes** |
| CORRY #7 | 1960 | 302428.68 | 871659.03 | AAA6555 | **yes** |
| CORRY #8 | 2002 | 302433.04 | 871655.1 | AAA6556 | **yes** |
| CORRY #9 | 1896 | 302419.75 | 871736.76 | AAA6552 | **yes** |
| NAS PENSACOLA #1 | 1239 | 302114 | 871701 | | no |
| NAS PENSACOLA #2 | 1267 | 302125 | 871641 | | no |
| CHAMPION #1 | 4078 | 303610.3 | 871855.7 | AAA5252 | no |
| CHAMPION #10 | 4221 | 303718.6 | 872012.6 | AAA5258 | no |
| CHAMPION #11 | 4213 | 303718.7 | 872024.1 | AAA5259 | no |
| CHAMPION #12R | 4215 | 303719.1 | 872047.5 | AAA5260 | no |
| CHAMPION #13R | 6008 | 303719.1 | 872059.1 | AAA5261 | no |
| CHAMPION #17 | 4094 | 303615.9 | 871924.2 | AAA5250 | no |
| CHAMPION #2 | 4116 | 303618.7 | 871902.1 | AAA5251 | no |
| CHAMPION #20 | 4034 | 303559.1 | 871935 | AAA5267 | no |
| CHAMPION #22 | 4027 | 303549.4 | 871932.7 | AAA5268 | no |
| CHAMPION #23 | 3945 | 303539.7 | 871930.4 | AAA5269 | no |

Appendix A. Principal Water Supply Systems in Southern Escambia County

| WELL NAME | NWF_ID | NAD83 Latitude | NAD83 Longitude | Florida Unique Well ID | WHPA Delineated |
|---|---|---|---|---|---|
| CHAMPION #25R | 3944 | 303530 | 871928.1 | AAA5270 | no |
| CHAMPION #29 | 3901 | 303458.9 | 871920.7 | AAA5243 | no |
| CHAMPION #30 | 4088 | 303612.7 | 872009.3 | AAA5264 | no |
| CHAMPION #31 | 4087 | 303613 | 872020.8 | AAA5263 | no |
| CHAMPION #32 | 4089 | 303613.3 | 872032.1 | AAA5262 | no |
| CHAMPION #33 | 3916 | 303507.6 | 871922.8 | AAA5242 | no |
| CHAMPION #34 | 4086 | 303612 | 871940.8 | AAA5266 | no |
| CHAMPION #35 | 4081 | 303612.3 | 871940.8 | AAA5265 | no |
| CHAMPION #5 | 4166 | 303653.9 | 871937.9 | AAA5253 | no |
| CHAMPION #6 | 4211 | 303718.1 | 871938.5 | AAA5254 | no |
| CHAMPION #7 | 4212 | 303718 | 871949.8 | AAA5255 | no |
| CHAMPION #8 | 4219 | 303718.4 | 872001.1 | AAA5256 | no |
| CHAMPION #9 | 4220 | 303718.5 | 872001.6 | AAA5257 | no |
| CRIST PLANT #1 | 4030 | 303349.2 | 871324.82 | AAA6422 | no |
| CRIST PLANT #2 | 3742 | 303353.21 | 871323.99 | AAA6423 | no |
| CRIST PLANT #3 | 3695 | 303339.69 | 871327.09 | AAA6421 | no |
| CRIST PLANT #4 | 3728 | 303353.37 | 871335.87 | AAA6418 | no |
| CRIST PLANT #5 | 3666 | 303324.69 | 871356.65 | AAA6420 | no |
| CRIST PLANT #6 | 3651 | 303319.34 | 871407.42 | AAA6419 | no |
| FARM HILL #1 | 4096 | 303616.87 | 872041.92 | AAA6439 | no |
| FARM HILL #2 | 4131 | 303632.56 | 872117.53 | AAA6440 | **yes** |
| FARM HILL #3 | 4097 | 303616.7 | 872042.4 | AAA6438 | **yes** |
| REICHOLD #11 | 2080 | 302501.43 | 871512.62 | AAA6412 | no |
| REICHOLD #14 | 2075 | 302457.93 | 871501.48 | AAA6411 | no |
| COTTAGE HILL #1 | 4278 | 303800.05 | 871910.03 | AAA6436 | no |
| COTTAGE HILL #2 | 4273 | 303749.18 | 871807.98 | AAA6437 | **yes** |
| COTTAGE HILL #3 | 5884 | 303740 | 871848 | AAA5176 | **yes** |

Total of 107 permitted wells, WHPAs delineated for 56 of these.

