Appendix D: Phase 2 Water Resource Assessment Final Report

Introduction

Aquifers and aquitards in Island County vary spatially in both thickness and elevation. In any given area of the county, there may be several aquifers present, and each aquifer will have different hydraulic characteristics (recharge, pressure, capacity, etc.) and susceptibility to seawater intrusion. Even within a single aquifer, the hydraulic characteristics can vary significantly from one location to another. It is this variability and complexity of our groundwater system that makes the question of 'How much water is there?' so difficult to answer. As a result, water resource planning and management efforts have primarily relied on review of water use proposals on an individual basis.

The primary goal of the Watershed Planning Phase II Assessment is to quantify the water resources within a water resource inventory area (WRIA). For many WRIAs the primary resource is a river system, and quantification of the resource is relatively straightforward, involving collection of flow data from that system. In WRIA 6 (Island County) our primary water resource is contained in multiple discontinuous aquifers, with variable connection to recharge areas and the saline waters of the Puget Sound. The complexity of our groundwater system makes it virtually impossible to accurately quantify the resource as a whole. As a result, the WRIA 6 planning unit opted to make the primary focus of its phase II assessment the evaluation of risk for seawater intrusion, utilizing water level elevations as the assessment tool.

In order to determine the water level elevation in an aquifer, two measurements are required. First a depth-to-water measurement is taken, finding the distance between the measuring point (typically the top of the well casing) and the water level. In order to convert this depth-to-water measurement into an elevation, the elevation of the measuring point must be determined. The depth-to-water is then subtracted from the measuring point elevation to find the water level elevation.

Determination of the elevation of the measuring point has traditionally been accomplished through the use of a differential level loop survey from the nearest vertical benchmark(s) to the well. Although traditional surveying can provide accurate elevation data, in many cases the time and costs associated with this method make it impractical. Recent advances in survey-grade GPS (Global Positioning System) technology have resulted in devices that are capable of determining the elevation of a location in a fraction of the time required for traditional surveying methods.

Data Collection

In order to evaluate the effectiveness of water level elevation as a tool for assessing seawater intrusion risk, water level elevation data from both intruded and non-intruded areas of the county was needed. To fulfill this need, data was collected from nearly 400 wells across the county, or roughly two wells per square mile. For each well utilized in the study, depth-to-water measurements were collected, and where possible a computerized data logger was installed in the wells to evaluate water level variations over time. In addition a water sample was collected from each well, and sent to a state-certified laboratory for major ion analysis.

Through a grant provided by the Washington State Department of Ecology, Island County was able to purchase a global positioning system (GPS) consisting of three survey-grade receivers and associated hardware. Two of these receivers were set up as permanent base stations to provide post-processing data, and the third was utilized as a roving unit to collect measuring point elevation data from each well utilized in the study.

Volunteers willing to let the county collect data from private and public water system wells were solicited via newspaper articles and direct mailings. In selecting wells for use in the study, we attempted to achieve an even distribution spatially at approximately two wells per square mile. Since we hoped to measure static (non-pumping) water levels, preference was given to wells with a limited number of users. Preference was also given to wells completed (screened) below sea level. In any given area, if more than one aquifer was present, we attempted to collect data from the two most frequently utilized aquifers situated below sea level.

Over 730 wells were volunteered, of which field crews visited more than 470. Not all wells that were visited by our field crews could be utilized in our study. Wells that did not have access for measuring depth-to-water, or wells that did not have the ability to provide an untreated water sample were not utilized in our study, resulting in a total of 379 wells from which all necessary data was successfully collected. Water level and chemistry data was collected from the study wells during the summers of 2001 and 2002, while the surveying of measuring point elevations was conducted from the spring of 2003 through the spring of 2004.

Aquifers can be influenced by tidal fluctuations in adjoining marine waters, resulting in variations in both water level and chemistry. Generally, wells that are affected by seawater intrusion and are tidally influenced tend to exhibit higher chloride concentrations and water levels during higher tides. In an attempt to collect consistent data, wells that fell within ½ mile of the marine shoreline were monitored (water sampling and depth-to-water measurements) during a +6 foot or higher tide stage.

