APPENDIX K

GROUNDWATER RESOURCE EVALUATION

HARTCROWSER

Earth and Environmental Technologies

Appendix K

Groundwater Resource Evaluation
Coordinated Water System Plan
Island County, Washington

September 9, 1988

J-1939

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APPENDIX K - GROUNDWATER RESOURCE EVALUATION
COORDINATED WATER SYSTEM PLAN
ISLAND COUNTY, WASHINGTON

SECTION K-I

INTRODUCTION

This report presents the results of our assessment of the groundwater resources of Island County prepared for use in the Coordinated Water System Plan (CWSP) for the County. The purpose of the assessment is to estimate the annual replenishment to groundwater storage (which in turn defines the upper limit for additional available groundwater in Island County) and to provide input on the amounts, locations, and general number of wells needed to develop these additional supplies for public water systems. The level of effort for this project was consistent with a regional planning study. Greater precision and detail will be produced in the upcoming Groundwater Management Plan (GWMP). The GWMP will add to this CWSP project the information necessary for management of the groundwater resources of Island County. This goal was met through an evaluation of existing data on the geology, hydrology, climate, and water use.

The project area consisted of Whidbey and Camano Islands. Whidbey was divided into three regions: north, central, and south. The division of these regions was based on natural boundaries between hydrologic systems. These regions (as well as the region of Camano) were further divided into nine subareas in order to allow for analysis of semi-autonomous hydrologic parts of the County. Exhibit K-1, at the end of this section, shows the boundaries of these regions and subareas. The other small islands of the County were not considered in our evaluation.

The report is divided into eight sections. Section K-I is the introduction. Section K-II is an executive summary that can be read as a "stand alone" document as it contains a summary of methods, assumptions, and results. Section K-III reviews the general considerations and a description of the methods of analysis used to obtain the results of the evaluation and a brief discussion of the weaknesses of the data base used for the project. Sections K-IV through K-VII discuss in detail each of the four main regions of the County: Camano, North Whidbey, Central Whidbey, and South Whidbey. The report is concluded with Section K-VIII - References.

Exhibits pertinent to each section are included at the end of each section. Each section on a region has two exhibits, one showing well and cross section locations as well as water quality information and a second showing hydrogeologic cross sections.

This report was prepared under subcontract to Economic and Engineering Services, Inc. (EES) for use in their engineering evaluation for Island County's Coordinated Water System Plan. It was authorized by EES through subcontract work order 4-121, dated April 4, 1987.

The project was managed and the work conducted by Mark Utting of Hart Crowser, Inc. John Segerson of EES was the Project Manager and provided direction as to the needs of the CWSP process. The United States Geologic Survey (USGS) provided information critical to this report before it was generally available to the public. The cross sections presented in this report have been adapted from their unpublished work.

This report has been prepared for the exclusive use of Island County and their consultants EES, for specific application to the referenced project, according to generally accepted hydrogeological practices. No other warranty, express or implied, is made.

SECTION K-II

EXECUTIVE SUMMARY AND CONCLUSIONS

An assessment of the groundwater resources and potential for additional development was performed as part of the Coordinated Water System Plan (CWSP) for Island County. The assessment provides a hydrogeologic overview of the groundwater system of the County and input for long-range planning for the future public water supply of the County. The information provided by the CWSP groundwater assessment includes:

- Description of the distribution and properties of the various aquifers (including depth and well yield);
- Estimation of the total amount of annual replenishment to the groundwater in each of nine subareas of the County;
- Quantification of the groundwater currently appropriated in each subarea;
- Assessment of the amount of groundwater not appropriated in each subarea and on an island-wide basis this water may be potentially available for additional development, but probably at rates less than total non-appropriation;
- Evaluation of existing and future areas of saltwater intrusion as well as iron and manganese water quality problems;
- General recommendations for additional development (locations, aquifers, and well yields) with emphasis on regional public water supply; and
- Discussion of issues pertinent to the County's groundwater supply.

The CWSP groundwater evaluation was conducted as a compilation, review, and evaluation of existing data. Considerable information has been collected and assessed as part of this project. Much of this information came from the files of the USGS and from reports they have prepared over the past 20 years. Additional sources of information were: soils maps of the County, previous reports prepared by consultants and others, climatological data obtained from various sources, well log and water right information on file with the Washington State Department of Ecology (Ecology), a summary table of the water supply systems of the County prepared as another part of the CWSP process, and information contained in the files of the Island County Health and Planning Departments. No new data were collected as part of the process.

The level of effort for the CWSP groundwater evaluation was commensurate with a regional planning effort. Site-specific and precise quantitative assessment were neither intended nor produced. More detailed information and evaluation will be needed for management (as opposed to planning) of regional groundwater. A more detailed assessment for the upcoming

Groundwater Management Plan (GWMP) will be produced based on the information in this report, USGS data, and other sources of information. The results of the GWMP evaluation may supersede some of the quantifications and recommendations of this CWSP effort.

The County has been divided into four major hydrologic regions for the purpose of this evaluation. Each of these regions have been divided into two or three subareas (Exhibit K-1). The results of the evaluation are presented in four main sections (K-IV through K-VII, one for each region) and a summary table (Table K-1) accompanied by a supporting section on the general considerations and methods of analysis that pertains to all of the regions. Each regional section plus the methods and considerations section (Section K-III) can be read as a "stand alone" report. The Executive Summary and Conclusions (Section K-II) and Table K-1 give the general results and conclusions of the county-wide assessment. Each section should be consulted for details on the specific results and conclusions for each region and subarea.

The following are the main conclusions and recommendations of the evaluation:

- Island County has potential for considerable expansion of its groundwater supply. A mass balance-recharge analysis indicates that a range of 25 to 50 million gallons per day (mgd) is currently inappropriate. The lower end of the range of 25 mgd represents potential additional withdrawal that may be possible if groundwater development is correctly managed through proper well placement and pumping. The upper end of the range represents the amount that could be possible if verified by comprehensive monitoring and additional, site- and area-specific evaluation. Development at this rate will likely cause some environmental changes that may or may not be socially, physically, or economically unacceptable. All groundwater in the Island County system is currently "used" for some purpose, i.e., maintaining the saltwater interface; discharge to springs, streams, or wetlands; pumpage from wells; or discharge to the Puget Sound. Any removal of water from the system will have some effect, many of which will be insignificant. Removal of too much by wells will cause effects that will be significant. Society will have to judge whether these effects are acceptable. Planners and engineers should consider both ends of ranges and use the lower end of the range to be conservative. As additional development exceeds the 25 mgd range, new development may be increased toward the 50 mgd figure, if monitoring and analysis indicate that environmental changes are acceptable. Specific recommendations for development and management will come from the Groundwater Management Plan currently in preparation for the County. Total groundwater available for development with proper management will likely be between the upper and lower amounts given in the recommended range.

- Areas for large capacity regional water supply wells or large capacity regional well fields do not appear to be present within Island County. Typically, 1,000 gallons per minute (gpm) is used as the minimum

pumping rate for a regional supply well design. A well producing 250 gpm or more is considered a high producer in Island County. Areas capable of supplying 250+ gpm to a well are present but are neither extensive nor numerous. Many such areas identified so far are near coastal areas and cannot be exploited because of existing or future saltwater intrusion potential.

- Additional groundwater will need to be developed through a series of low yield wells (often under 50 gpm but locally 100 to 250+ gpm). These wells should be placed inland, generally greater than one mile from the coast to minimize saltwater intrusion. Many of these wells will be finished below sea level and will require that their pumping water level remain at or above mean sea level to minimize saltwater intrusion potential. Pump placement and pumping rate guidelines may be produced by the GWMP.

- Groundwater producing units within the County have been divided into five main aquifers, designated E through A (top to bottom) to be consistent with the nomenclature of published and soon-to-be-released reports and the numerical groundwater model of the USGS. Aquifers E and D are generally above sea level and are typically only partially saturated. Groundwater can only be produced from saturated deposits. Thus, even if the deposit is 90 feet thick, only the bottom, saturated portion (often 10 feet or less) can be used to supply a well. Aquifer C lies just above to below sea level and often is the most heavily used aquifer in a region. Aquifers B and A, when present, lie well below sea level and are often tapped by only a few wells within a subarea. These two aquifers are not always present beneath a subarea. Fine-grain deposits, not capable of supplying a well, may be present in their place.

- Saltwater intrusion is the main water quality issue in the County and often is the limiting factor in increasing groundwater development. Too many wells in coastal areas, especially near points and headlands, have induced saltwater intrusion or have reduced water levels to below sea level making future saltwater intrusion likely. Increased development will require that wells be placed inland to reduce the potential for this common problem.

- The occurrence of high iron and/or manganese levels in groundwater appears to be widespread in Island County. Levels exceeding secondary water quality standards are frequent (generally 30 percent or more of reporting systems) and do not appear to be associated with a particular aquifer or location. Iron and manganese do not represent a significant health risk but usually are a source of problems with taste, odor, or staining in water supplies.

- Camano Island has an estimated annual replenishment of groundwater storage of 2 to 10 mgd based on a mass balance analysis. Additional potential for development will likely be less than this range.

- Northern Camano (the area north of the "panhandle" of South Camano) has the best potential for additional development with an estimated 1 to 7+ mgd of potential additional supply based on recharge of 6 to 12+ mgd and appropriation of 4.93 mgd. The central upland is the recommended area for additional development with potential well yields of under 50 gpm likely and local yields of 250+ gpm possible. Saltwater intrusion has already occurred in the northeast part of the area, in Aquifer D, near Livingston Bay and east of Triangle Cove. Several other coastal area wells report water levels below mean sea level indicating the potential for saltwater intrusion in the future. Iron and/or manganese exceeding state standards were reported in approximately 38 percent of the 85 wells in our database.

- Southern Camano (the narrow peninsula that forms the "panhandle") has little potential for development of any significant additional supply because of limited recharge, narrow land mass with all well locations close to the coast, and relatively heavy existing use. An estimated 1 to 2+ mgd of non-appropriated groundwater may be developed from Aquifer C with careful development, based on recharge of 2 to 3 mgd and appropriation of 0.72 mgd. Development of this water at full rate will likely require abandonment and replacement of existing wells as the saltwater interface moves inland as a result of increased pumping. All additional development should be confined to the central "spine" of the peninsula. Potential well yields are likely to be much less than 50 gpm because of limited available drawdown in existing and future wells. Saltwater intrusion has already occurred throughout much of the subarea. Coastal areas not yet experiencing saltwater intrusion report well water levels below mean sea level indicating the potential for saltwater intrusion in the future. Iron and/or manganese concentrations exceeding state standards were reported in approximately 43 percent of the 23 wells in our database.

- Whidbey Island has unappropriated recharge of 23 to almost 40 mgd based on a mass balance analysis.

- The Northern subarea of North Whidbey (north of Ault Field and Dugualla Bay) has unappropriation recharge (and therefore the upper end potential for development) of an estimated 1/2 to 1 mgd of additional supply based on recharge of 1 to 1-1/2 mgd and appropriation of 0.44 mgd. Inland areas at least one mile from the coast are recommended for additional development with potential well yields from Aquifers C and D of under 50 gpm likely. Saltwater intrusion is not currently a problem in the subarea. Coastal wells have not (with the exception of one well in our database) reported water levels below mean sea level indicating that saltwater intrusion is not likely in the immediate future. Iron and/or manganese exceeding state standards were reported in approximately 28 percent of the 25 wells in our database.

- The Eastern subarea of North Whidbey (east of Oak Harbor and south of Dugualla Bay) has unappropriated recharge (and therefore the upper end potential for development) of an estimated 1 to 1-1/2 mgd of additional supply based on recharge of 2 to 2-1/2 mgd and appropriation of 0.86

mgd. The central upland area, at least one mile from the coast is recommended for additional development with potential well yields of under 50 gpm likely but with some areas capable of 100 gpm. Aquifer C has the best potential for this development but Aquifer D may also have development potential. Saltwater intrusion is not currently a problem in the subarea with only one well reporting chloride levels in excess of 100 mg/L. Several coastal wells between Polnell and Strawberry Points have reported water levels below mean sea level indicating that saltwater intrusion may be a problem in the future. Iron and/or manganese exceeding state standards were reported in approximately 32 percent of the 33 wells in our database.

- The Southwestern subarea of North Whidbey (south of Ault Field and west of Crescent Harbor) has no potential for development of any significant additional supply because current appropriations are up to 7 times the estimated recharge indicating a potentially critical situation. A higher yield zone northwest of Oak Harbor was identified but additional development is not recommended because of the overdraft identified in the subarea. We estimate recharge on the order of 1 to 1-1/2 mgd and appropriation of 7.76 mgd. Saltwater intrusion has already occurred over many parts of the subarea, as a result of the overdraft situation. Many coastal areas not yet experiencing saltwater intrusion report water levels below mean sea level indicating the potential for saltwater intrusion in the future. Iron and/or manganese exceeding state standards were reported in approximately 40 percent of the 87 wells in our database.

- The Northern subarea of Central Whidbey (south of Penn Cove and north of Admiralty Bay) also appears to have an overdraft situation and therefore has no potential for development of any significant additional supply. Current appropriations are up to 2 times the estimated recharge. A few additional wells may be placed in the southern part of the subarea if careful monitoring indicates that additional saltwater intrusion is not induced. Yields of 50 gpm to possibly 100+ gpm are possible from Aquifer C. We estimate a total recharge on the order of 1 to 1-1/2 mgd and use of 2.36 mgd. Saltwater intrusion has already occurred over many coastal parts of the subarea, especially on the east coast between Harrington and Race Lagoons, along Penn Cove and near Admiralty Bay. Several coastal areas not yet experiencing saltwater intrusion report water levels below mean sea level indicating the potential for saltwater intrusion in the future. Iron and/or manganese exceeding state standards were reported in approximately 30 percent of the 27 wells in our database.

- The Southern subarea of Central Whidbey (the isthmus south of Admiralty Bay and north of Freeland) may have the potential for development of an estimated 0 to 2 mgd of additional supply based on recharge of 1 to 3+ mgd and appropriation of 1.12 mgd. The central upland areas, on the approximate north-south axis, are recommended for development with potential well yields of under 50 gpm likely but with some areas capable of 250 gpm. Aquifer C has the best potential for this development. Aquifer B may also have potential but saltwater intrusion

may be of concern. Saltwater intrusion is currently a problem in parts of the subarea with several wells reporting chloride levels in excess of 100 mg/L in the Greenbank-Dines Point area and along Admiralty Inlet north and south of Lagoon Point. Several coastal wells have reported water levels below mean sea level indicating that saltwater intrusion may be a problem in the future. Iron and/or manganese exceeding state standards appears to be less common in this subarea, compared to other parts of the County. Excessive levels were reported in only 8 percent of the 25 wells in our database.

- The Northwestern subarea of South Whidbey (east of Holmes Harbor, north of Useless Bay, and west of Langley) has good potential for development of additional supply based on recharge of from 7 to almost 13 mgd and appropriation of 1.55 mgd. An estimated 5 to 11+ mgd are currently unappropriated from this area. The central upland area, at least one mile from the coast, is recommended for development with potential well yields typically under 50 gpm but locally 100+ gpm. Aquifer C has the best potential for this development. Aquifer B may also have potential, but saltwater intrusion may be of concern. Saltwater intrusion is not currently a problem in the subarea with only one well in our data base (near Freeland) reporting chlorine levels in excess of 100 mg/L for Aquifer C. A few wells drilled along Holmes Harbor, near Rocky Point, reported brackish or saline water during drilling and were abandoned or pulled back. Some coastal wells have reported water levels below mean sea level indicating that saltwater intrusion may be a problem in the future. Iron and/or manganese exceed state standards in a reported 30 percent of the wells in our database.