# APPENDIX B

## Recent Pumpage Data and Pumpage Used for WHPA Delineation

Appendix B. Recent Pumpage Data and Pumpage Used for WHPA Delineation

| WELL NAME | 1991 Regional Model Pumpage (Mgal/d) | Mean 95/96 Pumpage (Mgal/d) | Mean Summer Pumpage 95/96 (Mgal/d) | Delineation Pumpage (Mgal/d) | Delineation Pumpage Source Code |
|---|---|---|---|---|---|
| MOLINO #1 | 0 | 0.11 | 0.14 | 0.162 | 3 |
| MOLINO #2 | 0 | 0.19 | 0.202 | 0.294 | 3 |
| MOLINO #3 | 0 | 0.29 | 0.323 | 0.442 | 3 |
| PEOPLES #3A | 0 | 0.62 | 0.827 | 0.950 | 3 |
| PEOPLES #4A | 0.055 | 0.34 | 0.385 | 0.523 | 3 |
| PEOPLES #5 | 0.551 | 0.22 | 0.362 | 0.336 | 3 |
| PEOPLES #8 | 0.503 | 0.37 | 0.447 | 0.566 | 3 |
| PEOPLES #9A | 0.429 | 0.58 | 0.64 | 0.887 | 3 |
| UWF #1 | 0.123 | NA | NA | 0.175 | 5 |
| UWF #2 | 0.123 | NA | NA | 0.175 | 5 |
| ECUA #1-(#6) | 0.291 | 1.13 | 1.447 | 1.872 | 2 |
| ECUA #10-LILLIAN | 0.462 | 0.83 | 1.718 | 1.728 | 1 |
| ECUA #11-BRONSON #1 | 0.363 | 0.44 | 0.724 | 0.756 | 1 |
| ECUA #13-MONTCLAIR 1 | 0.642 | 0.61 | 0.617 | 0.648 | 1 |
| ECUA #14-MONTCLAIR 2 | 0.416 | 0.56 | 0.750 | 0.756 | 1 |
| ECUA #15-MONTCLAIR 3 | 0.694 | 0.66 | 0.740 | 0.756 | 1 |
| ECUA #17-9TH AVENUE | 0 | 0.68 | 0.824 | 1.440 | 2 |
| ECUA #18-MCALLISTER | 1.937 | 1.52 | 1.970 | 1.980 | 1 |
| ECUA #19-AIRPORT NOR | 0.915 | 0.62 | 1.099 | 1.440 | 2 |
| ECUA #20-OLIVE RD | 1.294 | 1.16 | 1.375 | 1.404 | 1 |
| ECUA #21-DAVIS HWY | 1.825 | 1.35 | 1.686 | 1.692 | 1 |
| ECUA #22-SWEENEY | 1.983 | 2.47 | 2.692 | 2.700 | 1 |
| ECUA #23-ENSLEY | 0.062 | 0.19 | 0.211 | 0.720 | 2 |
| ECUA #24-BROAD ST | 0.139 | 2.15 | 2.720 | 2.736 | 1 |
| ECUA #25-DUNAWAY | 0.182 | 0.55 | 0.888 | 1.440 | 2 |
| ECUA #27-UNIVERSITY | 2.297 | 0.85 | 1.084 | 1.440 | 2 |
| ECUA #28-OLF 4A | 2.871 | 1.79 | 2.365 | 2.376 | 1 |
| ECUA #29-CARRIAGE HL | 0.572 | 0.22 | 0.333 | 0.864 | 2 |
| ECUA #3-(#9) | 0 | 1.26 | 1.866 | 1.872 | 1 |
| ECUA #30-AVONDALE | 0.025 | 0.15 | 0.249 | 1.008 | 2 |
| ECUA #37-VILLA | 1.223 | 1.32 | 1.640 | 1.656 | 1 |
| ECUA #38-ROYCE ST | 1.438 | 1.54 | 2.290 | 2.304 | 1 |
| ECUA #39-ELLYSON | 0.131 | 0.63 | 0.781 | 1.440 | 2 |
| ECUA #4-EAST PLANT | 2.535 | 1.29 | 2.079 | 2.088 | 1 |
| ECUA #40-CANTONMENT | 2.229 | 1.92 | 2.055 | 2.088 | 1 |
| ECUA #41-TENNANT | 0 | 0.23 | 0.427 | 1.080 | 2 |
| ECUA #42-MCCRORY | 0 | 0.54 | 0.733 | 2.160 | 2 |
| ECUA #5-WEST PLANT | 1.054 | 0.79 | 1.170 | 1.188 | 1 |
| ECUA #6-HAGLER | 2.226 | 2.60 | 3.061 | 3.096 | 1 |
| ECUA #7-WEST P'COLA | 0.677 | 0.80 | 1.247 | 1.260 | 1 |

Appendix B. Recent Pumpage Data and Pumpage Used for WHPA Delineation

| WELL NAME | 1991 Regional Model Pumpage (Mgal/d) | Mean 95/96 Pumpage (Mgal/d) | Mean Summer Pumpage 95/96 (Mgal/d) | Delineation Pumpage (Mgal/d) | Delineation Pumpage Source Code |
|---|---|---|---|---|---|
| ECUA #8-W & AVERY ST | 2.175 | 2.25 | 2.224 | 2.232 | 1 |
| ECUA #9-F & SCOTT ST | 2.919 | 0.32 | 0.548 | 1.152 | 2 |
| GONZALEZ #1 | 0.113 | 0.17 | 0.156 | 0.254 | 3 |
| GONZALEZ #2 | 0.236 | 0.24 | 0.324 | 0.373 | 3 |
| MONSANTO #10 | 0.992 | 1.43 | 1.468 | 1.427 | 6 |
| MONSANTO #2 | 0.992 | 0 | 0 | 0 | 4 |
| MONSANTO #5 | 0.992 | 0 | 0 | 0 | 4 |
| MONSANTO #6 | 0.992 | 0.40 | 0.590 | 0.402 | 6 |
| MONSANTO #7A | 0.992 | 1.22 | 1.380 | 1.219 | 6 |
| MONSANTO #8 | 0 | 1.30 | 1.343 | 1.304 | 6 |
| MONSANTO #9 | 0.992 | 0.93 | 0.935 | 0.934 | 6 |
| MONSANTO #A (#11) | 0.992 | 1.27 | 1.395 | 1.270 | 6 |
| MONSANTO #B | 0.992 | 1.02 | 1.100 | 1.021 | 6 |
| MONSANTO #C (#13) | 0.992 | 1.18 | 1.327 | 1.180 | 6 |
| MONSANTO #D (#14) | 0.992 | 1.22 | 1.462 | 1.221 | 6 |
| CORRY #10 | 0.573 | 0.36 | 0.414 | 0.556 | 3 |
| CORRY #11 | 0.573 | 0.28 | 0.413 | 0.435 | 3 |
| CORRY #12 | 0.573 | 0.25 | 0.337 | 0.381 | 3 |
| CORRY #13 | 0.573 | 0.33 | 0.381 | 0.506 | 3 |
| CORRY #14 | 0.573 | 0.26 | 0.337 | 0.406 | 3 |
| CORRY #15 | 0.573 | 0.33 | 0.425 | 0.504 | 3 |
| CORRY #16 | 0.573 | 0.27 | 0.356 | 0.417 | 3 |
| CORRY #7 | 0.573 | 0.25 | 0.324 | 0.381 | 3 |
| CORRY #8 | 0.573 | 0.22 | 0.321 | 0.344 | 3 |
| CORRY #9 | 0.573 | 0.12 | 0.196 | 0.189 | 3 |
| CHAMPION #1 | 0.933 | 0.58 | 1.140 | 0.583 | 6 |
| CHAMPION #10 | 0.933 | 1.29 | 1.284 | 1.291 | 6 |
| CHAMPION #11 | 0.933 | 1.04 | 1.016 | 1.040 | 6 |
| CHAMPION #12R | 0.933 | 1.54 | 1.711 | 1.537 | 6 |
| CHAMPION #13R | 0.933 | 0.26 | 0.299 | 0.261 | 6 |
| CHAMPION #17 | 0.933 | 0.48 | 0.496 | 0.479 | 6 |
| CHAMPION #2 | 0.933 | 0.94 | 1.138 | 0.943 | 6 |
| CHAMPION #20 | 0.933 | 0.93 | 0.969 | 0.926 | 6 |
| CHAMPION #22 | 0.933 | 0.62 | 0.933 | 0.625 | 6 |
| CHAMPION #23 | 0.933 | 1.34 | 1.431 | 1.337 | 6 |
| CHAMPION #25R | 0.933 | 0.89 | 1.021 | 0.891 | 6 |
| CHAMPION #29 | 0.933 | 1.27 | 1.301 | 1.271 | 6 |
| CHAMPION #30 | 0.933 | 1.78 | 1.805 | 1.778 | 6 |
| CHAMPION #31 | 0.933 | 1.13 | 1.167 | 1.127 | 6 |
| CHAMPION #32 | 0.933 | 1.44 | 1.456 | 1.436 | 6 |