Data Analysis

Data derived from the 379 sampled wells was utilized for the purposes of data analysis. The primary goals of the Phase II Assessment were to evaluate the use of water level elevation data as a tool for determining seawater intrusion risk, and to provide water level elevation data on a countywide basis to provide a new view of intrusion susceptibility.

Evaluation of water level elevation data as a seawater intrusion tool can be approached in several ways. One method involves comparing intrusion (or lack thereof) from the perspective of water chemistry to the water level elevation data. As discussed earlier, there are several problems associated with the use of chemistry for evaluation of seawater intrusion. These problems complicate the use of chemistry as a tool for validation of the water level elevation methodology for seawater intrusion analysis.

Several different methods were utilized in our analysis of the chemistry data. The most simple of these methods was simply comparing chloride concentrations to water level elevations as shown in Figure 7. One problem with this analysis is the significant number of 'false positives' where there are elevated chlorides that are not due to seawater intrusion. One area of known false positives for chloride data is Central Whidbey Island. Wells in this region are impacted by very hard groundwater, which results in elevated chloride concentrations that do not appear to be caused by conventional seawater intrusion. Figure 7 differentiates the wells in Central Whidbey from all other wells as shown in the legend. With the exception of the data from Central Whidbey, the plot displays the expected results, with elevated chloride concentrations occurring with lower water level elevations.

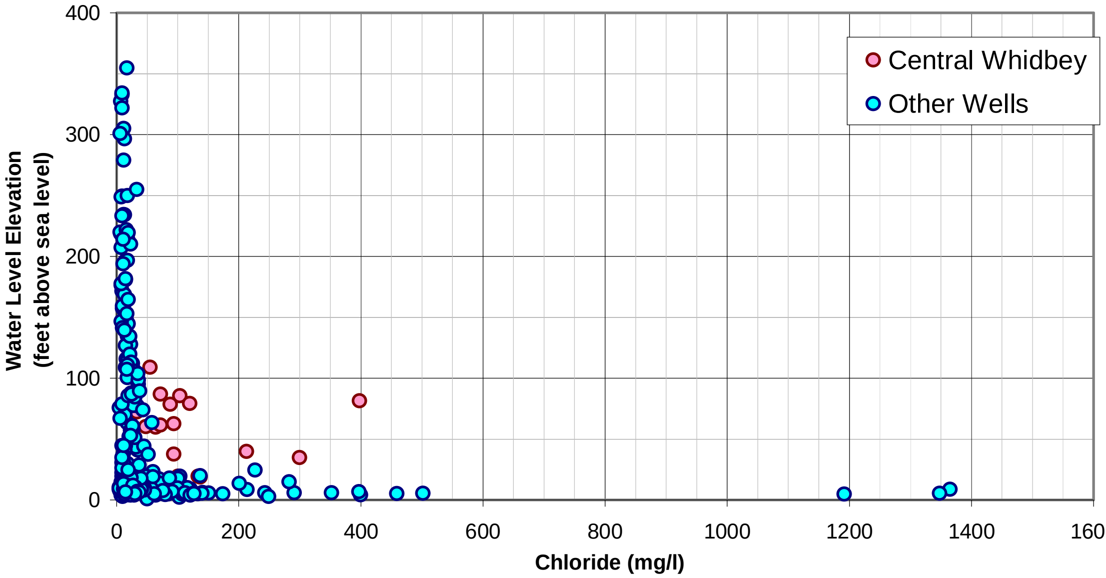

Figure 7.

Another type of analysis that has application to seawater intrusion is a piper diagram, where chemical sample results are plotted based on the relative proportion major ions (Figure 2). For each water sample, a point is plotted in the lower left triangle based on the proportions of positively charged ions (cations), and a second point is plotted in the lower right triangle based on the proportions of negatively charged ions (anions). These two points are then extrapolated up into the upper diamond to place a third point.