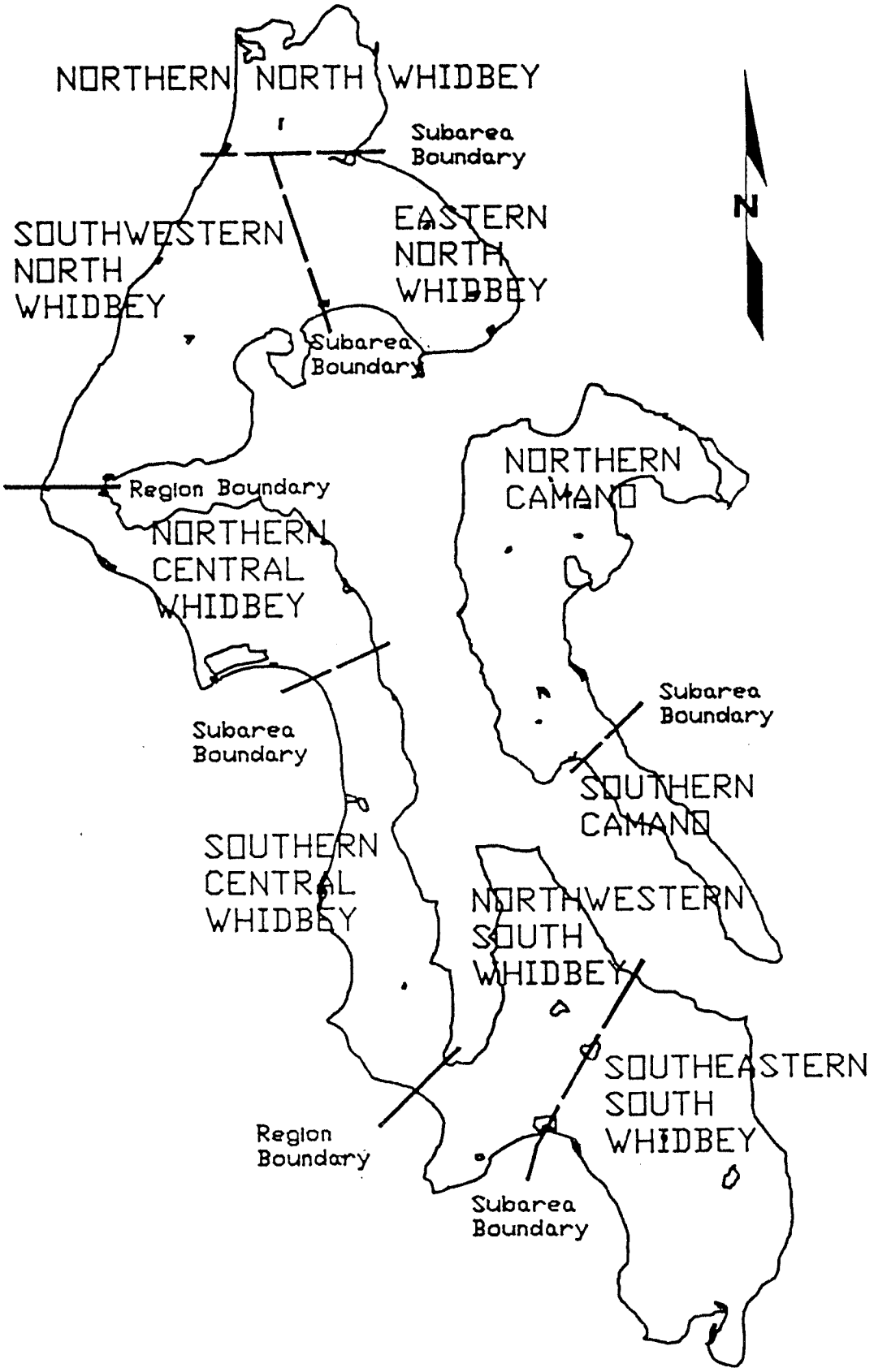
- The Southeastern subarea of South Whidbey (west of Useless Bay, and south of Langley) has good potential for additional development. Annual unappropriated groundwater in the system is in the range of 16 to almost 23 mgd based on recharge of 18 to 25+ mgd and appropriation of 2.38 mgd. The central upland area, at least one mile from the coast is recommended for development with potential well yields typically under 50 gpm but locally 250+ gpm. Aquifer C has the best potential for this development with a higher yield zone located near Langley. Development of a regional supply well field is not recommended for this area as saltwater intrusion would be likely from such a system at this location. Aquifer B may also have potential where higher yield zones can be identified. Saltwater intrusion is not currently a problem in the subarea with no wells in our database reporting chloride levels in excess of 100 mg/L. Some coastal wells have reported water levels below mean sea level indicating that saltwater intrusion may be a problem in the future. Iron and/or manganese exceed state standards in a reported 30 percent of the wells in our database.

Table K-1 - Summary of Aquifer and a for the Entire Subarea

Subarea	Aquifer	Presence	Current Appropriation in mgd	Unappropriated Annual Replenishment to Storage in mgd (upper bounds of additional development)
Northern Camano	E	West Only		
	D	All		
	C	West Only??		
	B	Central, Rest??	4.93	1 to 7-1/2
	A	No Data		
Southern Camano	E	South Only		
	D	All??		
	C	All		
	B	No Data	0.72	1 to 2-1/2
	A	No Data		
Northern North Whidbey	E	East and Central		
	D	East and Central		
	C	All		
	B	West, Rest??	0.44	1/2 to 1
	A	Not Likely		
Eastern North Whidbey	E	All,Discontinuous?		
	D	All,Discontinuous		
	C	All		
	B	Maybe	0.86	1 to 1-1/2
	A	No Data		
Southwestern North Whidbey	E	Most,Discontinuous		
	D	All		
	C	All	7.76	0
	B	Maybe		
	A	Maybe		
Northern Central Whidbey	E	Not Present		
	D	Mostly East		
	C	All	2.36	0
	B	All?		
	A	Maybe		
Southern Central Whidbey	E	N. Central Only		
	D	East and North		
	C	All	1.12	0 to 2
	B	Discontinuous		
	A	Maybe		
Northwestern South Whidbey	E	Not Present		
	D	In East Only		
	C	All	1.55	5 to 11+
	B	Probably All		
	A	Maybe Not		
Southeastern South Whidbey	E	Southeast, Only		
	D	Most Areas		
	C	All	5.65	16 to 23
	B	Maybe		
	A	No Data		
Camano Island			5.65	2 to 10
Whidbey Island			16.47	22 to 38+

Note: Mass balance for island totals doe

Region and Subarea Location Map



Hart Crowser, Inc.
J-1939 9/87
Exhibit K-1

SECTION K-III

GENERAL CONSIDERATIONS AND METHODS OF ANALYSIS

1. GENERAL CONSIDERATIONS

A variety of analytical methods were used for this evaluation. A primary focus was to use much of the data and conclusions developed by the USGS in their unpublished modeling study of Island County as well as the supporting data available in other USGS reports, listed in the references (Section K-VIII). Every attempt was made to limit duplication of their efforts wherever possible. No new data were collected to augment the existing data, although major data gaps were identified during the course of the evaluation. The precision of the recommendations is dependent on the quality of the available data. Limitations of the data and the necessary new information needed to refine the recommendations are discussed at the end of this section.

The county was divided into four major regions for the purpose of this report:

- Camano Island
- North Whidbey
- Central Whidbey
- South Whidbey

These four regions (Exhibit K-1) represent hydrogeologic areas that act generally autonomously. That is, hydraulic events in a region (such as pumping or saltwater intrusion) have little or no effect outside the region. The divisions are based on natural separations such as isthmuses (Point Partridge to Penn Cove and Holmes Harbor to Mutiny Bay) and surrounding water (Saratoga Passage-Port Susan). These separations isolate hydraulic response to one region.

Each region has been further divided into subareas that respond semi-autonomously. Major hydraulic events (such as full scale development) within the subarea may have some measurable impact on nearby subareas but smaller events are unlikely to be detectable. The subarea boundaries are based on both groundwater and surface water divides. The nine subareas that comprise the four regions are included on Exhibit K-1.

The general approach in our evaluation was to define the geology, hydrology, water quality, and water appropriations for each region of the county. Estimates of the total groundwater available in each subarea were based on analysis of:

- Geology (aquifers and their distribution, as well as surficial deposits and their impact on recharge);

- o Hydrology (how precipitation enters the ground and then flows through the various aquifers to discharge at sea, spring, or well); and

- o Water quality (primarily the impacts of saltwater intrusion induced by improper development of the groundwater resources).

A mass balance analysis was then used where:

Total annual replenishment to the groundwater system - Current appropriation = Additional withdrawal available

Total groundwater available was based on recharge to the system which defines the upper limit of how much can be used. Estimates of the total water currently used in the County were based on total appropriations on record with the Washington State Department of Ecology (Ecology). The effects of additional development were then assessed with respect to saltwater intrusion. The difference between availability and appropriation represented additional groundwater that is optimally available.

Development of all the "additional withdrawal available" will likely be impractical. This total figure assumes that all wells pumping from the system will be optimally placed and pumped and that environmental effects caused by pumping all recharge can be tolerated. Typically, this situation does not occur: many (if not all) existing well owners will not want to give up their existing wells that may not be at optimal locations. Elimination of discharge to wetlands, springs, and streams will also not likely be acceptable. In short, the groundwater system is in a dynamic balance. Removal of water from one part of the system will cause changes in other parts of the system. Evaluation of the acceptability of these changes is beyond the scope of this report and will have to be decided as development occurs.

We have used a "realistic" approach in our analyses. This approach is a balance between conservative and optimistic. In many cases (such as estimating aquifer recharge) many of the values for the parameters used in the analysis were selected from a range of values estimated from existing data. Since no field measurements were taken as part of this project, the conservative approach would be to use the low end of the range while the optimistic approach would be to use the high end. Since the complete analysis uses several sets of estimated parameters, using only the conservative (or optimistic) end of the ranges would give misleading results. Using all the conservative input values would indicate that no additional groundwater could be developed, while using only optimistic values would overestimate the amount of additional supplies that were available such that saltwater intrusion would certainly occur if these amounts were pumped.

Our "realistic" approach uses a range of parameter estimates that falls in the middle between totally conservative and totally optimistic. The results are recommendations that are expressed as ranges (i.e., 16 to

23 mgd appear available for additional development). The lower end of the range represents the amount of water that is probable, while the upper end represents additional yield that may be possible, but only with management that may indicate replacement of the existing wells with a new system of optimally placed wells, verification through additional monitoring, field data collection, and analysis. The upper end of the range may appear to represent the use of all recharge to a region or subarea. This may or may not be the case as the uncertainty of the input data could under-estimate total recharge. Monitoring and analysis will be the final indicator of total recharge and total available for use.

2. AQUIFER PROPERTIES AND DISTRIBUTION

The distribution and properties of an aquifer control how much water a well can yield and in part how much water can be developed from a region or subarea. The distribution, type of deposit, and hydraulic properties of an aquifer are all controlled by its geologic history. Major aquifers in Island County typically consisting of layers of sand and occasionally gravel, were deposited by glacial and interglacial processes over the last million plus years. (Bedrock aquifers are present beneath the northern portion of North Whidbey Island but yield only small amounts of water to wells. They do not play a significant role in groundwater development in Island County.) The geologic history of an aquifer deposit controls the aquifer parameters of permeability, transmissivity, storativity, thickness, and areal extent. Areally extensive, thick, coarse-grained deposits with large transmissivities (many tens to hundreds of 1,000 gpd/ft) generally yield more water than limited, thin, fine-grained deposits with small transmissivities (a few 1,000 gpd/ft).

The unconsolidated deposits of Island County comprise a complex sequence of interbedded glacial and interglacial deposits often associated with fluvial (river) processes. Previous attempts by earlier workers to define the aquifers of Island County by geologic units have proven unsuccessful because of the complex nature and apparent similarity of some of the deposits. Aquifers are now defined by the USGS based on hydraulic connection, stratigraphy, and topographic position. Each aquifer (designated A through E) contains deposits of several formations. Because the aquifers have been fluvially deposited, their properties vary over distance. The distribution of aquifers used by both the USGS in their reports and models, and by us in this report, do not necessarily imply that the aquifers are present and uniform at all the locations shown. Rather they vary in properties and may not be present at some of the locations indicated on the exhibits.

A. Methodology

In order to develop an understanding of the presence and distribution of the aquifers in the County we reviewed the existing data with emphasis placed on the unpublished work of the USGS.

Draft cross sections produced by Jones (1987) were reviewed and compared with: well logs on file with Ecology, The Shoreline Atlas for Island County, several USGS geologic reports, and various consultants reports. In order to maintain continuity with the soon-to-be-published modeling study of the county, we have used the alphabetic aquifer designations used by Sapik (in-press).

3. WELL AND AQUIFER YIELD

Potential well yield is the amount of water that a single, properly designed and constructed well can produce. Potential aquifer yield is defined as the amount of water that can be withdrawn from an aquifer using as many wells as needed, causing environmental changes (such as saltwater intrusion) that are acceptable. Potential well yield is often realized while potential aquifer yield is unlikely to be achieved as wells are not usually placed at optimal locations, of optimal design, nor operated at optimal pumping schedules. Based on full-development programs in other parts of the country where saltwater intrusion is a factor, the cost for total, safe (non-degrading) development of Island County aquifers would be prohibitive.

We have estimated potential well yields for each of the subareas so that possible regional supply areas can be identified. Regional supply areas typically require well yields of 1,000+ gpm. In Island County, where well yields can be quite a bit less than in other parts of western Washington, we have used a 250 gpm minimum limit for potential regional supply wells. Several of these wells completed in an area may be viable as a regional supply well field.

A. Methodology

We used the specific capacity method to estimate short-term (one week) potential well yield. Where well driller's records included data for either pump- or bail-testing, the potential yield was estimated by:

$$Q = 2/3 * Sc * Ad$$

Where:

Sc is the short-term specific capacity (equal to the pumping rate divided by the drawdown during a one- to four-hour test). Ad is the available drawdown (the difference between the static water elevation and the elevation of the well screen or mean sea level where the pump could be located). The two-thirds factor allows for reduced water levels during dry periods and decreased specific capacity during long-term pumping.

For some of the 450 wells included in a five-year water quality database compiled by the USGS, transmissivities (where listed) were converted to approximate specific capacities using the method of Walton (1962). In cases where the well was finished below sea

level, available drawdown was taken as the difference between the static water level and sea level. Limiting drawdown to sea level allows the calculation of potential yield where saltwater intrusion is not likely to be induced by over pumping. In some cases, the potential yield is less than the actual current yield, where wells operate such that the pumping water level is below sea level.

Yield from each individual aquifer has not been calculated as part of this project as the necessary information has not been collected for the County. We have estimated potential total yield from each subarea (discussed above).

4. EXISTING WATER APPROPRIATIONS

Water that is currently being used either through human activities or through necessary natural discharge, represents water that is already allocated and not available for additional groundwater development. Water wells with registered rights represent a major type of existing use. Recorded water rights information is available from the files of the Department of Ecology. This type of water use is readily quantified. Unrecorded water rights are also a type of existing water use. As they are unrecorded, it is only possible to estimate their total impact on total water use. Since this type of use is usually small relative to total groundwater use, errors caused by overlooking unregistered wells are typically offset by over estimating registered-right water well use. Typically most registered wells are pumped at less than their allocated rights over the course of a year. Since our analysis assumes that wells are pumped at their registered rates, the errors of not counting unregistered wells and over estimating use by registered wells tend to be self canceling. In some cases, the impact of unregistered wells may be significant on a local scale. Therefore, further studies focused on smaller areas may require compilation of unregistered wells.

Groundwater discharge to the surrounding water of Island County represents another type of "existing water use" in Island County. This discharge is necessary to maintain the balance between the saltwater-freshwater interface within the aquifers. Overuse of this discharge can lead to saltwater intrusion. This discharge is not quantified in our water budget. Instead we are assuming that while additional withdrawals are increased, monitoring will also be increased as the upper range of the recommended withdrawal rate is approached. In this way performance of the system will indicate whether discharge is adequate to maintain the saltwater-freshwater interface at positions that are acceptable. The USGS model has been designed to estimate the position of the interface.

Discharge to maintain surface water flows is not a significant factor in Island County. There are no mandated minimum river or stream flows (thereby requiring groundwater discharge) in Island County. Wetlands are caused either by low permeability soils in recharge areas and/or

discharge of groundwater in discharge zones. No effort was made to assess the groundwater component in the County's wetlands.

A. Methodology

Department of Ecology water right records were reviewed and groundwater rights for annual use totaled for each subarea. Effort was made to separate supplementary rights and avoid false duplication. Individual (unrecorded) rights were not totaled and the assumption was made that the effects of this type of use were canceled by the incomplete use of registered rights.

5. WATER QUALITY AND SALTWATER INTRUSION

Saltwater intrusion is the major water quality issue in the County. Many coastal communities have experienced degradation of their water supplies through over pumping and/or poor well placement. Saltwater intrusion can be minimized or reduced with proper management (an eventual result, we hope, of this and other related projects). Management options include: limiting total groundwater development to rates less than the estimated recharge to the aquifer, properly locating wells inland away from high pumpage areas, designing and operating wells to keep in-casing water levels at or above sea level, and monitoring in the aquifer for early indications of degradation. The effects of saltwater intrusion are reversible. The time and cost required for this process, however, make prevention the preferable policy.

Natural constituents can also be of concern. The most common natural contaminants in Island County include iron and manganese. These metals have only state secondary water quality standards and are not considered harmful when exceeding the standards. Typically, shallow groundwater will have lower concentrations of natural contaminants than deeper groundwater. This situation was not observed in the County as is discussed later.

A. Methodology

Several sources of information were used to assess saltwater intrusion and other types of water quality problems. Chloride and electrical conductivity data collected by the USGS on 450 wells in the County for the period 1978 through 1983 were compiled into a database and wells indicating more than 100 mg/L chloride were identified as having indications of saltwater intrusion. A similar evaluation was also made for data in older published reports, while excessive levels of iron and manganese were also identified in the Island County Water System Inventory.

6. RECHARGE

Recharge to the groundwater system in all of Island County comes from precipitation. Recharge occurs when more precipitation enters the

ground than is removed by either runoff or evapotranspiration, and flow gradients in the underlying groundwater system have a downward component. Both of these conditions are met in most of the County such that more than 90 percent of the land surface acts as recharge area. Surface deposits and their associated ground cover have an impact on runoff and evapotranspiration rates. However, because recharge rates are generally smaller than the infiltration capacity of the surface soils, and evapotranspiration by most of the vegetation typical of the County is controlled by limitations in the moisture holding capacity of the soil, recharge occurs over practically all areas except the extreme coastal and associated near-shore marsh areas.