Appendix B. Recent Pumpage Data and Pumpage Used for WHPA Delineation

| WELL NAME | 1991 Regional Model Pumpage (Mgal/d) | Mean 95/96 Pumpage (Mgal/d) | Mean Summer Pumpage 95/96 (Mgal/d) | Delineation Pumpage (Mgal/d) | Delineation Pumpage Source Code |
|---|---|---|---|---|---|
| CHAMPION #33 | 0.933 | 0.96 | 1.062 | 0.957 | 6 |
| CHAMPION #34 | 0.933 | 1.17 | 1.397 | 1.166 | 6 |
| CHAMPION #35 | 0.933 | 1.18 | 1.278 | 1.179 | 6 |
| CHAMPION #5 | 0.933 | 1.23 | 1.245 | 1.227 | 6 |
| CHAMPION #6 | 0.933 | 1.33 | 1.337 | 1.330 | 6 |
| CHAMPION #7 | 0.933 | 1.19 | 1.192 | 1.186 | 6 |
| CHAMPION #8 | 0.933 | 1.03 | 1.089 | 1.027 | 6 |
| CHAMPION #9 | 0.933 | 1.05 | 1.124 | 1.049 | 6 |
| CRIST PLANT #1 | 0.367 | NA | NA | 0.55 | 7 |
| CRIST PLANT #2 | 0.367 | NA | NA | 0 | 4 |
| CRIST PLANT #3 | 0.367 | NA | NA | 0.55 | 7 |
| CRIST PLANT #4 | 0.367 | NA | NA | 0 | 7 |
| CRIST PLANT #5 | 0.367 | NA | NA | 0.55 | 7 |
| CRIST PLANT #6 | 0.367 | NA | NA | 0.55 | 7 |
| FARM HILL #1 | 0.090 | 0.03 | 0.023 | 0 | 4 |
| FARM HILL #2 | 0.238 | 0.11 | 0.061 | 0.169 | 3 |
| FARM HILL #3 | 0 | 0.17 | 0.278 | 0.317 | 3 |
| REICHOLD #11 | 0.100 | NA | NA | 0.215 | 5 |
| REICHOLD #14 | 0.100 | NA | NA | 0.215 | 5 |
| COTTAGE HILL #1 | 0.133 | 0.16 | 0.196 | 0 | 4 |
| COTTAGE HILL #2 | 0.133 | 0.18 | 0.209 | 0.283 | 3 |
| COTTAGE HILL #3 | 0 | 0 | 0 | 0.241 | 3 |
| **TOTAL PUMPAGE** | **75.2** | | | **98.9** | |

Notes:

NA denotes that pumpage data is not available.

1. The 1995/1996 mean summer pumpage was utilized for delineation. See text for discussion of how 1995/1996 mean summer pumpage was determined.