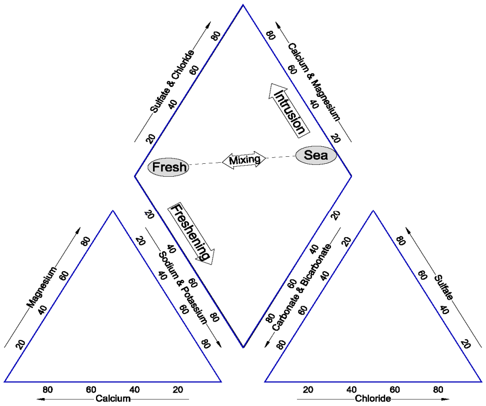

Figure 8.

In general, fresh groundwater samples will land near the area labeled as ‘fresh’ in the upper diamond, while pure seawater will plot near the ‘sea’ label. Water that results from conservative mixing (mixing without ionic exchange reactions) between freshwater and seawater would plot along the line labeled ‘mixing’. When mixing occurs in the presence of aquifer materials, ion exchange reactions often occur between the groundwater and the aquifer material, which alter the chemical composition of the water. This change in chemical composition results in a deviation from the conservative mixing line on the piper diagram, moving the point upward into the upper portion of the diamond during intrusion, and downward toward the lower portion of the diamond during freshening. Using this method, it is possible to deduce not only if a water sample is impacted by intrusion, but also if the intrusion was getting worse (intrusion exchange) or better (freshening exchange) at the time the sample was taken.

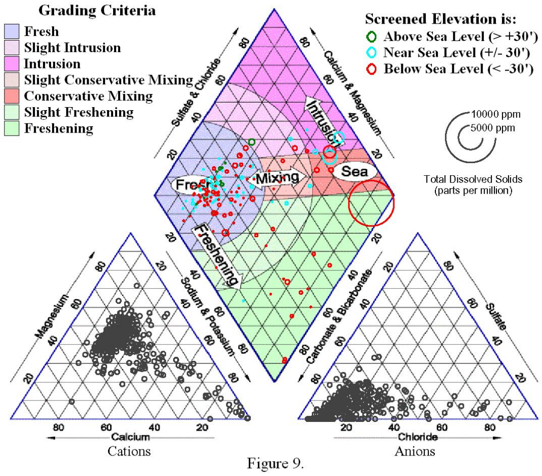

Figure 9.

Figure 9 is a piper diagram plotting the chemistry data from all of the wells utilized in the Phase 2 assessment. The color of the each data point in the upper diamond reflects the elevation of the bottom of the well as shown in the legend. The radius of each upper diamond data point reflects the total dissolved solids (TDS) for that sample, with larger circles having greater quantities of dissolved minerals. A program was developed that automatically evaluates the sample results, assigning each sample a code indicating where it lands on the diagram as shown in figure 9. The samples collected as part of the Phase II assessment were processed using the above methodology to evaluate the ion balance of each, and then these results were grouped and the average water level elevation (in feet above MSL) for each grouping was evaluated. The results of this evaluation are presented in Table 1. This analysis was performed on data that excluded wells that are completed above sea level and those wells in Central Whidbey where anomalous chemistry is known to occur.

Table 1.

	Water Level Elevation (ft MSL)		
Piper Diagram Analysis	**Avg**	**Min**	**Max**
Normal Groundwater	16.0	-29.3	139.3
Slight Freshening Exchange	18.1	5.1	44.4
Freshening Exchange	34.0	6.5	300.7
Slight Conservative Mixing	5.5	2.0	7.5
Conservative Mixing	4.6	3.9	5.4
Slight Intrusion Exchange	6.2	5.7	
Intrusion Exchange	5.7	3.1	8.6

Another diagnostic tool used to analyze chemical sampling results as they relate to seawater intrusion is to evaluate the ratio of chloride to electrical conductivity. This analysis is especially suited for evaluating areas where extremely hard groundwater results in elevated chloride concentrations. The concept behind this tool is that electrical conductivity is directly related to the overall quantities of dissolved solids. For any given concentration of chloride, one would expect a much higher conductivity value if the chlorides were the result of very hard water due to the presence of other dissolved constituents.