The rate of recharge is controlled by precipitation, evapotranspiration of water by plants, runoff, and change in soil moisture storage. None of these parameters is known with much certainty in Island County, thus a wide range of recharge estimates exists for each subarea. The uncertainty is higher in the southern part of the County where precipitation data are contradictory. NOAA weather service annual rainfall maps (which interpolate between official weather stations) disagree by as much as 100 percent with several published and unpublished reports for semi-official stations on South Whidbey Island. Both sources of data have credibility and were therefore used in our evaluation, resulting in a wide range of recharge rates for South Whidbey.

Infiltration of septic effluent from drain fields and return flow from irrigation are also types of recharge. In order to remain somewhat conservative in our analysis, these flows were not quantified. Use of these flows in calculating total recharge may be inappropriate for long-term planning in that changing land use pattern may result in removal of some or all of this potential recharge. In addition, some drain field water is evapotranspirated and lost from the system. We have assumed all appropriated water is consumed as is legally possible and that long-term planning is better based on "natural" recharge alone.

Evapotranspiration was estimated for the County using the Thornthwaite method to estimate potential evapotranspiration. Actual evapotranspiration was estimated based on the assumption that the soil has an average moisture holding capacity of 6 inches. This "water depth" of 6 inches is based on an average soil depth of about 3 feet and a field capacity of 0.15.

Runoff was assumed to be small but not negligible. Estimates of runoff were made based on the Dunne and Black (1968) mechanism generating stormflow. Using our experience, and the number of small intermittent and perennial streams indicated on the topographic maps, we estimated the approximate range as a percentage of precipitation contributed runoff.

A. Methodology

A mass balance for recharge was used where:

Recharge = Precipitation - Evapotranspiration - Runoff - Storage Change

A range of precipitation data was obtained from climatological data collected by the Weather Service, Rainfall data reported in Anderson (1968), unpublished USGS collected data (Jones, personal communication, 1987), and unpublished records collected of the Island County Extension Service (Meehan, personal communication, 1987). Evapotranspiration was calculated using published climatological data. Runoff was estimated based on the methods described above. Storage change (soil moisture) was assumed to be zero over the long-term average. That is, dry years cancel out wet years over the long run.

The results give the daily recharge rate averaged over the year. For example, a recharge rate of 1 mgd indicates that 365 million gallons are recharged over the year and not that 1 million gallons are recharged each and every day. Typically, most recharge will occur over the wetter months of December through May.

7. DATA GAPS

During the course of this evaluation several weaknesses in the available data were noted. We believe that it is necessary to augment the existing data in order to increase the accuracy of the estimates made in this report. When the following data are collected and reviewed, the current assessment should be revised and modifications made where appropriate.

A. Precipitation

Precipitation data are not adequate to make the necessary recharge calculations for Island County. In some cases there appear to be major discrepancies among data sources. The official weather bureau isohyetal map disagrees by up to 100 percent with data collected and published from several semi-official meteorological stations on Whidbey. The data for North Whidbey generally agree but the differences increase toward the south. In several locations on South Whidbey, rainfall is reported in the 38 to 40 inches per year range, while the "official" map indicates values in the low twenties range. Incorrect assessment of rainfall could lead to large errors in estimating additional groundwater available for development. In our analysis we have used the range of rainfall values to generate a range of recommendations for additional withdrawal. Additional rainfall data (requiring five to ten years to collect) will allow for a refinement of the additional withdrawal range. We understand that the Island County Extension Service is in the process of collecting these data.

B. Surficial Geology

The surficial geology of Island County has only been partially mapped (one quadrangle). This information is fundamental in interpreting the hydrogeology of an area. Typically, this type of basic information is produced by the USGS. As of now, we understand that no maps are being produced nor are there plans for any major mapping in the future. Surficial geology is important in defining the geologic units (both at and near the surface), estimating recharge, and identifying areas that may have sensitivity in supplying infiltrated precipitation to groundwater systems feeding saltwater intrusion areas.

C. Water Levels

Accurate water level data (especially near coastal areas), including relative elevation of the well head or other water level measuring point, are not abundant for Island County. Collection of these data is vital in estimating flow rates in the aquifers and evaluating saltwater intrusion. The data now available can be used to give a general sense of flow but more data points, especially for deeper aquifers, are needed. The collection of additional data will allow for a refined quantification of groundwater resources in the County.

D. Aquifer Designation

We have used the definition of the aquifers produced by the USGS (A through E) in our assessment. These unit definitions were produced for input to the soon-to-be-released numerical groundwater model and report on the County. These definitions were adequate for the purposes of this report, but discrepancies between some of the plotted well logs and the continuous aquifers generated by the USGS were noted. Future refinement of flow in critical areas will require a review of the aquifer designations and modification where appropriate. For example, in some areas on the unpublished cross sections, aquifers were projected through silt zones noted on well logs. Such projections are required for a modeling effort, but may not be appropriate for future detailed reviews of areas sensitive to saltwater intrusion.

SECTION K-IV

CAMANO ISLAND

Camano Island has unappropriated replenishment of storage (and therefore an upper bound of potential for development) of 2 mgd to perhaps a much as 10 mgd of additional groundwater supply. Most of this quantity appears available in the northern subarea of the island. The narrowness of the southern peninsula makes additional groundwater development difficult, without producing additional saltwater intrusion problems.

The island has been divided into a northern and southern subarea for the purpose of this report, based on topography and separation of groundwater flow systems. The Southern subarea consists of the narrow peninsular area south of an imaginary line between Eiger Bay and Mountain View Beach (Exhibit K-1). The Northern subarea comprises all of the area north of this line. Each subarea is discussed below, separately.

Groundwater use and development in one subarea does not generally effect the adjacent subarea, except perhaps near the subarea boundary. Hydrologic changes near a boundary may cause an impact across the boundaries established for this report. These boundaries are not absolute as they shift with changes in the water balance.

Summary data and assessments for Camano Island are included in Table K-1, while well and cross section locations are shown on Exhibit K-2. Hydrogeologic cross sections are shown on Exhibit K-3.

1. NORTHERN CAMANO

Northern Camano has the best potential for development of additional supplies on Camano Island. Approximately 1 to 7+ mgd of unappropriated annual replenishment to storage may be available for additional use. A large number of smaller wells, locally to 250+ gpm, but typically under 50 gpm, placed inland at least one mile, and adequately separated from each other, will be needed to maximize the additional development. The central portion of the Island is likely the best area for placement of well fields for a small scale regional supply.

A. Principal Aquifers and Well Yields

Four of the five main aquifers in Island County have been identified in Northern Camano. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer E is only present in the west portion of the subarea, lying at elevations of 150 to 350 feet above mean sea level. Although the sand and gravel deposits that comprise this unit are up to 90+ feet thick, only the lower portion is usually saturated limiting its suitability to domestic well use. The aquifer typically has a

saturated thickness of less than 10 feet, although well data in Section 25 indicate as much as 30 feet of saturated thickness. From a properly designed and constructed well are generally less than 50 gpm. There are insufficient data to estimate representative aquifer transmissivities in this area.

Aquifer D appears to lie beneath all of Northern Camano and acts as one of the main aquifers in the region. It lies at an elevation of 200 feet above to 100 feet below mean sea level. Wells tapping this aquifer are generally 50 to 200 feet deep. Although the USGS reports a thickness of greater than 150 feet of the saturated and unsaturated sand and gravel deposits that comprise this unit, it is usually only partially saturated to a thickness of 10 to 40 feet, where lying above sea level. Local well yields can exceed 250 gpm (such as near T31/R3 Section 19) but are typically less than 50 gpm. Transmissivities range from 20,000 to 50,000 gpd/ft in the high yield areas. In the lower yield areas they are likely to be on the order of a few 1,000 gpd/ft.

Aquifer C forms the other main aquifer in the northern Camano subarea especially on the west portion of the Island. It lies at an elevation of 100 feet above to 100 feet below sea level. Wells tapping this aquifer are generally 150 to 350 feet deep. The aquifer consists of a saturated thickness of sand (and occasionally gravel) on the order of 20 to 40 feet. Theoretical maximum well yields are generally limited by static water levels that are near sea level such that most wells should not be pumped at more than 50 gpm. Yields of 200+ gpm appear physically possible from some wells but only with the likelihood of lowering the pumping water level below sea level and increasing the potential for saltwater intrusion. Transmissivities on the order of 3,000 to 10,000 gpd/ft are indicated by the limited data.

Aquifer B is present beneath the central portion of northern Camano (near Carp and Smith Lakes), and may be present beneath other portions of the subarea. Wells deep enough to verify its presence and properties, have not been drilled throughout the area. The USGS test well drilled near Kristoferson Lake indicated that aquifer B was not present beneath the north-central part of the subarea. The aquifer typically lies at an elevation of 150 to 250 feet below mean sea level. Wells tapping this aquifer are generally greater than 400 feet deep. Water bearing zones in this aquifer are generally 10 to 20+ feet thick. Theoretical well yields are generally less than 50 gpm as transmissivities are typically less than 5,000 gpd/ft.

No data are available on Aquifer A in the northern Camano area. It was not observed in the USGS test well drilled to a depth of almost 600 feet near Kristoferson Lake. Aquifer A may or may not be present in other parts of the subarea. If so, its properties may be similar to those reported for this aquifer in other subareas.

B. Water Quality and Saltwater Intrusion

Northern Camano Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended state levels. Saltwater intrusion into freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron and/or manganese is not as serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion is currently a problem in the north and east parts of the subarea, and is most apparent in Aquifer D. Many wells in the area surrounding Livingston Bay have reported saltwater intrusion problems as have wells east of Triangle Cove. Many wells in these areas not yet experiencing saltwater intrusion have reported water levels below mean sea level and therefore have the strong potential for saltwater intrusion in the future. These areas are outlined on Exhibit K-2.

Other parts of the Northern Camano subarea have not reported widespread saltwater intrusion. Several wells in coastal areas have reported both static and pumping water levels below mean sea level and are therefore susceptible to future saltwater intrusion. In addition, all wells in coastal areas should be considered as having high potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and/or manganese problems are very common in the subarea with 38 percent of the 85 class I, II, III and IV wells in our database reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. Excessive iron and manganese levels do not appear to be associated with any specific location or aquifer as substandard water has been reported in both major aquifers at all parts of the subarea. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Northern Camano subarea.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Northern Camano subarea. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The lower end of the additional development range represents the amount that is very likely feasible while the upper end of the range may be possible but only with optimal well placement, verification through monitoring, and more detailed analysis.

(1) Recharge

A mass-balance analysis indicates that approximately 6 to 12+ mgd recharge the groundwater system of Northern Camano Island. The analysis, shown in Subappendix K-A, is based on rainfall of 23 to 29 inches per year, runoff of approximately 5 percent of year. Runoff is indicated by the perennial and intermittent streams in the subarea. The recharge area on Northern Camano is estimated to range from 32 to 35 square miles.

(2) Existing Appropriations

A summation of existing water rights indicates that approximately 4.93 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as explained in Section K-III.

(3) Additional Use

The difference between recharge and use indicates that 1 to 7+ mgd of unappropriated replenishment of groundwater storage may be available for additional development. Many low yield wells will be needed to develop this additional supply. Aquifers D and C appear to have the best potential for this development. Since well yields in these aquifers are typically less than 50 gpm, many tens of wells will be needed. Locally wells can produce 250+ gpm and in these locations fewer wells will be needed. The center portion of the subarea (for example T32N/R2E Sections 25 and 36, T31N/R2E near the boundaries of Sections 1 and 2, 11 and 12, as well as 13 and 14) is the best location for development, as:

a) The potential for saltwater intrusion is probably at its lowest in this area; and

b) Few public supply wells are located in this area with which to interfere.

Other areas can be developed but wells placed closer to the coast will increase the potential for saltwater intrusion.

Development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride (or electrical conductivity). Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

2. SOUTHERN CAMANO

Southern Camano has little potential for development of additional supplies. Approximately 1 to 2+ mgd may possibly be available for additional use but a) a large number of smaller wells (pumping at well under 50 gpm), properly placed at the center of the peninsula, with adequate spacing, and b) elimination many if not all existing coastal wells will be needed to maximize the additional development.

A. Principal Aquifers and Well Yields

Three of the five main aquifers in Island County have been identified in Southern Camano. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer E is present in the southern portion of the subarea only, lying at elevations of 100 to 200 feet above mean sea level. The saturated portion of the aquifer is typically 0 to 10 feet thick, which is usually too thin for drilled wells making it of little value for water supply use. The few wells that tap this aquifer are generally less than 75 feet deep. Yields from a properly designed and constructed well are generally much less than 50 gpm. There are insufficient data to estimate representative aquifer transmissivities.

Aquifer D appears to lie beneath all of Southern Camano but has insufficient saturated thickness to act as a main aquifer in the region. It lies at an elevation of 20 to 150 feet above mean sea level, at a depth of 100 to 200 feet. Our database contains no information on wells tapping this aquifer in Southern Camano. The sand and gravel deposits that comprise this unit are probably only partially saturated to a thickness of less than 10 feet. Wells finished in this aquifer are likely to have yields much less than 50 gpm. Transmissivity data are not available but estimated values are likely to be less than 1,000 gpd/ft.

Aquifer C forms the primary aquifer in the Southern Camano subarea. It lies from approximate sea level to 100 feet below sea level. Wells tapping this aquifer are generally 150 to 400 feet deep. The fine to medium sand aquifer has a typical saturated thickness of 30 to 60 feet. Theoretical maximum well yields are generally limited by static water levels that are near sea level such that most wells should not be pumped at more than 50 gpm. Many wells appear to have static water levels below sea level and therefore have theoretical yields of 0. Some of the wells have the physical capability of producing 100 gpm or more but only by lowering the pumping water level even more below sea level and increasing the potential for saltwater intrusion. Transmissivities are on the order of 3,000 to 20,000 gpd/ft.

No data are available on Aquifers A and B in the Southern Camano subarea. These aquifers may or may not be present. If so, their properties may be similar to those reported in other areas. The narrowness of the peninsula and their positions below sea level would make them unsuitable for major development because of the potential for saltwater intrusion.

B. Water Quality and Saltwater Intrusion

Southern Camano Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended state levels. Saltwater intrusion into freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron and/or manganese is not considered serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion has been observed in much of the subarea. Wells throughout the area have reported saltwater intrusion problems. Many wells in these areas not yet experiencing saltwater intrusion have reported water levels below mean sea level and therefore have the strong potential for saltwater intrusion in the future. These areas are outlined on Exhibit K-2. All wells in coastal areas have high potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and manganese problems are very common in the subarea with 43 percent of the 23 class I, II, III and IV wells in our database reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. Excessive iron and manganese do not appear to be associated with any specific location or aquifer as substandard water has been reported in both major aquifers at all parts of the subarea. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Southern Camano subarea.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Southern Camano subarea. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The lower end of the additional development range represents the amount that is very likely feasible while the upper end of the range may be possible but only with optimal well placement, verification through monitoring, and more detailed analysis.

(1) Recharge

A mass-balance analysis indicates that approximately 2 to 3 mgd recharge the groundwater system of Southern Camano Island. The analysis, shown in Subappendix K-A, is based on rainfall of 25 to 32 inches per year, runoff of approximately 0 to 3 percent of precipitation, and evapotranspiration of 18 to 20 inches per year. A lack of runoff is suggested by the absence of perennial and intermittent streams in the subarea. The 3 percent rate was used as a conservative factor. The recharge area on Southern Camano is estimated to range from 5 to 6 square miles.

(2) Existing Appropriation

A summation of existing water rights indicates that approximately 0.72 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells is likely to offset the non-inclusion of domestic wells as is explained in Section K-III.