2. The 1995/1996 mean summer pumpage was adjusted upward to reflect well under-utilization.

3. The mean annual pumpage for 1995/1996 was adjusted upward by a factor of 1.54 to derive delineation pumpage.

4. This well was not simulated.

5. The USGS 1995 mean annual water use (Marella, in preparation) was used as the delineation pumpage.

6. The actual 1995/1996 mean annual pumpage was used as the delineation pumpage.

7. The current permitted Average Daily Withdrawal (ADR) was used as the delineation pumpage.

# APPENDIX C

## Time-of-Travel Associated with 200-ft and 500-ft Radius Circles

Appendix C. Times-of-Travel Associated with 200-ft and 500-ft Radius Circles

| WELL NAME | 200-ft Circle (years) | 500-ft Circle (years) |
|---|---|---|
| MOLINO #1 | >100 | >100 |
| MOLINO #2 | 88 | 92 |
| MOLINO #3 | >100 | >100 |
| PEOPLES #3A | 2.0 | 2.8 |
| PEOPLES #4A | 3.6 | 4.6 |
| PEOPLES #5 | 4.1 | 5.9 |
| PEOPLES #8 | 4.7 | 6.5 |
| PEOPLES #9A | 1.9 | 2.7 |
| ECUA #1-(#6) | 2.3 | 3.3 |
| ECUA #10-LILLIAN | 2.2 | 3.1 |
| ECUA #11-BRONSON #1 | 3.7 | 5.5 |
| ECUA #13-MONTCLAIR 1 | 6.2 | 8.0 |
| ECUA #14-MONTCLAIR 2 | 6.6 | 8.9 |
| ECUA #15-MONTCLAIR 3 | 6.3 | 8.9 |
| ECUA #17-9TH AVENUE | 1.4 | 2.0 |
| ECUA #18-MCALLISTER | 1.1 | 1.6 |
| ECUA #19-AIRPORT NOR | 0.8 | 1.5 |
| ECUA #20-OLIVE RD | 0.8 | 1.4 |
| ECUA #21-DAVIS HWY | 2.4 | 3.2 |
| ECUA #22-SWEENEY | 1.1 | 1.6 |
| ECUA #23-ENSLEY | 1.9 | 2.9 |
| ECUA #24-BROAD ST | 2.4 | 3.0 |
| ECUA #25-DUNAWAY | 15 | 18 |
| ECUA #27-UNIVERSITY | 0.8 | 1.7 |
| ECUA #28-OLF 4A | 0.4 | 0.9 |
| ECUA #29-CARRIAGE HILLS | 4.2 | 5.4 |
| ECUA #3-(#9) | 1.9 | 2.6 |
| ECUA #30-AVONDALE | 2.2 | 3.2 |
| ECUA #37-VILLA | 2.8 | 4.0 |
| ECUA #38-ROYCE ST | 0.9 | 1.7 |
| ECUA #39-ELLYSON | 1.1 | 1.9 |
| ECUA #4-EAST PLANT | 1.7 | 2.4 |
| ECUA #40-CANTONMENT | 7.2 | 7.1 |
| ECUA #41-TENNANT | 3.8 | 4.7 |
| ECUA #42-MCCRORY | 0.3 | 0.7 |
| ECUA #5-WEST PLANT | 4.5 | 6.4 |
| ECUA #6-HAGLER | 0.5 | 0.8 |
| ECUA #7-WEST P'COLA | 3.4 | 4.9 |
| ECUA #8-W & AVERY ST | 2.3 | 3.5 |
| ECUA #9-F & SCOTT ST | 3.1 | 4.3 |

Appendix C. Times-of-Travel Associated with 200-ft and 500-ft Radius Circles

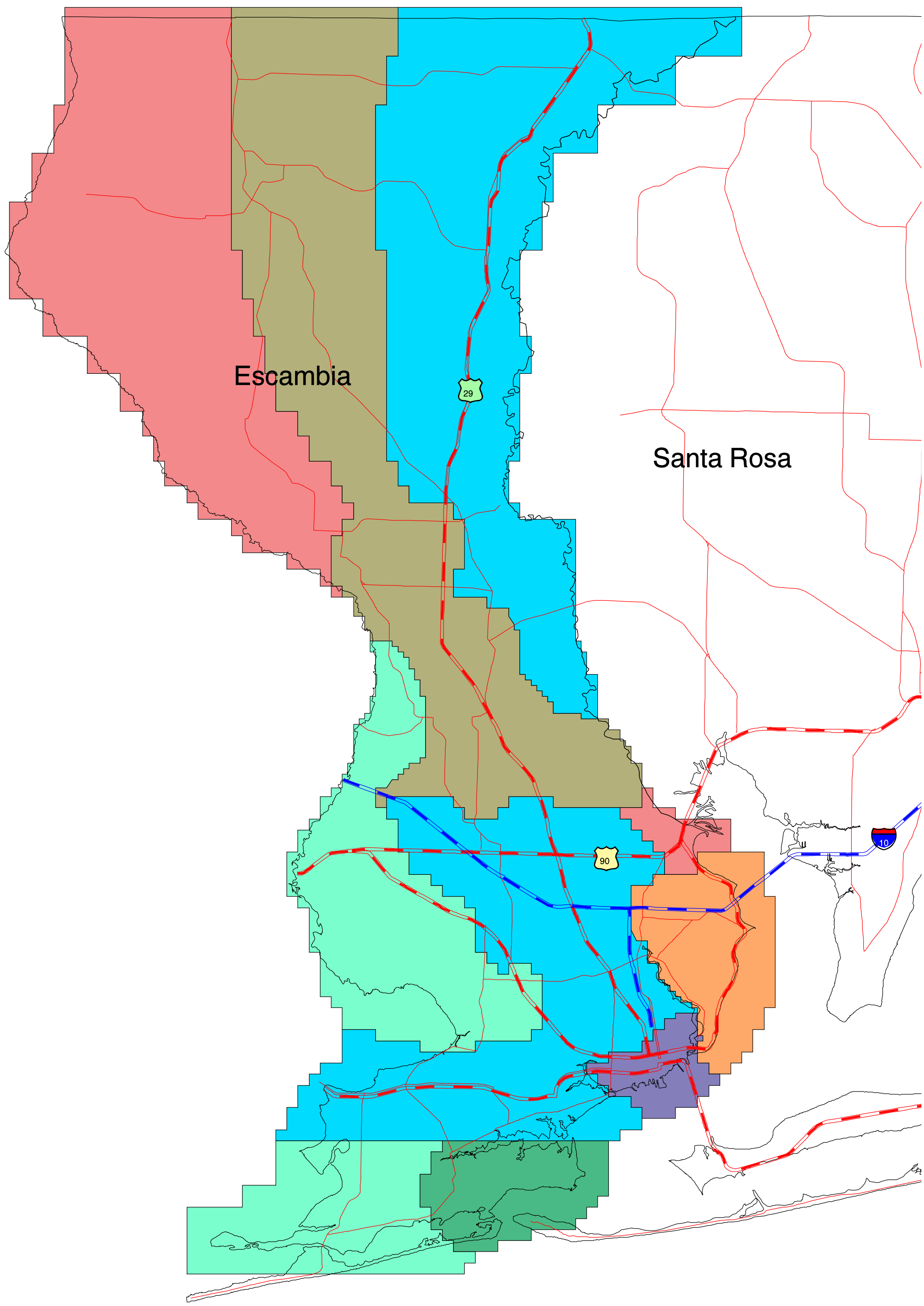
| WELL NAME | 200-ft Circle (years) | 500-ft Circle (years) |
|---|---|---|
| GONZALEZ #1 | 9.4 | 10 |
| GONZALEZ #2 | 10 | 12 |
| CORRY #10 | 2.5 | 3.6 |
| CORRY #11 | 2.6 | 3.8 |
| CORRY #12 | 2.6 | 3.8 |
| CORRY #13 | 2.9 | 4.2 |
| CORRY #14 | 2.8 | 4.0 |
| CORRY #15 | 3.0 | 4.4 |
| CORRY #16 | 2.7 | 3.8 |
| CORRY #7 | 2.5 | 3.7 |
| CORRY #8 | 3.0 | 4.0 |
| CORRY #9 | 3.1 | 4.3 |
| FARM HILL #2 | 10 | 12 |
| FARM HILL #3 | 7.9 | 8.2 |
| COTTAGE HILL #2 | 18 | 20 |
| COTTAGE HILL #3 | 13 | 14 |