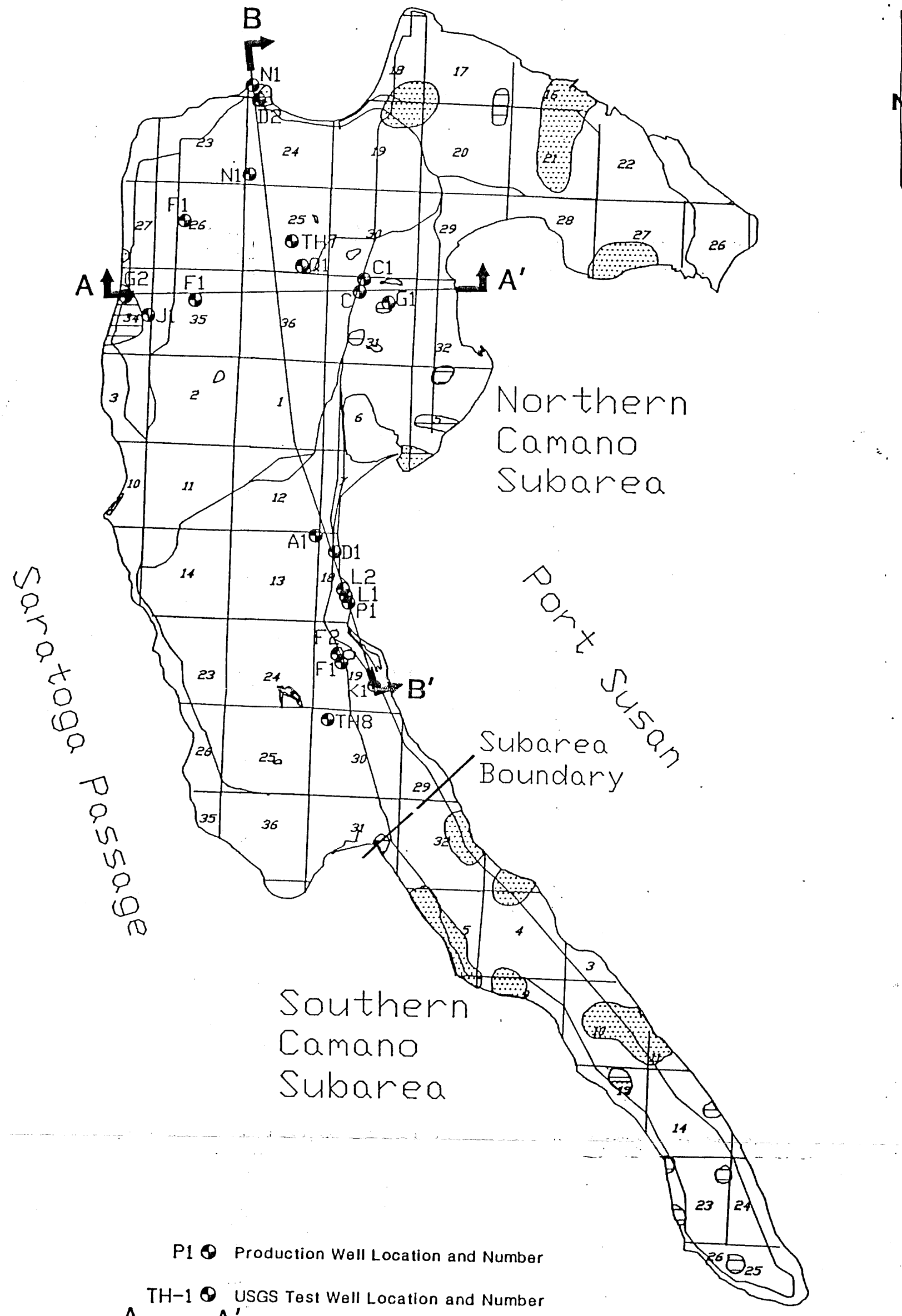
(3) Additional Use

The difference between recharge and use indicates that 1 to 2 mgd of unappropriated replenishment of groundwater storage may be available for additional development. Only a widely spaced network of low yield wells (much less than 50 gpm) is recommended to develop this additional supply. Aquifer C appears to have the only potential for this development and this zone may already be over-stressed by pumping concentrations that are not properly located. Many tens of wells will be needed to properly develop the remaining supply. The center portion (the "spine" of the peninsula) is the best location for development, as the potential for saltwater intrusion is probably at its lowest in this area. Other areas can be developed but wells placed closer to the coast will increase the potential for saltwater intrusion.

Development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

Well/Cross Section Location and Water Quality Map

Camano Island

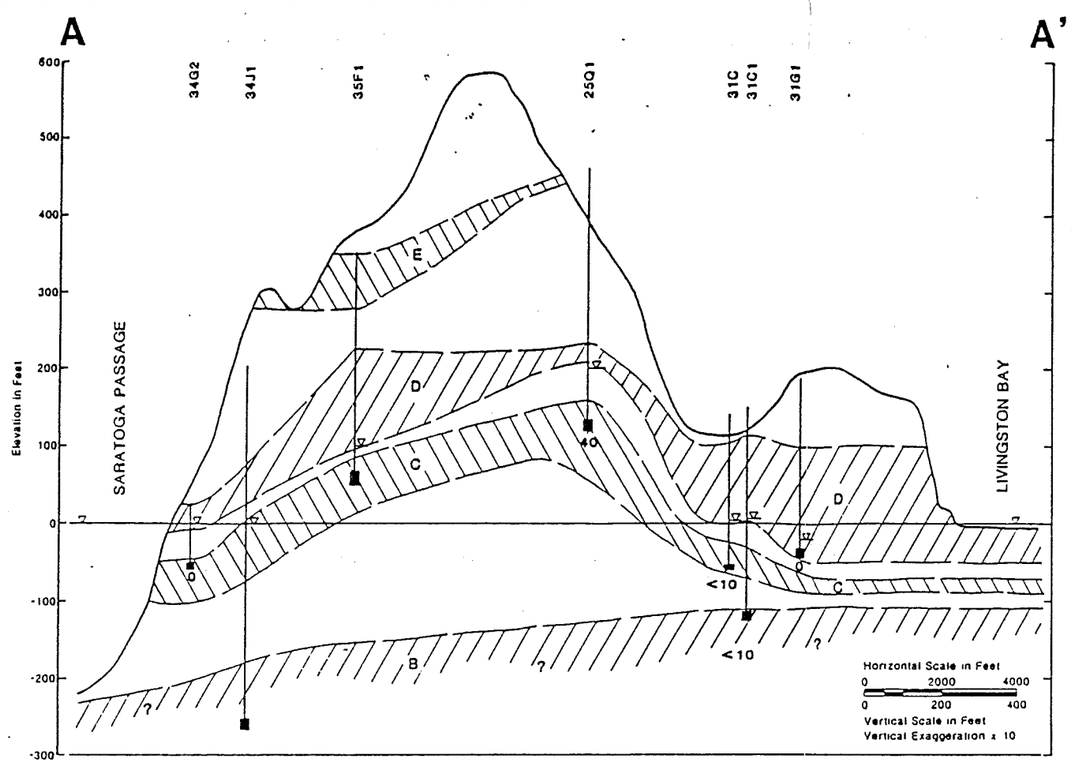


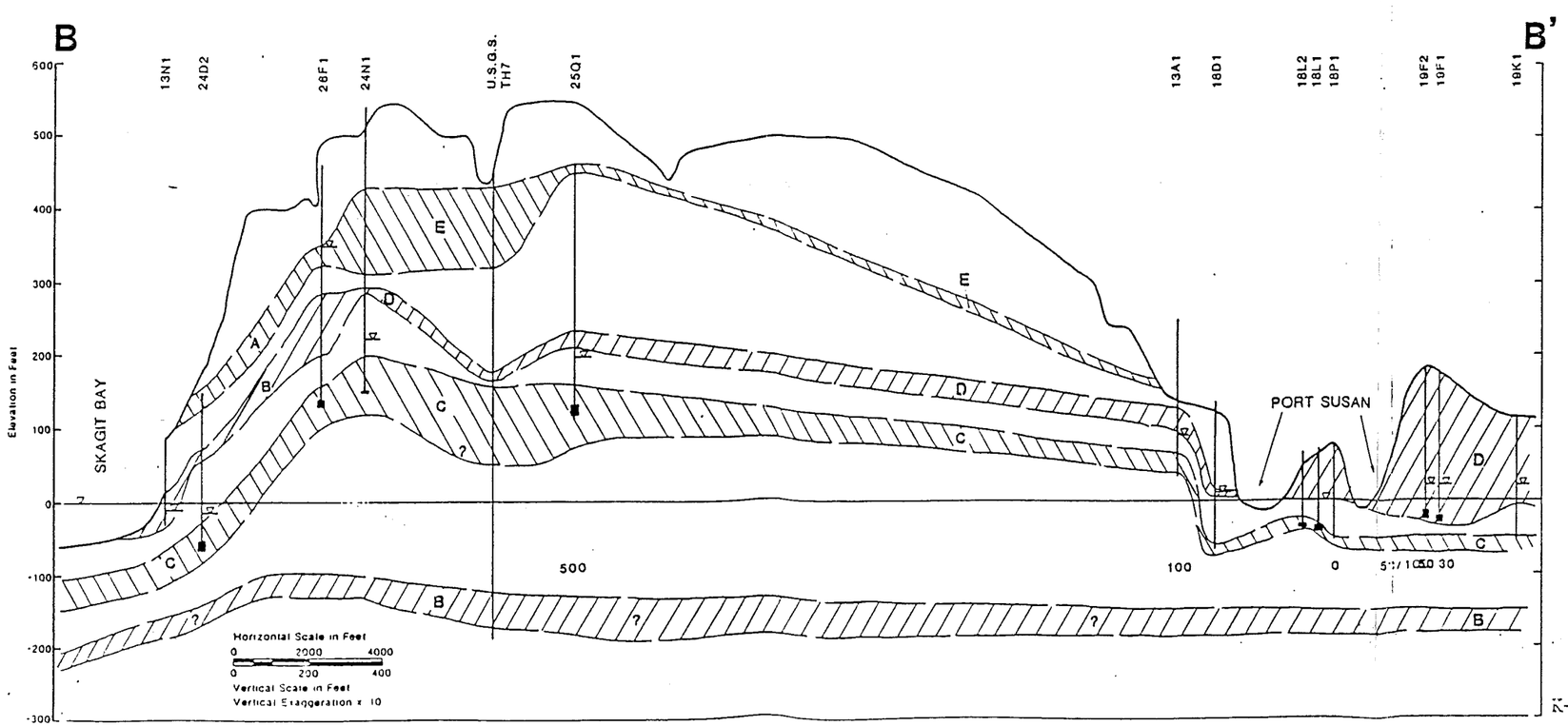
K-IV-8

Hart Crowser, Inc.
J-1939 9/87
Exhibit K-2

Hydrogeologic Cross Sections A-A' and B-B'

Camano Island





32Q3 — Well Number
Well Location
Water Level
Screened Section
100 — Theoretical Maximum One-week Well Yield in gpm

A — Aquifer Location and Designation

Note: Hydrogeologic Cross Sections were adapted from unpublished USGS Cross Sections.

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Exhibit K-3

SECTION K-V

NORTH WHIDBEY ISLAND

North Whidbey Island has unappropriated replenishment of storage (and therefore an upper bound of potential for development) of about 2 to 2-1/2 mgd of additional groundwater supply. All of this development should be planned for the Northern and Eastern subareas as the Southwestern subarea appears to be overappropriated at this time. No one area was identified as capable of supplying a major portion of this total. Rather a series of lower yield wells or well fields, distributed throughout the Eastern and Northern subareas, will be needed to maximize development.

North Whidbey has been divided into Northern, Eastern, and Southwestern subareas for the purpose of this report, based on topography and general groundwater divide. The boundaries between these subareas are not absolute, especially as far as deeper aquifers are concerned. Groundwater use in one subarea can affect groundwater flow and quantities available in adjacent subareas, thereby moving the "boundary." Quantities recommended for additional development are related to the total available for the entire North Whidbey area. Because the Southwestern subarea appears to be highly overappropriated, the recommendations for the other subareas may need reduction if over use in the Southwestern portion draws significant groundwater flow from beyond the indicated boundary.

The boundary for the Northern subarea runs approximately east-west through the low land from Dugualla Bay. The boundary between the Eastern and Southwestern subareas runs approximately northwest-southeast between Crescent Harbor and Ault Field. The subareas are shown on Exhibit K-1. Because the properties of the aquifers, representative well statistics, and water quality are different in each of the subareas, each is discussed below separately.

Summary data and assessments for North Whidbey Island are included in Table K-1, while well and cross section locations are shown on Exhibit K-4. Hydrogeologic cross sections are shown on Exhibit K-5.

1. NORTHERN NORTH WHIDBEY ISLAND

Northern North Whidbey has about 1/2 to 1 mgd of unappropriated replenishment of aquifer storage (and therefore an upper bound) of additional groundwater supplies of similar magnitude. The presence of shallow bedrock and lack of significant high yield zones indicates that a series of low yield wells (generally under 50 gpm) or well fields will be needed for full development. These wells will need to be located inland and require careful design and operation to minimize saltwater intrusion problems.

A. Principal Aquifers and Well Yields

Three of the five main aquifers in Island County have been identified in Northern North Whidbey Island. Each of these aquifers

is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer E is present beneath the east and center parts of the subarea. Our records do not include any wells that tap this aquifer as the sand that comprises the aquifer is mostly unsaturated. No doubt, some shallow domestic wells are completed in this aquifer but it does not act as a major water supply aquifer in the subarea. The aquifer lies at an elevation of 150 to 250 feet above mean sea level and is therefore not susceptible to saltwater intrusion. The few wells that tap this aquifer are probably in the range of 50 to 150 feet deep. Although the USGS reports that this aquifer is up to 30+ feet thick in some places, its usable, saturated thickness is under 10 feet. Well yields are probably on the order of 10 gpm, or less. Transmissivity data are not available but we estimate values of the order of a few 100 gpd/ft.

Aquifer D is one of the two main aquifer in the Northern North Whidbey subarea. It lies at an elevation of 50 to 200 feet above sea level and is not susceptible to saltwater intrusion. Wells tapping this aquifer are generally 50 to 200 feet deep. The aquifer typically has saturated water bearing zones of sand (and occasionally gravel) which are 10 to 20 feet thick. Theoretical maximum well yields are typically less than 50 gpm. No higher yield zones were located with our limited data base. Transmissivities are small, generally less than 5,000 gpd/ft.

Aquifer C is the other main aquifer in the subarea. It appears to lie beneath all of the Northern North Whidbey subarea except where bedrock outcrops or is near the surface, near Deception Pass. The aquifer lies at an elevation of 50 feet above to 50 feet below mean sea level. Wells tapping this aquifer are generally 75 to more than 200 feet deep. Water bearing zones in this aquifer are generally 10 to 30+ feet thick. Theoretical well yields are generally less than 50 gpm although some areas (such as the one identified in T33N/R2E Section 5) are capable of 100+ gpm. In many areas, static water levels near sea level limit available drawdown and therefore, well yield. Transmissivities are variable, ranging from less than 3,000 gpd/ft up to 20,000+ gpd/ft.

Aquifer B may be present beneath the Northern North Whidbey subarea but our database indicates that no wells have been drilled deep enough to encounter it. The USGS test wells drilled just to the south of the subarea reported Aquifer B at an elevation of 300 feet below sea level and its presence nearby indicates that it may also lie at a similar elevation beneath Northern North Whidbey. Its properties and possible distribution are not known.

Bedrock is likely to lie at relatively shallow depths beneath the subarea. It was reported in the USGS test well at elevations below 550 feet below mean sea level. Reported geologic faulting to the

south of the subarea boundary has brought bedrock to shallower depths and even surface exposure in the extreme north of the subarea near Deception Pass. Bedrock is not a good aquifer in the area and yields only domestic quantities of water to wells. Its shallow presence likely precludes Aquifer A beneath the Northern North Whidbey area.

B. Water Quality and Saltwater Intrusion

Northern North Whidbey Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended state levels. Saltwater intrusion into freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron and/or manganese is not as serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended state levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion is currently not a problem in the Northern North Whidbey subarea. Chloride levels exceeding 100 mg/L have not been reported in any of the wells in our database.

Saltwater intrusion has not occurred because groundwater use is relatively low, as is indicated by relatively high static water levels in Aquifer C. Only one well in our database has reported a groundwater level below mean sea level. Low hydraulic gradients and proximity to Skagit Bay make the Dugualla Bay area potentially susceptible to future saltwater intrusion, especially as groundwater use increases. The susceptible area is shown on Exhibit K-4. All wells in coastal areas have the potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and/or manganese problems are very common in the subarea with approximately 28 percent of the class I, II, III and IV wells in our database (25 wells for the subarea) reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. Excessive iron and manganese do not appear to be associated with any specific location or aquifer as substandard water has been reported in both major aquifers at all parts of the subarea. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Northern North Whidbey subarea.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Northern North Whidbey subarea. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The analysis indicated that

only 1/2 to 1 mgd are potentially available for additional development.

(1) Recharge

A mass-balance analysis indicates that approximately 1 to 1-1/2 mgd recharge the groundwater system of the Northern North Whidbey area. The analysis, shown in Subappendix K-A, is based on rainfall of 19 to 22 inches per year, runoff of approximately 0 to 3 percent of precipitation, and evapotranspiration of 16.5 to 18.5 inches per year. Runoff is probably close to zero but may approach a few percent of precipitation because of the bedrock in the northern part of the subarea. The recharge area on Northern North Whidbey is estimated to be from 9 to 11 square miles.

(2) Existing Appropriation

A summation of existing water rights indicates that approximately 0.44 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as is explained in Section K-III.

(3) Additional Use

The difference between recharge and appropriation indicates that a small amount, 1/2 to 1 mgd, of additional groundwater may be available for development. This water is best developed from individual wells with yields of 50 gpm or less, or small well fields, located inland at least one mile from the coast and completed in Aquifers C and D. No major high yield areas were identified or are recommended for the additional supply development.

All new development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

2. EASTERN NORTH WHIDBEY ISLAND

Eastern North Whidbey may have potential for development of 1 to 1-1/2 mgd of additional groundwater supplies. Many tens of smaller wells (locally to 100+ gpm, but typically under 50 gpm), located inland at least one mile from the coast, properly spaced, will be needed to maximize the additional development. Full development will likely

require abandonment of coastal wells and replacement by inland, optimally located new wells.

A. Principal Aquifers and Well Yields

Four of the five main aquifers in Island County appear to lie beneath Eastern North Whidbey Island. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer E is present throughout much of the subarea, although it appears to be thin and discontinuous. Aquifer E wells are typically 30 to 150 feet deep and tap mostly sand deposits with a saturated thickness that varies from 0 to about 20 feet thick. The aquifer lies from 250 feet above mean sea level to sea level. Well yields are typically less than 50 gpm. Transmissivity data indicate typical values of less than 5,000 gpd/ft.

Aquifer D is present beneath all of the subarea. It comprises the second most important aquifer in the eastern North Whidbey subarea. The aquifer lies at an elevation from 200 feet above mean sea level to sea level, making saltwater intrusion possible in the coastal areas along Crescent Harbor where it is lowest. The wells tapping this aquifer are typically 50 to 200 feet deep. The saturated, water bearing zones in this aquifer are typically 0 to 20 feet thick. Theoretical maximum well yields are typically less than 50 gpm although a few localized zones can produce 100+ gpm. Transmissivities are generally less than 5,000 gpd/ft.

Aquifer C forms the main aquifer in the Eastern North Whidbey subarea. It lies at an elevation of 150 feet above to 200 feet below sea level. The wide range in elevations is likely the result of a complex history of glacial erosion and deposition. Wells tapping this aquifer are generally 150 to 300 feet deep. The aquifer consists of fine to medium sand with occasional gravel zones and has a typical saturated thickness of 10 to 40 feet. Theoretical maximum well yields are typically less than 50 gpm but in areas with high static water levels (such as the center uplands) yields of 100+ gpm are possible because of relatively high available drawdown. Transmissivity data are insufficient for evaluation, but based on similar deposits in other areas, we estimate a range of 5,000 gpd/ft to 30,000+ gpd/ft.

Aquifer B has been reported in two deep wells drilled in the subarea. The aquifer appears to lie at elevations of 100 to 200 feet below mean sea level. Wells tapping this aquifer are generally 350 to more than 450 feet deep. Water bearing zones in this aquifer appear to be small, under 10 feet thick. Theoretical well yields are unknown but likely to be less than 50 gpm as static water levels near sea level are often the limiting factor. Transmissivities may be small, under 5,000 gpd/ft, as the aquifer appears to have thin

(10 feet or so) water bearing zones, of only low to moderate permeability.

Aquifer A may not be present beneath the Eastern North Whidbey area. It was not observed in the 850-foot USGS test well, drilled to an elevation of 440 feet below sea level in the middle of the subarea. The properties and possible distribution of the aquifer are not known.

B. Water Quality and Saltwater Intrusion

Eastern North Whidbey Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended state levels. Saltwater intrusion into fresh water supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron and/or manganese is not considered serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended state levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion is not a major problem within the Eastern North Whidbey subarea. Only one well in our database indicates saltwater intrusion and this is located at Davis Landing. There are also several wells in the subarea, not yet experiencing saltwater intrusion but reporting water levels below mean sea level. These wells have the potential for saltwater intrusion in the future, especially as groundwater use increases. These areas all lie near coastal areas, between Strawberry and Polnell Points. The potential intrusion areas are outlined on Exhibit K-4. All wells in coastal areas have the potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and manganese concentrations exceeding recommended state standards appear to be typical of those throughout the County. A total of 11 out of 33 (or about 32 percent) of the class I, II, III and IV wells in our database reported iron and/or manganese exceeding the State Recommended Drinking Water Standard. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Eastern North Whidbey subarea and are not considered health hazards.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Eastern North Whidbey subarea. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The lower end of the

additional development range represents the amount that is very likely feasible while the upper end of the range may be possible but only with optimal well placement (including abandonment of most, if not all, coastal wells), verification through monitoring, and more detailed analysis.

(1) Recharge

A mass-balance analysis indicates that approximately 2 to almost 2-1/2 mgd recharge the groundwater system of the Eastern North Whidbey subarea. The analysis, shown in Subappendix K-A, is based on rainfall of 21 to 24 inches per year, runoff of approximately 0 to 5 percent of precipitation, and evapotranspiration of 18 to 20 inches per year. No perennial and only a few intermittent streams are mapped for the area so runoff may not be significant. There are, however, several swamps and ponds in the area and these may play a role in runoff generation by producing near-surface, saturated, soil areas that can generate runoff during the wetter times of the year. In order not to overestimate recharge we have added a conservative runoff factor of 3 percent of precipitation for the subarea. The recharge area on Eastern North Whidbey is estimated to be about 15 to 18 square miles.

(2) Existing Appropriation

A summation of existing water rights indicates that approximately 0.86 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as is explained in Section K-III.

(3) Additional Use

The difference between recharge and use indicates that 1 to 1-1/2 mgd of unappropriated replenishment of storage may be available for additional development. Many low yield wells will be needed to develop this additional supply. Localized, higher yield wells (100+ gpm) may be possible from Aquifer C in the central part of the subarea where static water levels are higher, although exploration will be needed to define these zones. The preferred location for additional wells is at least one mile or more from the coast. Aquifer D has some potential for additional development but well yields are likely to be low, under 50 gpm.

Since well yields are typically less than 50 gpm, many tens of wells will be needed. Where higher yield wells of 100+

gpm can be established, somewhat fewer wells will be needed. Development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

3. SOUTHWESTERN NORTH WHIDBEY ISLAND

Southwestern North Whidbey appears to have little potential for development of additional groundwater supplies as appropriations exceed the estimated recharge by as much as seven times. This ratio may be an overestimate as all of the appropriated water may not be consumed. Over-appropriations of this magnitude are likely to worsen the already considerable saltwater intrusion problems, if pumping continues at these high rates.

A. Principal Aquifers and Well Yields

All five of the main aquifers in Island County have been identified in Southwestern North Whidbey subarea. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer E is present beneath most the subarea. The sand and gravel that comprise the aquifer is mostly unsaturated and is tapped by only a few domestic wells. Although the USGS reports that this aquifer is over 90 feet thick in some places it appears to have saturated thickness of only 0 to 10 feet. The aquifer lies at an elevation of 150 to 50 feet above mean sea level and is not susceptible to saltwater intrusion. The few wells tapping this aquifer are typically less than 100 feet deep. Well yields are typically less than 50 gpm although higher yields of 100+ gpm are feasible at locations in the Oak Harbor area. Transmissivity data are limited but representative values are likely to be less than 1,000 gpd/ft.

Aquifer D is present beneath all of the subarea and forms one of the main aquifers, especially in the west. The sand and occasional gravel that comprise the aquifer are only partly saturated. Saturated, water bearing zones are typically only 5 to 20 feet thick. The aquifer lies at an elevation from 100 feet above mean sea level to sea level. Wells tapping this aquifer are typically 150 to 250 feet deep. Well yields are typically less than 50 gpm because of limited available drawdown but can exceed 100 gpm locally. Transmissivities range from under 5,000 gpd/ft to over 45,000 gpd/ft.

Aquifer C is the other main aquifer in the Southwestern North Whidbey subarea. It lies at an elevation of just about sea level to 250 feet below mean sea level. Wells tapping this aquifer are

generally 200 to 300 feet deep. The aquifer typically has saturated water bearing zones of sand and gravel from 20 to 50 feet thick. Theoretical maximum well yields are typically less than 50 gpm and are limited by static water levels that are near sea level in some areas, especially near the coast. Yields of 250+ gpm are possible in localized areas of higher transmissivity such as northwest of Oak Harbor (T32N/R1E parts of Sections 27, 33, and 34). Transmissivities are variable with values ranging from 1,000 gpd/ft to 30,000+ gpd/ft.

Aquifer B may lie beneath most, if not all, of the Southwest North Whidbey subarea. Only a few wells are completed in Aquifer B, but several deep wells have verified its presence and indicated its properties throughout the area, e.g., USGS test well drilled near the Ault Field, as well as a few supply wells in the area. The aquifer typically lies at an elevation of 250 to 400 feet below mean sea level. Wells tapping this aquifer are generally 300 to 500 feet deep. Water bearing zones in this aquifer are discontinuous and up to 40 feet thick. Theoretical well yields are generally less than 50 gpm as transmissivities are less than 5,000 gpd/ft and water levels are close to sea level, limiting available drawdown.

Aquifer A is probably present beneath the Southwestern North Whidbey subarea as it was observed in the two USGS test wells drilled in the area. Its properties and possible distribution are not known as no hydrologic testing was conducted on this aquifer in these wells.

B. Water Quality and Saltwater Intrusion

Southwestern North Whidbey Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended state levels. Saltwater intrusion into freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron or manganese is not considered as serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended state levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion is currently a problem in much of the coastal and some inland areas of all sea level and below aquifers in the Southwestern North Whidbey subarea. Chloride levels exceeding 100 mg/L were reported in many wells along the coast, especially along the west coast and along the entrance to Penn Cove (Exhibit K-5). Saltwater intrusion has already begun at these coastal locations and may exist at other areas not covered in our database. Continued over pumping as is indicated in the recharge-use analysis will probably exacerbate the situation producing more saltwater intrusion.

There are also several wells in the subarea, not yet experiencing saltwater intrusion but reporting water levels below mean sea level. These wells have the potential for saltwater intrusion in the future, especially as groundwater use increases. These areas all lie near coastal areas and are outlined on Exhibit K-4.

All wells in coastal areas have the potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and/or manganese problems are very common in the subarea with approximately 40 percent of the class I, II, III and IV wells in our database of 87 wells reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. Excessive iron and manganese do not appear to be associated with any specific location or aquifer as substandard water has been reported in both major aquifers at all parts of the subarea. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Southwestern North Whidbey subarea.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Southwestern North Whidbey subarea. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The analysis indicated that no additional supplies are available for this subarea as apparent use already exceeds recharge.

(1) Recharge

A mass-balance analysis indicates that approximately 1 to 1-1/2 mgd recharge the groundwater system of the Southwestern North Whidbey subarea. The analysis, shown in Subappendix K-A, is based on rainfall of 16 to 20 inches per year, runoff of approximately 0 to 5 percent of precipitation, and evapotranspiration of 15 to 18 inches per year. Runoff is probably close to zero but may approach a few percent as indicated by the intermittent streams and swampy areas mapped in the subarea. The recharge area on Southwestern North Whidbey is estimated to range from 21 to 24 square miles.

(2) Existing Appropriation

A summation of existing water rights indicates that approximately 7.76 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as is explained in

Section K-III. If not, then this use estimate may be too high.

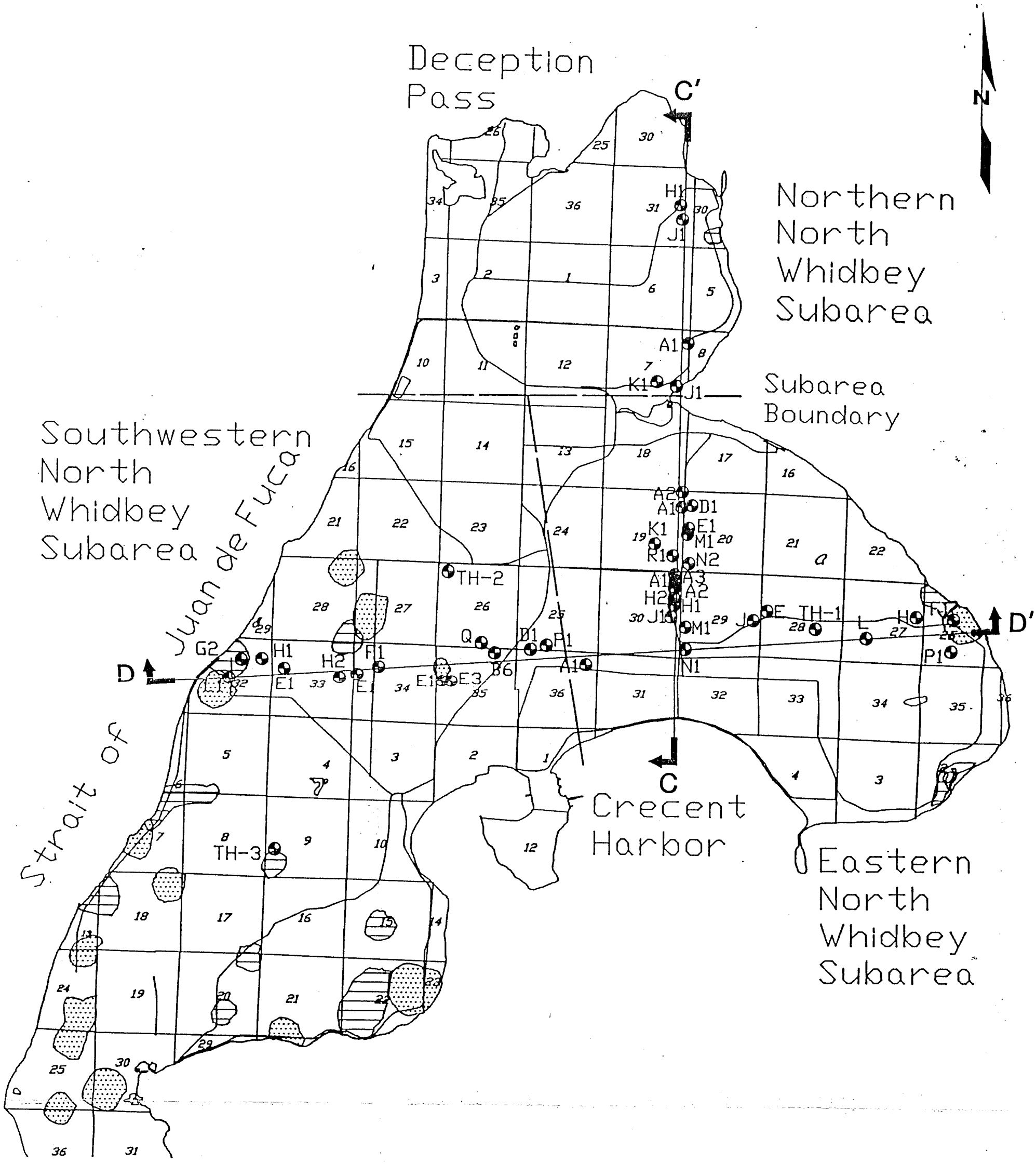
(3) Additional Use

The difference between recharge and appropriation indicates that no additional groundwater may be available for development. The current appropriations are as much as seven times the estimate for recharge. If all the appropriated water is consumed at the registered rate then water will be removed from the system at a rate far greater than replenishment. Such removal will likely cause increased saltwater intrusion, a condition that already exists in many parts of the subarea.

Any new development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

Well/Cross Section Location and Water Quality Map

North Whidbey Island



K-V-12

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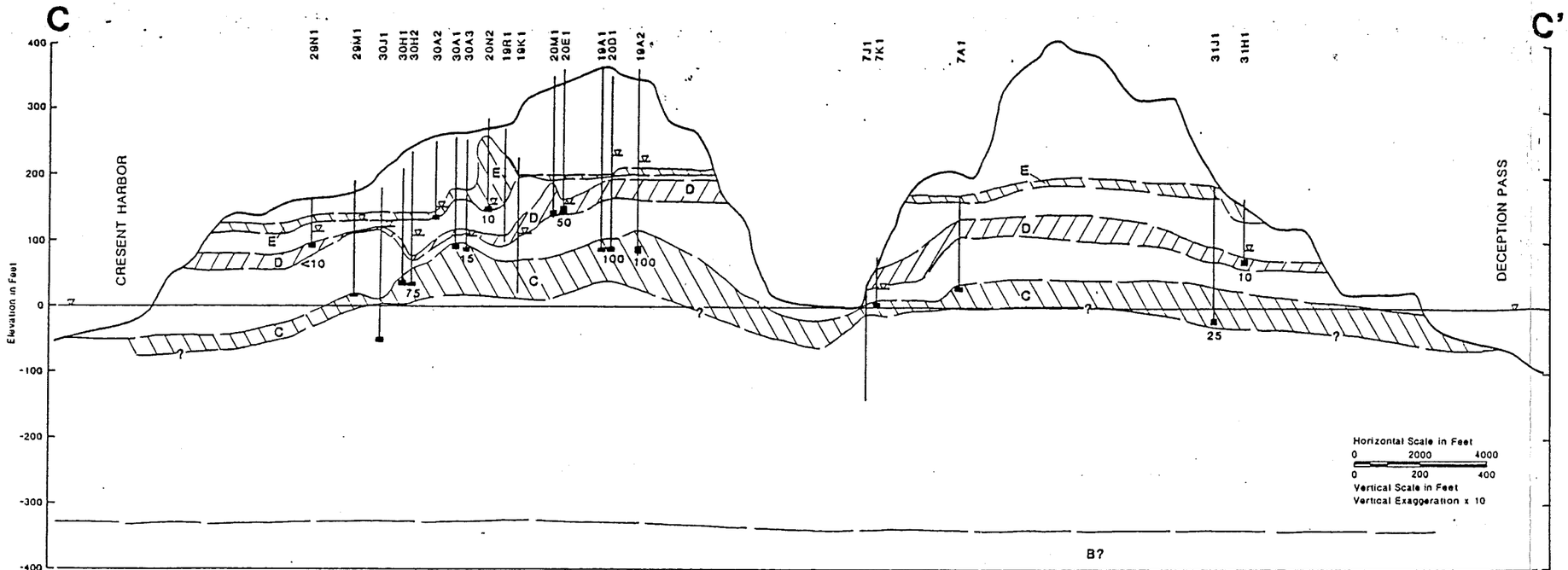
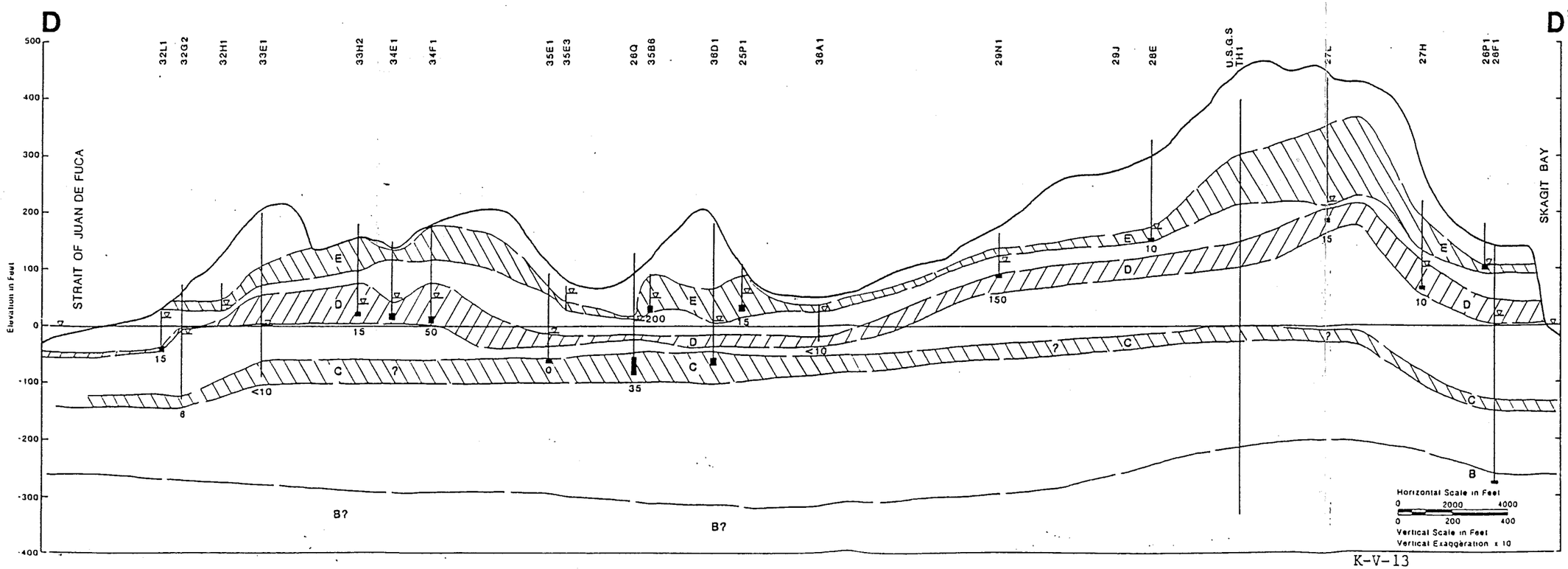
Exhibit K-4