WHPAs delineated for 56 wells.

# APPENDIX D

## Model Input and Hydraulic Parameters

# Material Properties Model Layer 1



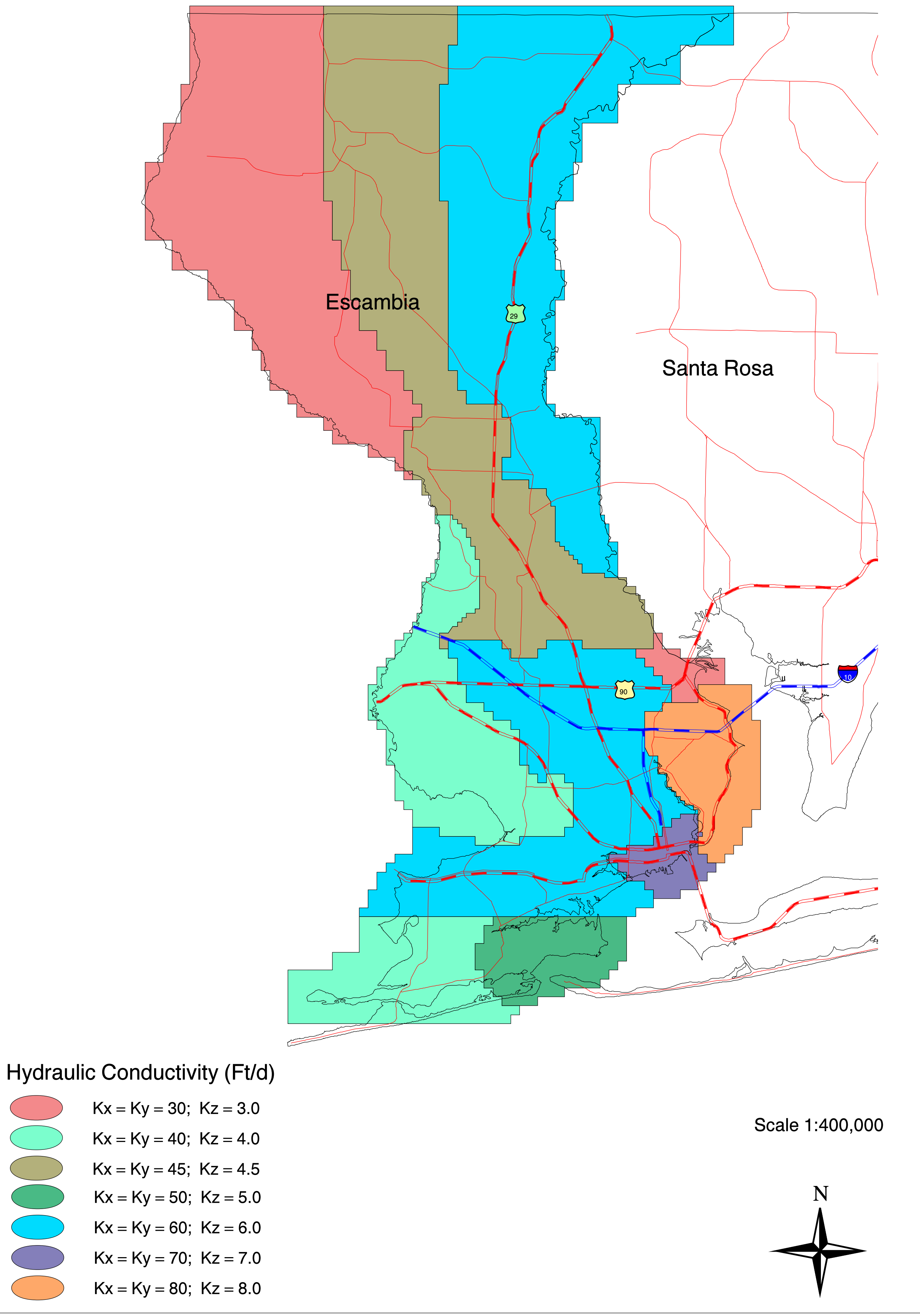

Hydraulic Conductivity (Ft/d)

- Kx = Ky = 30;  Kz = 3.0
- Kx = Ky = 40;  Kz = 4.0
- Kx = Ky = 45;  Kz = 4.5
- Kx = Ky = 50;  Kz = 5.0
- Kx = Ky = 60;  Kz = 6.0
- Kx = Ky = 70;  Kz = 7.0
- Kx = Ky = 80;  Kz = 8.0

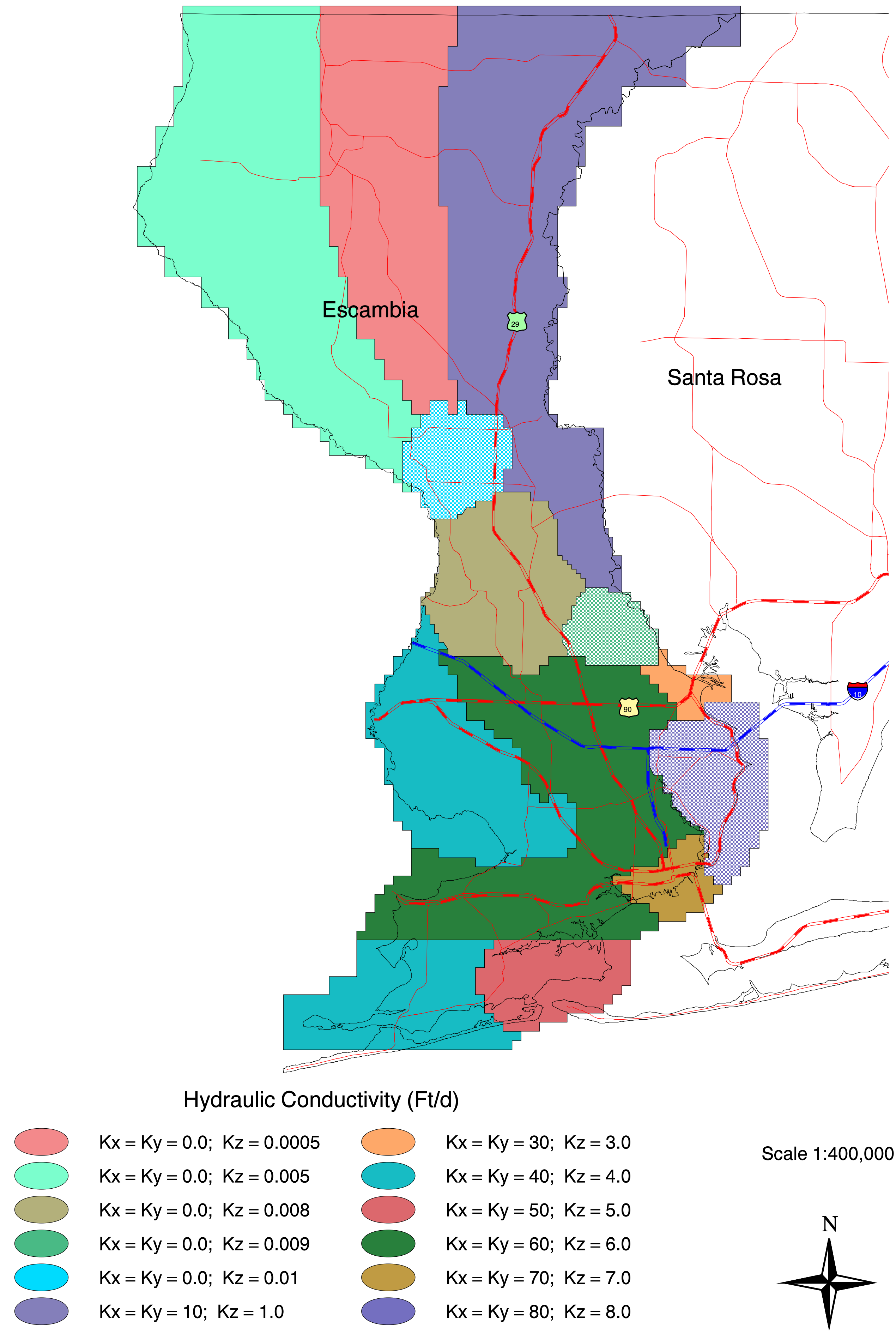
Scale 1:400,000

N

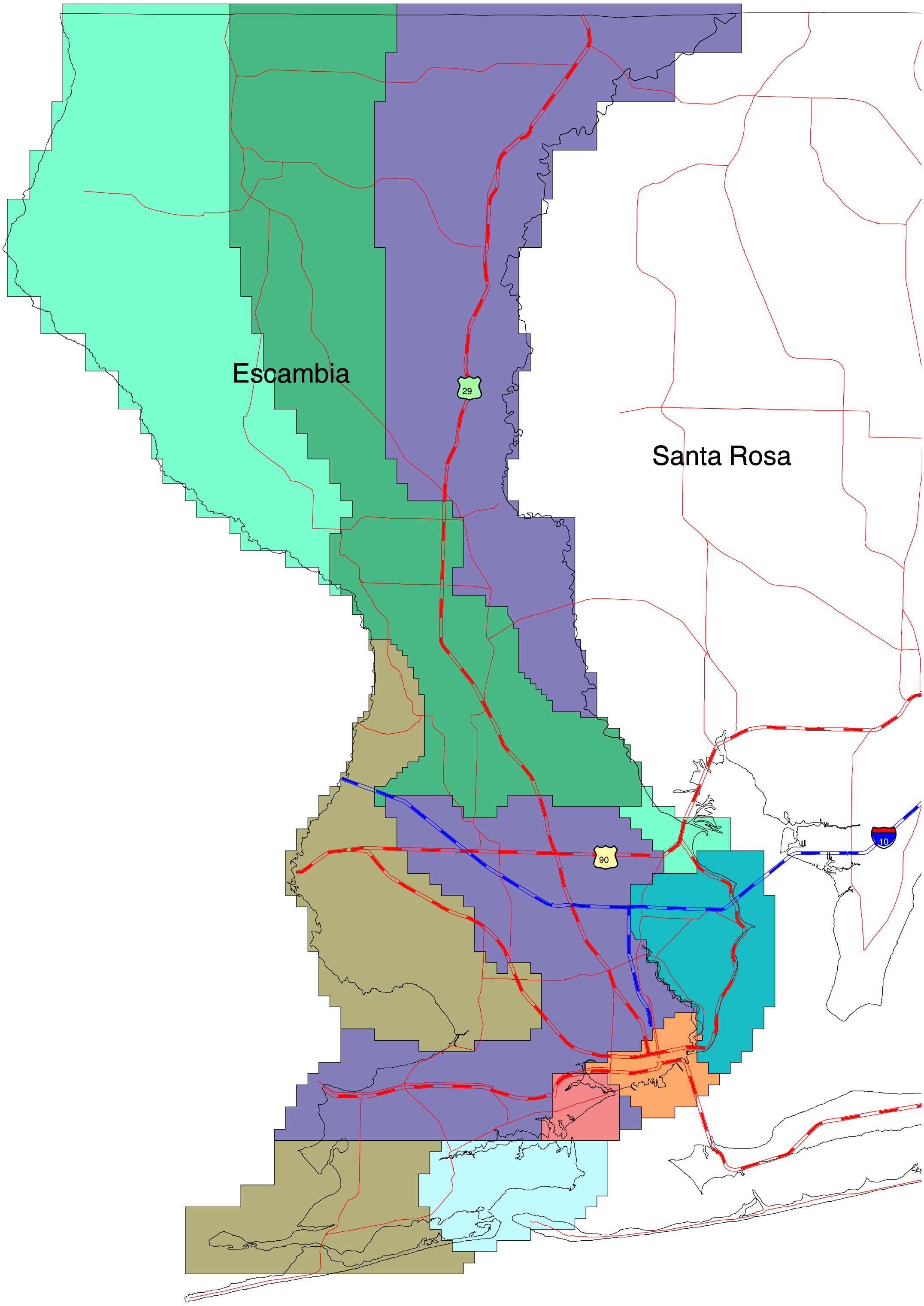
# Material Properties Model Layer 2



# Material Properties Model