Hydrogeologic Cross Sections C-C' and D-D'

North Whidbey Island





12H1 Well Number
Well Location
Water Level
Screened Section
50 Theoretical Maximum One-week Well Yield in gpm
A Aquifer Location and Designation

Note: Hydrogeologic Cross Sections were adapted from unpublished USGS Cross Sections.

Hart Crowser, Inc.
J-1939 9/87
Exhibit K-5

SECTION K-VI

CENTRAL WHIDBEY ISLAND

Central Whidbey Island has potential for only limited development. The estimated unappropriated replenishment of groundwater storage is about 0 to 2+ mgd. This range defines the upper bound of additional groundwater supply. Any development should be planned for the Southern subarea as the Northern subarea appears to be over appropriated at this time. No one portion of the Southern subarea of Central Whidbey appears capable of supplying a major portion of this total. Rather a series of lower yield wells or well fields, distributed throughout the center of the Southern Central Whidbey isthmus will be needed to maximize development.

The Central Whidbey region has been divided into Northern and Southern subareas for the purpose of this report, based on topography and general groundwater divide. The boundary runs approximately east-west from Admiralty Bay to Saratoga Passage, at the top of the narrow isthmus at Sections 19 and 20 in T31N/R2E. This boundary is shown on Exhibit K-1. Because the properties of the aquifers, representative well statistics, and water quality are different in each of the subareas, each is discussed below separately.

Summary data and assessments for Central Whidbey Island are included in Table K-1, while well and cross section locations are shown on Exhibit K-6. Hydrogeologic cross sections are shown on Exhibit K-7.

1. NORTHERN CENTRAL WHIDBEY ISLAND

Northern Central Whidbey appears to have little potential for development of additional groundwater supplies as appropriations exceed the estimated recharge by as much as two times. A few additional wells may possibly be located at the southern end of the subarea for a small additional yield but careful design and operation will be necessary to minimize additional saltwater intrusion problems.

A. Principal Aquifers and Well Yields

Four of the five main aquifers in Island County have been identified in Northern Central Whidbey subarea. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer D is present beneath the east and far west parts of the subarea. The sand and gravel that comprise the aquifer are mostly unsaturated. It is tapped by only a few wells. The USGS reports that this aquifer is over 90 feet thick in some places and is present beneath much of Northern Central Whidbey, but our analysis indicates that it is only saturated to a thickness of 0 to 40 feet. The aquifer lies at an elevation of 50 feet above to 50 feet below

mean sea level. The few wells tapping this aquifer are typically 150 to 250 feet deep. Well yields are typically less than 50 gpm.

Transmissivity data are not available but representative values are likely to be on the order of a few 1,000 gpd/ft.

Aquifer C is the main aquifer in the Northern Central Whidbey subarea. It lies at an elevation of 10 feet above to 100 feet below mean sea level. Wells tapping this aquifer are generally 200 to 300 feet deep. The aquifer typically has saturated water bearing zones of sand (and occasionally gravel) up to 20 feet thick. Theoretical maximum well yields are typically less than 50 gpm and are limited by static water levels that are near sea level in some areas, especially near the coast. Yields of 100+ gpm are possible in localized areas of higher transmissivity such as near the central part of subarea near the Coupeville Naval Air field. Transmissivities are variable with values ranging from 1,000 gpd/ft to 30,000 gpd/ft.

Aquifer B appears to lie beneath most, if not all, of the Northern Central Whidbey subarea. Only a few wells are completed in Aquifer B, but several deep wells have verified its presence and properties, throughout the area. The USGS test well drilled near the Naval Air field as well as a few supply wells in the area indicated that this aquifer is present. The aquifer typically lies at an elevation of 100 to 200 feet below mean sea level. Wells tapping this aquifer are generally 350 to 450 feet deep. Water bearing zones in this aquifer are generally thin, less than 10 feet thick. Theoretical well yields are generally less than 50 gpm as transmissivities are less than 5,000 gpd/ft and water levels are close to sea level, limiting available drawdown.

Aquifer A is probably present beneath the Northern Central Whidbey subarea as it was observed in the USGS test wells drilled in the area. Its properties and possible distribution are not known.

B. Water Quality and Saltwater Intrusion

Northern Central Whidbey Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended state levels. Saltwater intrusion into freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron and/or manganese is not as serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the state recommended state levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion has been reported in many coastal areas of sea level and below aquifers in the Northern Central Whidbey subarea.

Chloride levels exceeding 100 mg/L were reported in many wells along the coast, especially along Saratoga Passage between Harrington and Race Lagoons, along Penn Cove near Coupeville, and along Admiralty Bay near the ferry terminal. Saltwater intrusion has already begun at these coastal locations and may exist at other areas not covered in our database. Continued over pumping as is indicated in the recharge-use analysis will further degrade the situation.

There are also several wells in the subarea, not yet experiencing saltwater intrusion but reporting water levels below mean sea level. These wells have the potential for saltwater intrusion in the future, especially as groundwater use increases. These areas all lie near coastal areas and are outlined on Exhibit K-6.

All wells in coastal areas have the potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and manganese problems are very common in the subarea with approximately 30 percent of the class I, II, III and IV wells in our data base (of 27 wells) reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. Excessive iron and manganese do not appear to be associated with any specific location or aquifer as substandard water has been reported in both major aquifers at all parts of the subarea. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Northern Central Whidbey subarea.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Northern Central Whidbey subarea. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The analysis indicated that no additional supplies are available for this subarea but some small amounts may be possible but verification through monitoring and more detailed analysis will be necessary.

(1) Recharge

A mass-balance analysis indicates that approximately 1 to 1-1/2 mgd recharge the groundwater system of the Northern Central Whidbey subarea. The analysis, shown in Subappendix K-A, is based on rainfall of 17 to 21 inches per year, runoff of approximately 0 to 3 percent of precipitation, and evapotranspiration of 18 to 20 inches per year. The range of precipitation is based on the uncertainty of the rainfall data for the area (see Section K-III). Runoff is probably close to zero but may approach a few percent as indicated by the perennial and intermittent streams mapped in the

subarea. The recharge area on Northern Central Whidbey is approximately 19 to 22 square miles.

(2) Existing Appropriation

A summation of existing water rights indicates that approximately 2.36 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as is explained in Section K-III.

(3) Additional Use

The difference between recharge and appropriation indicates that no additional groundwater may be available for development. The current appropriations are one to two times the estimate for recharge. If all the appropriated water is consumed at the registered rate then groundwater will be removed from the system at a rate greater than replenishment. Such removal will likely cause increased saltwater intrusion, a condition that already exists in many parts of the subarea.

All new development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

2. SOUTHERN CENTRAL WHIDBEY ISLAND

Southern Central Whidbey may have potential for development of 0 up to 2 mgd of additional groundwater supplies. A large number of smaller wells (locally to 100+ gpm, but typically under 50 gpm), properly placed along the central uplands of the isthmus that comprise the subarea, will be needed to maximize the additional development. In addition, existing coastal wells may have to be replaced by inland wells to realize full development.

A. Principal Aquifers and Well Yields

All five of the main aquifers in Island County appear to lie beneath Southern Central Whidbey subarea. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer E is present throughout much of the subarea, in the upland areas. It is tapped by only a few wells and these are used

primarily for domestic purposes. Aquifer E wells are typically less than 50 feet deep and tap mostly sand deposits with a saturated thickness of less than 10 feet. The aquifer lies at 150 feet or more above mean sea level. Well yields are typically less than 50 gpm. Transmissivity data are not available but based on the nature of the aquifer, typical values are likely to be on the order of a few 1,000 gpd/ft.

Aquifer D is present beneath much of the subarea. The aquifer lies at an elevation of 150 to 80 feet above mean sea level, making saltwater intrusion within this aquifer impossible. The wells tapping this aquifer are typically 100 to 200 feet deep. The saturated, water bearing zones in this aquifer are typically under 20 feet thick in the south and east part of the subarea, while it is generally unsaturated in the southwest, between Lagoon Point and Mutiny Bay. Well yields are typically less than 50 gpm. Transmissivities are insufficient to quantify but are likely to be less than 5,000 gpd/ft.

Aquifer C forms the main aquifer in the Southern Central Whidbey subarea. It lies at an elevation of 50 feet above to 80 below mean sea level. Wells tapping this aquifer are generally 150 to 300 feet deep. The aquifer consists of fine to medium sand with occasional gravel zones and has a typical saturated thickness of 10 to 40 feet. Theoretical maximum well yields are typically less than 50 gpm and are limited by static water levels that are near sea level along most of the coastal areas. Several areas with localized theoretical yields of 250+ gpm were located indicating that local yields of 250+ gpm are possible in areas of higher transmissivity. Current higher yield areas lie in a small area near the southern Holmes Harbor area (T30N/R2E Section 33 and T2 9N/R2E Section 3) and near Lagoon Point (T30N/R2E Section 19) but concentrating heavy development in these coastal areas may induce saltwater intrusion. Transmissivities are variable with values ranging from less than 1,000 gpd/ft up to 60,000+ gpd/ft

Aquifer B is discontinuous but present beneath much of the Southern Central Whidbey subarea. The aquifer typically lies at an elevation of 100 to 200 feet below mean sea level. Wells tapping this aquifer are generally 300 to more than 400 feet deep. Water bearing zones in this aquifer are up to 40 feet thick but can be saline. Several wells were abandoned or pulled back to shallower depths because of saline water. Theoretical well yields are generally less than 50 gpm as static water levels near sea level are often the limiting factor. In many locations, static levels are below sea level indicating that theoretical yields are zero. Transmissivities are small with reported values of 100 gpd/ft to 3,000 gpd/ft.

Aquifer A may be present beneath the Southern Central Whidbey subarea. It was observed in the only deep well (below an elevation of 300 feet below sea level) drilled in the subarea. Its properties and possible distribution are not known.

B. Water Quality and Saltwater Intrusion

Southern Central Whidbey Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended levels. Saltwater intrusion into freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron and/or manganese is not as serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended state levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion is currently a problem in several parts of the Southern Central Whidbey subarea, which have already experienced chloride levels exceeding 100 mg/L. The area reporting the most widespread intrusion is near Greenbank, from a mile or so north to Dines point, along the coast up to almost a mile inland. Most wells reporting this condition are finished in Aquifer C. Other areas to report saltwater intrusion lie along the coast on the Admiralty Inlet side, north and south of Lagoon Point. These areas are shown on Exhibit K-6.

There are also several wells in the subarea, not yet experiencing saltwater intrusion but reporting water levels below mean sea level. These wells have the potential for saltwater intrusion in the future, especially as groundwater use increases. These areas all lie near coastal areas. The potential intrusion areas are outlined on Exhibit K-6. All wells in coastal areas have the potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and manganese problems appear to be less common in the subarea (compared to other areas and subareas) with only 8 percent of the class I, II, III and IV wells in our database (25 wells) reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. The apparent lower concentration levels of iron and manganese many be coincidental as a larger database could present a different picture. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Southern Central Whidbey subarea and are not considered health hazards.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Southern Central Whidbey area. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing use equals the maximum amount available for additional development under optimal conditions. The lower end of the additional development range represents the amount that is very likely feasible while the upper

end of the range may be possible but only with optimal well placement (including replacement of many coastal wells), verification through monitoring, and more detailed analysis.

(1) Recharge

A mass-balance analysis indicates that approximately 1 to 3+ mgd recharge the groundwater system of the Southern Central Whidbey subarea. The analysis, shown in Subappendix K-A, is based on rainfall of 20 to 25 inches per year, runoff of approximately 3 to 7 percent of precipitation, and evapotranspiration of 18 to 20 inches per year. The large range of precipitation is based on the uncertainty and contradictory nature of the rainfall data for the area (see Section K-III). Runoff is indicated by the perennial and intermittent streams in the subarea. The recharge area on Southern Central Whidbey is estimated to range from 20 to 23 square miles.

(2) Existing Appropriation

A summation of existing water rights indicates that approximately 1.12 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as is explained in Section K-III.

(3) Additional Use

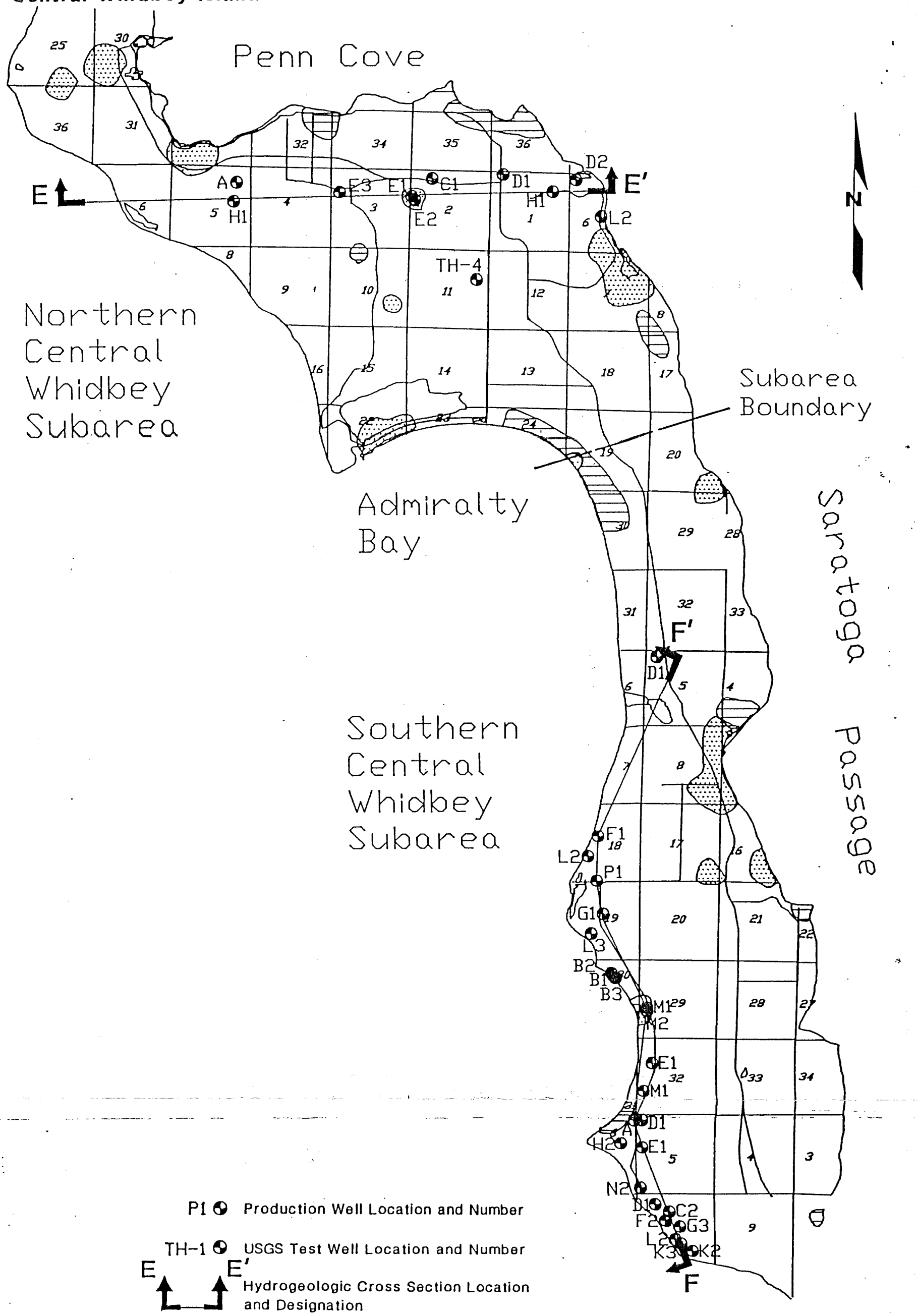
The difference between recharge and appropriation indicates 0 to 2+ mgd of replenishment to groundwater storage is currently unappropriated. This range defines the upper bounds of groundwater that may be available for additional development. Many low yield wells will be needed to develop this additional supply. Localized, higher yield wells (250+ gpm) are possible although exploration will be needed to define these zones. Aquifer C has the best potential for additional development, however, care will be required to minimize saltwater intrusion, as much of this aquifer lies below sea level. The preferred location for additional wells is along the center portion of the upland areas, at least one mile or more from the coast. Aquifer B does not appear to have good potential for additional development as saltwater intrusion and/or water levels near or below sea level are reported at many locations.