Layer 3

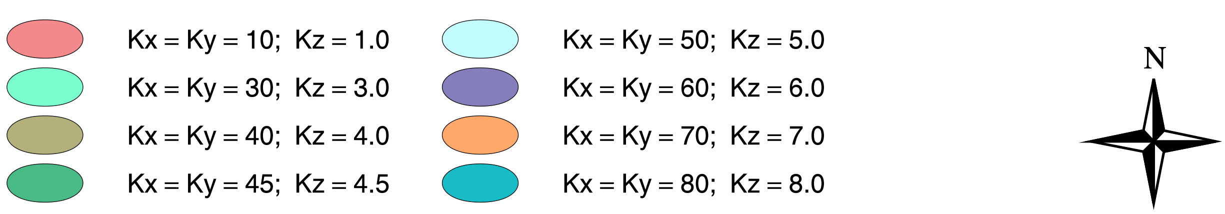


# Material Properties Model Layer 4

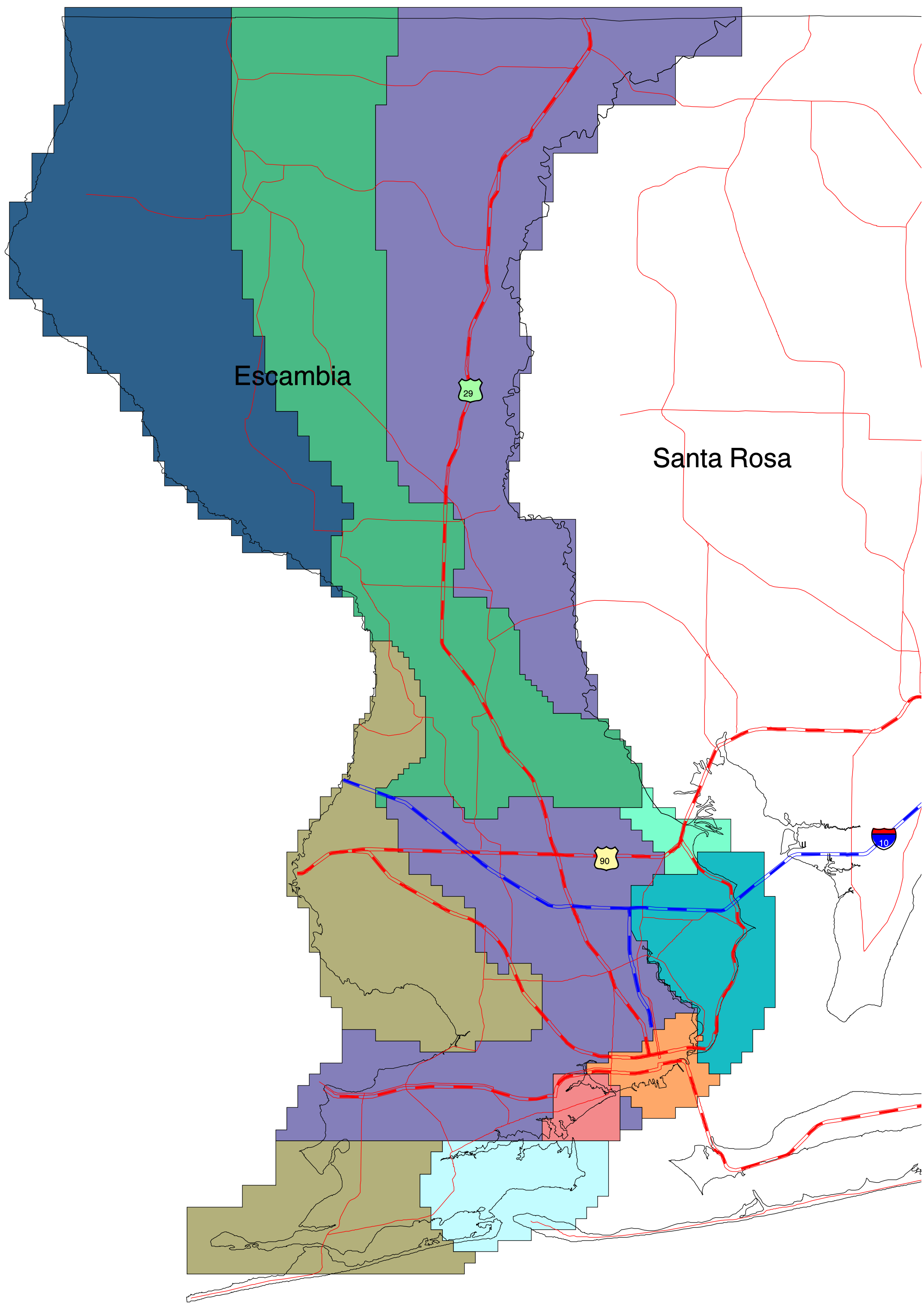



Hydraulic Conductivity (Ft/d)