Since well yields are typically less than 50 gpm, many tens of wells will be needed. Where higher yield wells of 250+ gpm can be established, fewer wells will be needed. The

higher yield areas described above are not recommended for heavy development as saltwater intrusion may result. Rather, test well drilling in the central upland parts of the isthmus is recommended to located and assess high yield areas with lower potential for saltwater intrusion. Development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

Well/Cross Section Location and Water Quality Map

Central Whidbey Island



P1 Production Well Location and Number

TH-1 USGS Test Well Location and Number

E E' Hydrogeologic Cross Section Location and Designation

Area with One or More Wells with Water Levels Below Mean Sea Level

Area with One or More Wells Indicating Saltwater Intrusion (Cl ≥ 100 ppm)

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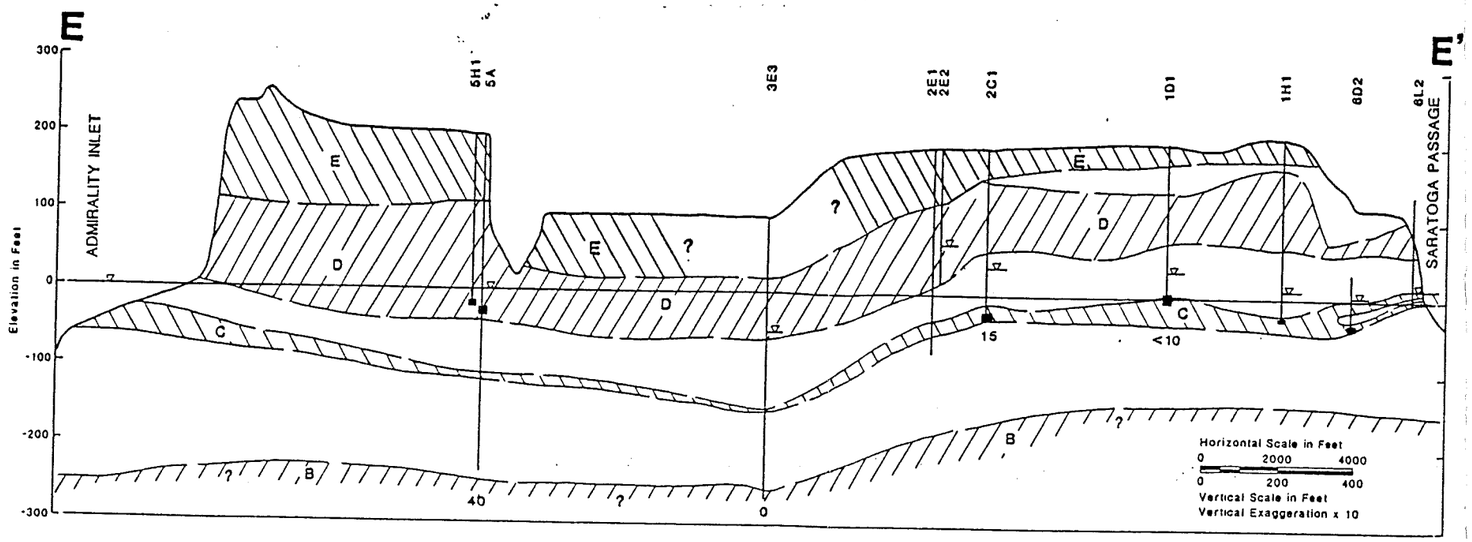
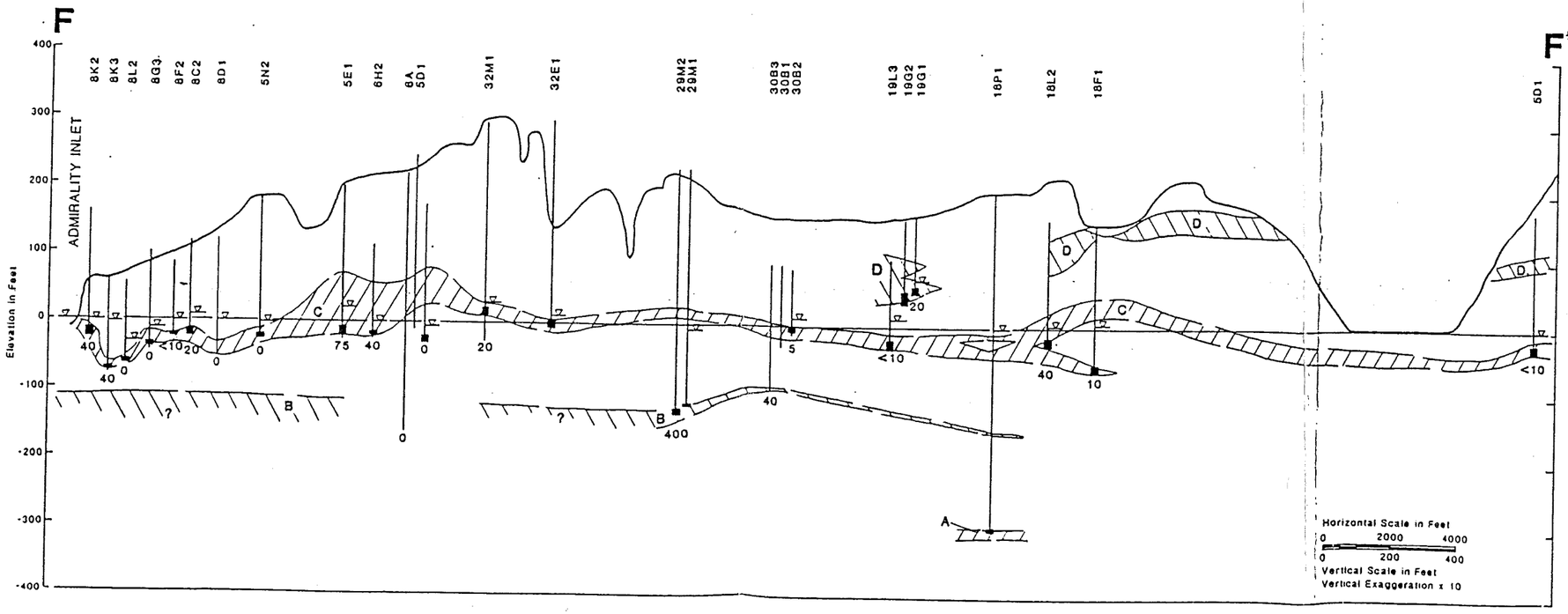
Exhibit K-6

Hydrogeologic Cross Sections E-E' and F-F'

Central Whidbey Island





10C2 Well Number
Well Location
Water Level
Screened Section
10 Theoretical Maximum One-week Well Yield in gpm

A Aquifer Location and Designation

Note: Hydrogeologic Cross Sections were adapted from unpublished USGS Cross Sections.

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Exhibit K-7

SECTION K-VII

SOUTH WHIDBEY ISLAND

South Whidbey Island has good potential for additional development. Currently, there appears to be an unappropriated replenishment of aquifer storage of about 21 to 34 mgd. This range defines the upper bound of additional groundwater supply. No one area appears capable of supplying a major portion of this total. Lesser portions of the total available for additional development can be produced from a series of wells or well fields distributed throughout South Whidbey Island. Full development will require optimal well placement which will include abandonment of some coastal wells.

The South Whidbey region has been divided into Northwestern and Southeastern subareas for the purpose of this report, based on topography and general groundwater divide. The boundary runs approximately from Useless Bay, through Lone Lake to the northeast corner of T30N/R3E Section 32. This boundary (shown on Exhibit K-1) is less defined than those separating the major regions and some of the subareas. Therefore, the separate quantities available for additional development in each subarea (discussed below) are not independent. Rather, the sum of these quantities is fixed and the distribution of additional water in each subarea can be reduced if heavy development occurs in the adjacent subarea. Because the properties of the aquifers, representative well statistics, and water quality are different in each of the subareas, each is discussed below separately.

Summary data and assessments for South Whidbey Island are included in Table K-1, while well and cross section locations are shown on Exhibit K-8. Hydrogeologic cross sections are shown on Exhibit K-9.

1. NORTHWESTERN SOUTH WHIDBEY ISLAND

Northwestern South Whidbey has good potential for development of additional supplies. Approximately 5 to 11+ mgd of unappropriated replenishment to groundwater storage may be available. A large number, perhaps 60 to 100 or more, of smaller wells (locally to 100+ gpm, but typically under 50 gpm), properly placed inland (preferably at least one mile) with adequate spacing, will be needed to maximize the additional development. The central portion of the subarea is likely best for placement of well fields for a small scale regional supply.

A. Principal Aquifers and Well Yields

Three of the five main aquifers in Island County have been identified in the Northwestern South Whidbey subarea. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer D is present in the eastern part of the subarea only, where it is thin and discontinuous. The USGS reports that this aquifer is present beneath much of Northwestern South Whidbey subarea, however, it appears to be unsaturated in all but the area tapped by the few wells that lie in the very northern portion of the subarea near Rocky Point. These wells are typically less than 100 feet deep. In this area it appears to be saturated to a thickness of less than 10 feet. The aquifer lies at an elevation of 250 to 75 feet above mean sea level. Well yields are typically less than 50 gpm. Transmissivity data are not available but representative values are likely to be on the order of a few 1,000 gpd/ft.

Aquifer C is the main aquifer in the Northwestern South Whidbey subarea. It lies at an elevation of 75 feet above to 50 feet below mean sea level. Wells tapping this aquifer are generally 150 to 300 feet deep. The aquifer typically has saturated thicknesses of sand (and occasionally gravel) on the order of 20 to 50 feet. Theoretical maximum well yields are typically less than 50 gpm and are limited by static water levels that are near sea level in some areas, especially the northern peninsula and along Holmes Harbor. In these cases the wells should be pumped at considerably less than 50 gpm. Yields of 250+ gpm are possible in localized areas of higher permeability, such as near Freeland, Rocky Point, and Mutiny Bay; but pumping at these rates may induce saltwater intrusion in coastal areas. Transmissivities are extremely variable with values as low as 2,000 gpd/ft to one estimate of 100,000 gpd/ft for a gravel zone north of Oliver Lake and an estimate of 300,000+ gpd/ft at one location on the Holmes Harbor coast.

Aquifer B is probably present beneath most if not all of the Northwest South Whidbey subarea. Only a few wells are completed in this aquifer, but several deep wells have verified its presence and properties. The USGS test well drilled north of Goss Lake as well as a few supply wells in the area indicated that this aquifer is present, although brackish water reported along Holmes Harbor would limit its usefulness. The aquifer typically lies at an elevation of 50 to 200 feet below mean sea level. Wells tapping this aquifer are generally 300 to more than 400 feet deep. Water bearing zones in this aquifer are generally 10 to 30 feet thick. Theoretical well yields are generally less than 50 gpm as transmissivities are probably low. No data are available to assess transmissivity in Aquifer B in this subarea.

Aquifer A is probably not present beneath Northwestern South Whidbey subarea. It was not observed in the USGS test wells drilled in the subarea. Its properties and possible distribution are not known.

B. Water Quality and Saltwater Intrusion

Northwestern South Whidbey Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended levels. Saltwater intrusion into

freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron and/or manganese is not considered as serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended state levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion is not currently a problem in the main aquifer of the Northwestern South Whidbey subarea (Aquifer C). Chloride levels exceeding 100 mg/L were reported in only one well in our database, located near Freeland. Several deeper wells tapping Aquifer B were abandoned before completion because brackish water was encountered. These wells were drilled along Holmes Harbor and at the north peninsula area near Rocky Point.

There are also several wells in the subarea, not yet experiencing saltwater intrusion but reporting water levels below mean sea level. These wells have the potential for saltwater intrusion in the future, especially as groundwater use increases. These areas all lie near coastal areas: Holmes Harbor, Freeland, Double Bluff and the northeast coast, west of Langley. The potential intrusion areas are outlined on Exhibit K-8.

All wells in coastal areas have the potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and manganese problems are very common in the subarea with approximately 30 percent of the class I, II, III and IV wells in our data base reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. Excessive iron and manganese do not appear to be associated with any specific location or aquifer as substandard water has been reported in both major aquifers at all parts of the subarea. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Northwestern South Whidbey subarea.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Northwestern South Whidbey area. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The lower end of the additional development range represents the amount that is very likely feasible while the upper end of the range may be possible but only with optimal well placement (including replacement of most coastal wells), verification through monitoring, and more detailed analysis.

(1) Recharge

A mass-balance analysis indicates that approximately 7 to almost 13 mgd recharge the groundwater system of the Northwestern South Whidbey subarea. The analysis, shown in Subappendix K-A, is based on rainfall of 25 to 35 inches per year, runoff of approximately 3 to 7 percent of precipitation, and evapotranspiration of 18 to 21 inches per year. The large range of precipitation is based on the uncertainty and contradictory nature of the rainfall data for the area (see Section K-III). Runoff is indicated by the perennial and intermittent streams in the subarea. The recharge area on Northwestern South Whidbey is estimated to range from 22 to 24 square miles.

(2) Existing Appropriation

A summation of existing water rights indicates that approximately 1.55 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as is explained in Section K-III.

(3) Additional Use

The difference between recharge and appropriations indicates that 5 to 11+ mgd may be available for additional development. Many low yield wells will be needed to develop this additional supply, although local, higher yield (250+ gpm) are possible with exploration. Aquifer C has the best potential for this development. Aquifer B may also have potential for additional development if higher transmissivity zones can be found inland from the coast. Since well yields in these aquifers are typically less than 50 gpm, many tens of wells will be needed; however where higher yield wells of 250+ gpm can be established, fewer wells will be needed. The center portion of the subarea is recommended for additional development. This location is recommended to reduce the potential for saltwater intrusion, not because of known higher yield zones. A few higher yield areas were located near Freeland, Rocky Point, and Mutiny Bay. Because of their proximity to the coast, heavy development in these areas is likely to induce saltwater intrusion and is therefore not recommended.

Areas outside of the interior region can be developed but wells placed closer to the coast will increase the potential for saltwater intrusion.

Development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

2. SOUTHEASTERN SOUTH WHIDBEY ISLAND

Southeastern South Whidbey has good potential for development of additional supplies. Approximately 16 to almost 23 mgd of unappropriated replenishment of groundwater storage define the upper limit to additional development. A large number of smaller wells (locally to 250+ gpm, but typically under 50 gpm), properly placed inland (preferably at least one mile) with adequate spacing, will be needed to maximize additional development. Full development may require replacement of many coastal wells. The central portion of the Island is likely the best area for placement of well fields for a small scale regional supply.

A. Principal Aquifers and Well Yields

Four of the five main aquifers in Island County have been identified in Southeastern South Whidbey subarea. Each of these aquifers is discussed below, along with estimates of theoretical, maximum, short-term (one week continuous pumping) well yields. The aquifers are discussed from shallowest to deepest.

Aquifer E is present in the southeastern part of the subarea, only. It is tapped by only a few wells and these are located near Deer Lake. These wells typically occur at elevations in excess of 300 feet above mean sea level and are less than 50 feet deep. The aquifer appears to be mostly unsaturated with a saturated thickness of less than 10 feet. Well yields are typically less than 50 gpm. Transmissivities data are not available but are likely to be on the order of a few 1,000 gpd/ft, but may be much higher in small localized gravel zones as reported for one well near Deer Lake.