Scale 1:400,000



# Material Properties Model Layer 5



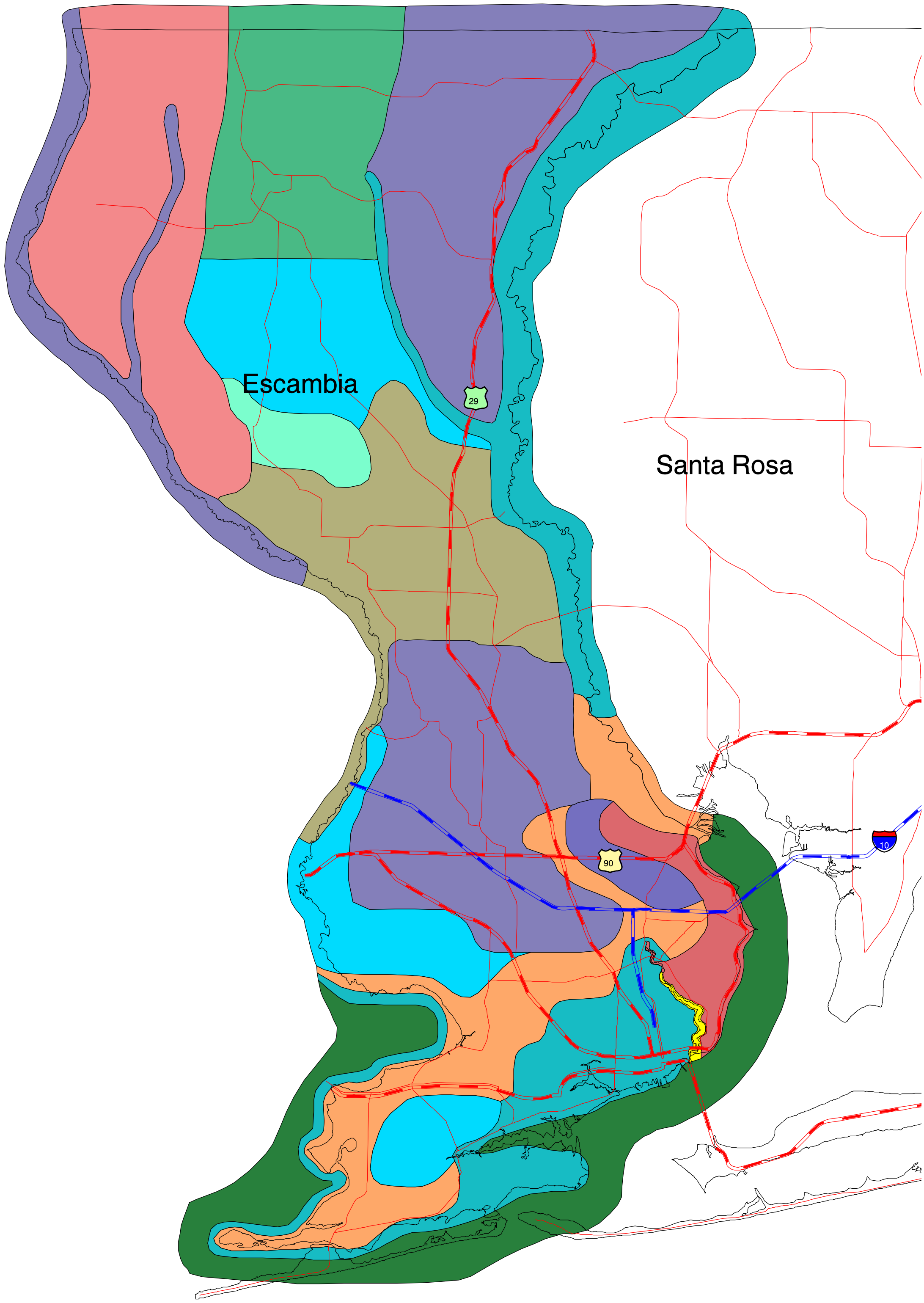

Hydraulic Conductivity (Ft/d)

Scale 1:400,000

- Kx = Ky = 1.0;  Kz = 0.01
- Kx = Ky = 10;  Kz = 1.0
- Kx = Ky = 30;  Kz = 3.0
- Kx = Ky = 40;  Kz = 4.0
- Kx = Ky = 45;  Kz = 4.5
- Kx = Ky = 50;  Kz = 5.0
- Kx = Ky = 60;  Kz = 6.0
- Kx = Ky = 70;  Kz = 7.0
- Kx = Ky = 80;  Kz = 8.0

N

# Material Properties Model Layer 6




## Hydraulic Conductivity (Ft/d)

- Kx = Ky = 0.0;  Kz = 0.0001
- Kx = Ky = 0.0;  Kz = 0.0005
- Kx = Ky = 0.0;  Kz = 0.001
- Kx = Ky = 0.0;  Kz = 0.0025
- Kx = Ky = 0.0;  Kz = 0.005
- Kx = Ky = 0.0;  Kz = 0.01
- Kx = Ky = 0.0;  Kz = 0.05
- Kx = Ky = 0.0;  Kz = 0.1
- Kx = Ky = 0.0;  Kz = 0.2
- Kx = Ky = 0.0;  Kz = 0.25
- Kx = Ky = 0.0;  Kz = 0.5
- Kx = Ky = 0.0;  Kz = 0.17

Scale 1:400,000

N

# Potentiometric Surface of the Surfical Zone
# Revised Regional Model Constant Head Boundary