Aquifer D is present beneath most if not all of the subarea. It serves as one of the major aquifers on the Southeast South Whidbey subarea, especially for domestic and small community well systems. The aquifer lies at an elevation of 300 to 50 feet above mean sea level, making saltwater intrusion impossible. The wells tapping this aquifer are typically 100 to 200 feet deep. The saturated, water bearing zones in this aquifer are typically less than 10 feet thick in the southern part of the subarea, while 20 to 30 feet in the northern part. Well yields are typically less than 50 gpm. Transmissivities are generally less than 5,000 gpd/ft.

Aquifer C forms another main aquifer in the Southeastern South Whidbey subarea. It lies at an elevation of 100 feet above to 50 feet below sea level. Wells tapping this aquifer are generally 100 to 300 feet deep. The aquifer, composed of fine to medium sand with

occasional gravel zones, has a typical saturated thickness of 10 to 50 feet. Theoretical maximum well yields are typically less than 50 gpm and are limited by static water levels that are near sea level near Useless Bay. Yields of 250+ gpm are locally possible in areas of higher transmissivity such as near Langley but concentrating heavy development in high transmissivity areas near coastal areas may induce saltwater intrusion. Transmissivities are variable with values as low as 2,000 gpd/ft up to 50,000+ gpd/ft.

Aquifer B may be present beneath most of the Southeastern South Whidbey subarea but data are only available where it is tapped extensively by wells in the Lone Lake area. Its presence has also been verified by the USGS test well drilled south of Langley. The aquifer typically lies at an elevation of 50 to 300 feet below mean sea level. Wells tapping this aquifer in the Lone Lake area are generally 200 to more than 300 feet deep. Other locations could require wells 400 or more feet deep. Water bearing zones in this aquifer are generally 20+ feet thick. Theoretical well yields are generally less than 50 gpm as static water levels near and below sea level are often the limiting factor. Transmissivity data are limited but values of 30,000 gpd/ft are reported. We estimate that typical values range from several 1,000 to several tens of 1,000 gpd/ft.

Aquifer A is probably not present beneath the southeastern South Whidbey subarea. It was not observed in the USGS test wells drilled south of Langley and was not reported in our data base. Its properties and possible distribution are not known.

B. Water Quality and Saltwater Intrusion

Southeastern South Whidbey Island has two main water quality considerations: saltwater intrusion and iron and/or manganese exceeding the recommended state levels. Saltwater intrusion into freshwater supplies is the most serious problem as excessive chloride levels associated with saltwater intrusion can render a water supply unusable. Excessive iron or manganese is not as serious. State levels for these constituents were established for aesthetic, not health reasons. Exceeding the recommended state levels is not thought to lead to health problems, but may produce a water supply that is unpalatable or stains clothing and fixtures.

Saltwater intrusion is not currently a problem in the Southeastern South Whidbey subarea. No chloride levels exceeding 100 mg/L were reported for any of the wells for which we have information.

There are, however, a few wells in the subarea, not yet experiencing saltwater intrusion but reporting water levels below mean sea level. These wells have the potential for saltwater intrusion in the future, especially as groundwater use increases. These areas all lie near coastal areas. The potential intrusion areas are outlined on Exhibit K-8. All wells in coastal areas have the

potential for saltwater intrusion and should be pumped in a properly engineered manner.

Iron and manganese problems are very common in the subarea with approximately 30 percent of the class I, II, III and IV wells in our database reporting iron and/or manganese exceeding the State Recommended Drinking Water Standard. Excessive iron and manganese do not appear to be associated with any specific location or aquifer as substandard water has been reported in both major aquifers at all parts of the subarea. These constituents are associated with weathering of the glacial and interglacial materials that form the aquifers in the Southeastern South Whidbey subarea.

C. Recharge and Groundwater Available for Additional Development

A groundwater recharge and appropriation analysis was used to quantify additional development in the Southeastern South Whidbey subarea. A mass balance approach was used in the analysis (described in Section K-III) where recharge minus existing appropriation equals the maximum amount available for additional development under optimal conditions. The lower end of the additional development range represents the amount that is likely feasible while the upper end of the range may be possible but only with optimal well placement (including replacement of many coastal wells), verification through monitoring, and more detailed analysis.

(1) Recharge

A mass-balance analysis indicates that approximately 18 to 25+ mgd recharge the groundwater system of the Southeastern South Whidbey subarea. The analysis, shown in Subappendix K-A, is based on rainfall of 30 to 38 inches per year, runoff of approximately 3 to 7 percent of precipitation, and evapotranspiration of 18 to 21 inches per year. The large range of precipitation is based on the uncertainty and contradictory nature of the rainfall data for the area (see Section K-III). Runoff is indicated by the perennial and intermittent streams in the subarea. The recharge area on Southeastern South Whidbey subarea is estimated to range from 34 to 37 square miles.

(2) Existing Appropriation

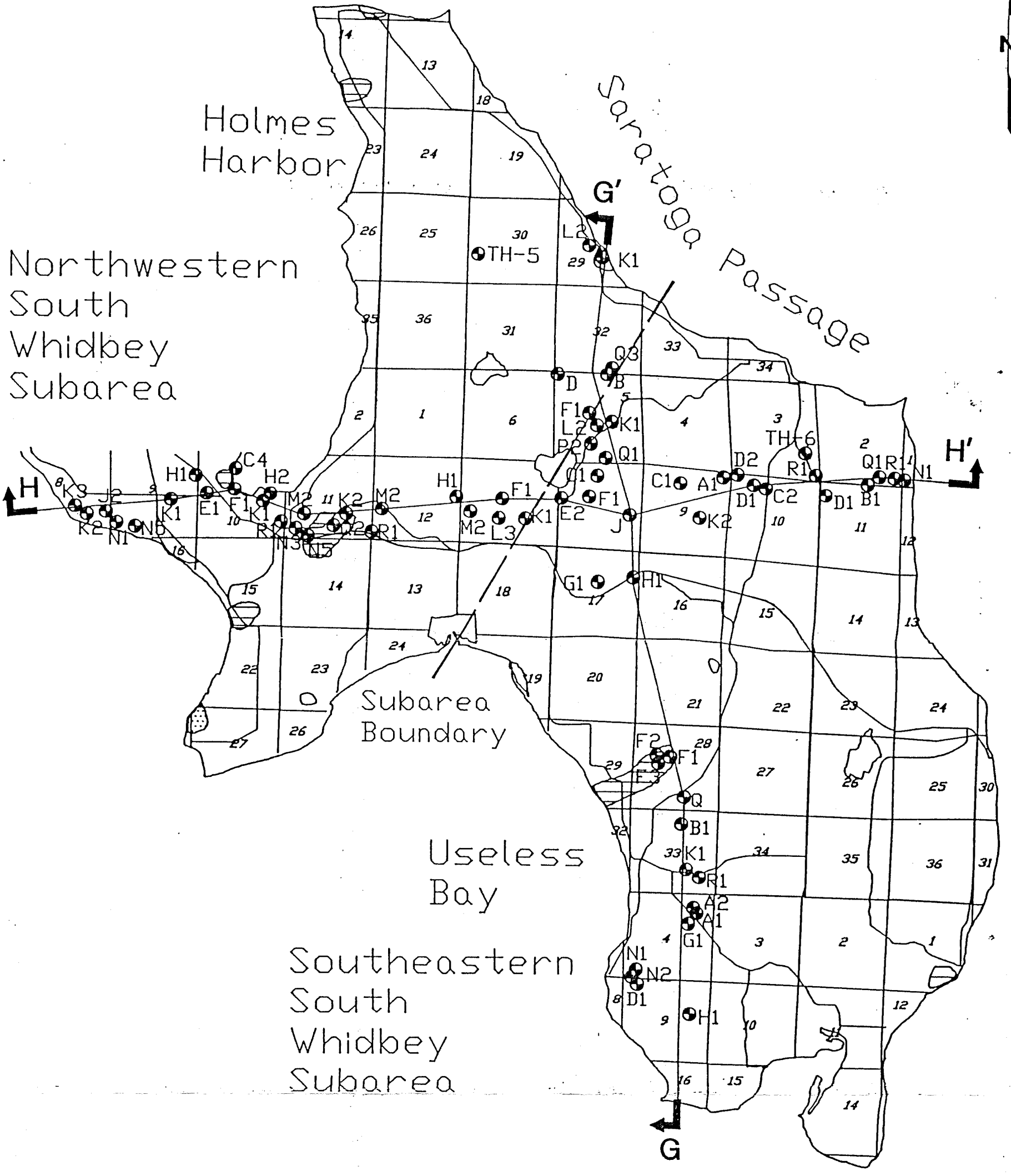
A summation of existing water rights indicates that approximately 2.38 mgd are already appropriated in the subarea. This summation includes water rights for domestic, public supply, and irrigation use. Single family wells were not included in the summation but use at less than appropriation levels by registered wells are likely to offset the non-inclusion of domestic wells as is explained in Section K-III.

(3) Additional Use

The difference between recharge and appropriation indicates that 16 to almost 23 mgd may be available for additional development. Many low yield wells will be needed to develop this additional supply, although local, higher yield wells (250+ gpm) are possible at some locations. Exploration will be needed to define these zones. Aquifer C has the best potential for this development, and will require care to minimize saltwater intrusion, as this aquifer lies below sea level. The preferred location for additional wells is inland, one mile or more from the coast. Aquifer B may also have good potential for additional development if higher transmissivity zones can be identified. Since well yields in these aquifers are typically less than 50 gpm, many tens of wells will be needed. Where higher yield wells of 250+ gpm can be established, fewer wells will be needed. One higher yield area was located near Langley. Others are likely to lie beneath other parts of the subarea. Heavy development in high yield areas near the coast (such as near Langley) may induce saltwater intrusion and is therefore not recommended without an area-specific evaluation.

Development should be accompanied with monitoring of new and existing wells for water levels, pumping quantities, and chloride or electrical conductivity. Wells should be pumped at rates that allow water levels to remain at or above mean sea level in the well.

Well/Cross Section Location and Water Quality Map
South Whidbey Island



P1 ◓ Production Well Location and Number

TH-1 ◓ USGS Test Well Location and Number

G G′ Hydrogeologic Cross Section Location and Designation

Area with One or More Wells with Water Levels Below Mean Sea Level

Area with One or More Wells Indicating Saltwater Intrusion (Cl ≥ 100 ppm)

0 1 2
Scale in Miles

K-VII-9

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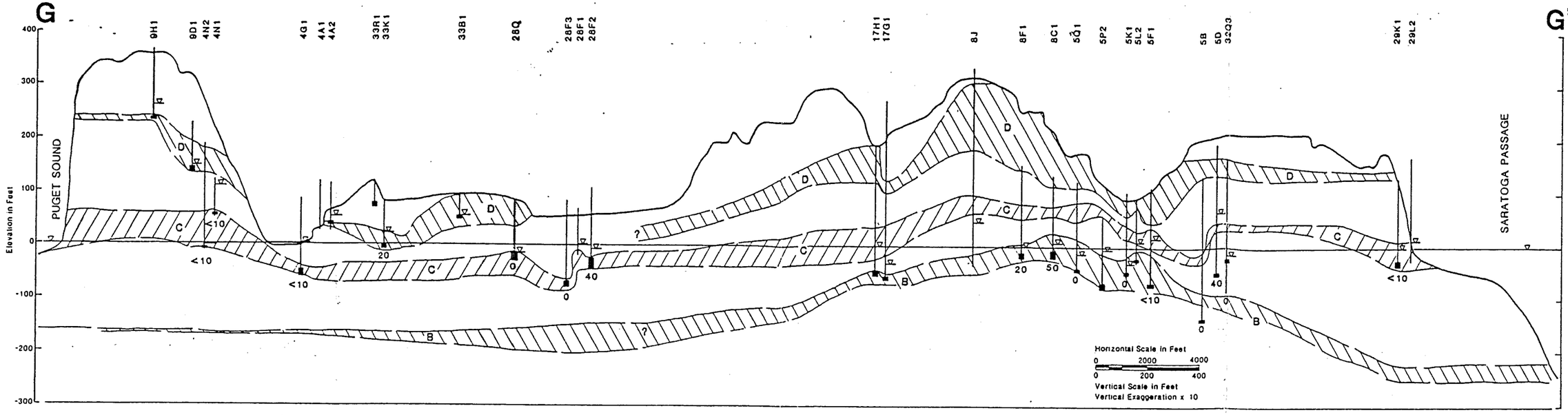
Exhibit K-8

Hydrogeologic Cross Sections G-G' and H-H'

South Whidbey Island



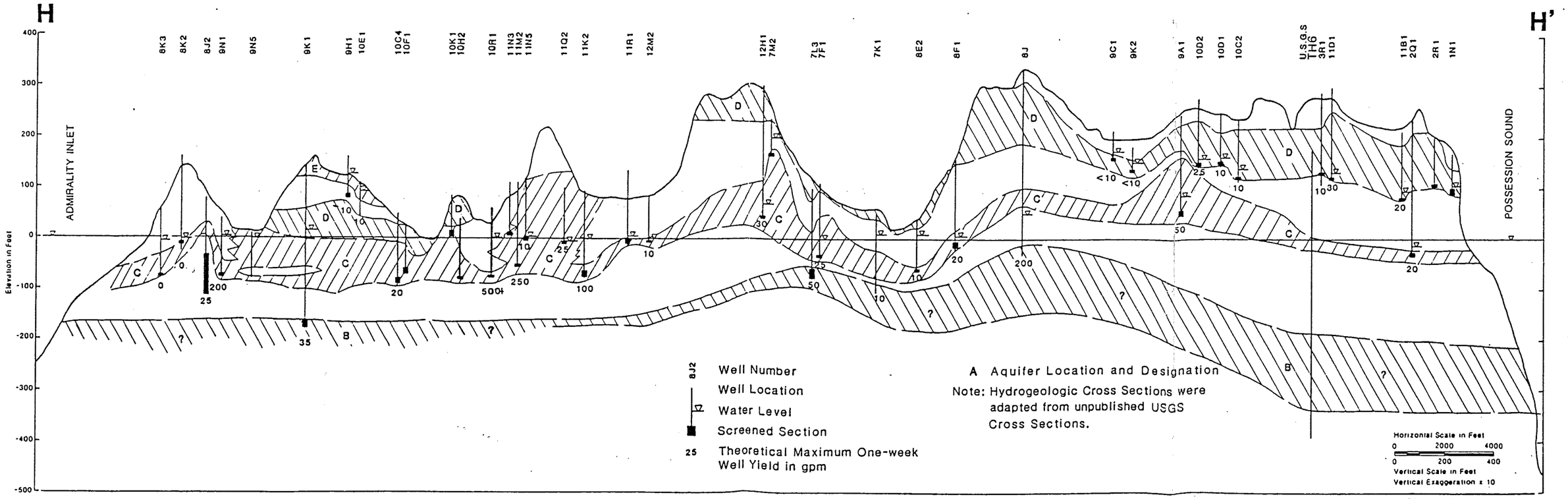


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Exhibit K-9

Walters, K.L., 1971, Reconnaissance of Sea-water Intrusion along Coastal Washington, 1966-1968: Washington Department of Ecology Water-supply Bulletin, 32, 208p.

Washington State Department of Ecology, 1987, Registered water rights, computer file printout for Island County.

Washington State Department of Ecology, 1987, Water well logs for Island County, on file with the Redmond Office of the Washington State Department of Ecology.

Washington State Department of Ecology, 1979, Coastal Zone Atlas of Washington, Volume Four: Island County. DOE 77-21-4.

Washington State University, 1966. Washington Climate for Clallam, Jefferson, Island, San Juan, Skagit, Snohomish, and Whatcom Counties, Pullman.

Subappendix K-A: Infiltration Potential Analysis for Island County

Recharge to Island County was calculated using the equation:

Re=P-Ro-ET-dS

Where:

Re Represents recharge to the area
P Represents preciptiation based on the 1930-57 isohyetal map, Water Supply Bulletin 25, Island County Extension Service data, and information contained in the files of the USGS.
Ro Represents runoff based on the mechanism of Dunne and Black and interpretation of various maps.
ET Represents evapotranspiration based the Thornthwaite method using climatic data and a soil moisture holding capacity of 6 in. (40 in. soil depth with a field capacity of 0.15).
dS Represents change in storage which is assumed to be 0 over the long term.

The following input values were used, producing the indicated recharge rates:

SUBAREA	PRECIPITATION in/yr		RUNOFF in/yr		EVAPOTRANSPIRATION in/yr		RECHARGE AREA square miles		INFIL. POT. MGD	
	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
NORTHERN CAMANO	29	23	1.5	1.1	20	18	35	32	12.6	6.0
SOUTHERN CAMANO	32	25	0.8	0.0	20	18	6	5	3.2	1.7
NORTHERN N. WHIDBEY	22	19	0.6	0.0	18.5	16.5	11	9	1.5	1.1
EASTERN N. WHIDBEY	24	21	1.2	0.0	20	18	18	15	2.4	2.2
SOUTHWESTERN N. WHIDBEY	20	16	1.0	0.0	18	15	24	21	1.2	1.1
NORTHERN C. WHIDBEY	21	17	0.6	0.0	19	16	22	19	1.5	0.9
SOUTHERN C. WHIDBEY	25	20	2.0	0.6	20	18	23	20	3.3	1.3
NORTHWESTERN S. WHIDBEY	35	25	2.8	0.6	21	18	24	22	12.9	6.8
SOUTHEASTERN S. WHIDBEY	38	30	2.8	0.7	21	18	37	34	25.2	18.4