Figure 10 is a chloride vs. conductivity plot displaying the samples taken during the Phase II Assessment; sample points are color-coded based on the water level elevations as shown in the legend.

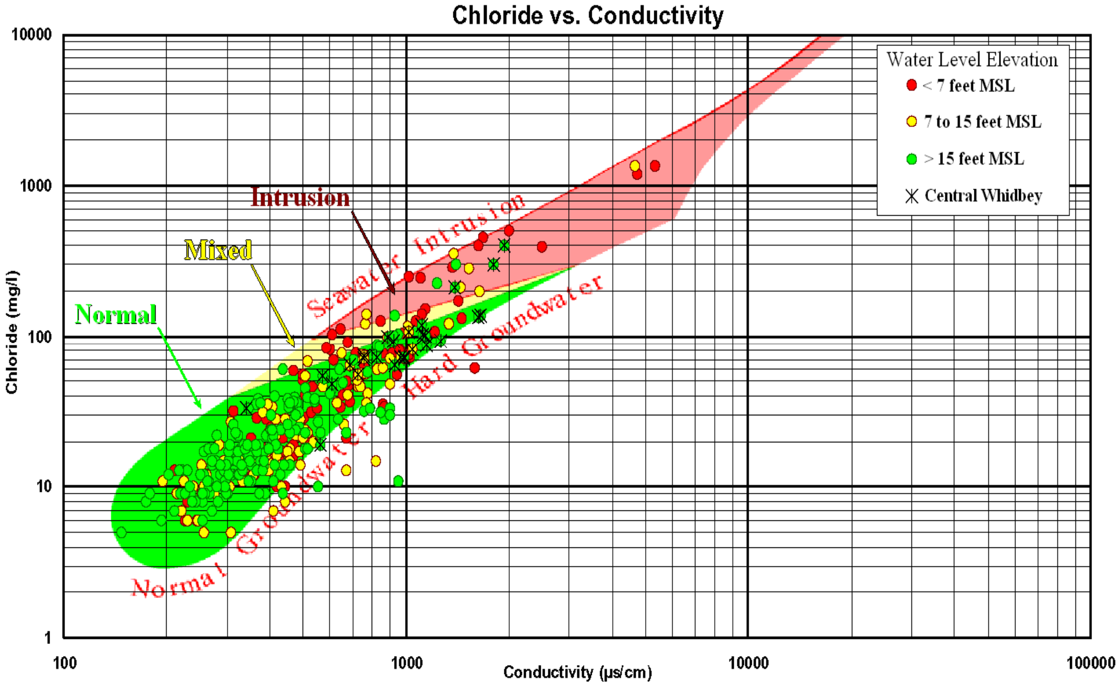

Figure 10.

Table 2 summarizes the results of this analysis, grouping results by the diagnostic technique presented in Figure 10, and comparing those results with average water level elevations for each group of results. This analysis was performed on data that excluded wells that are completed above sea level and those wells in Central Whidbey where anomalous chemistry is known to occur.

Chloride vs. Conductivity	Water Level Elevation (ft MSL) Avg	Min	Max
Normal (green)	16.2	-29.2	300.7
Mixed (yellow)	7.9	2.0	19.7
Seawater Intrusion (red)	8.4	3.1	24.

Table 2.

Another method for evaluating water level elevation as a tool for seawater intrusion risk assessment is to compare water level elevation data to the conceptual model for groundwater flow in a marine island environment as discussed earlier. The conceptual model predicts water level elevations should be highest near the center of the island, with water levels dropping toward the shoreline. The conceptual model also predicts that if seawater intrusion was to occur in an area, it would occur first along the shoreline, moving inland as the situation worsens.

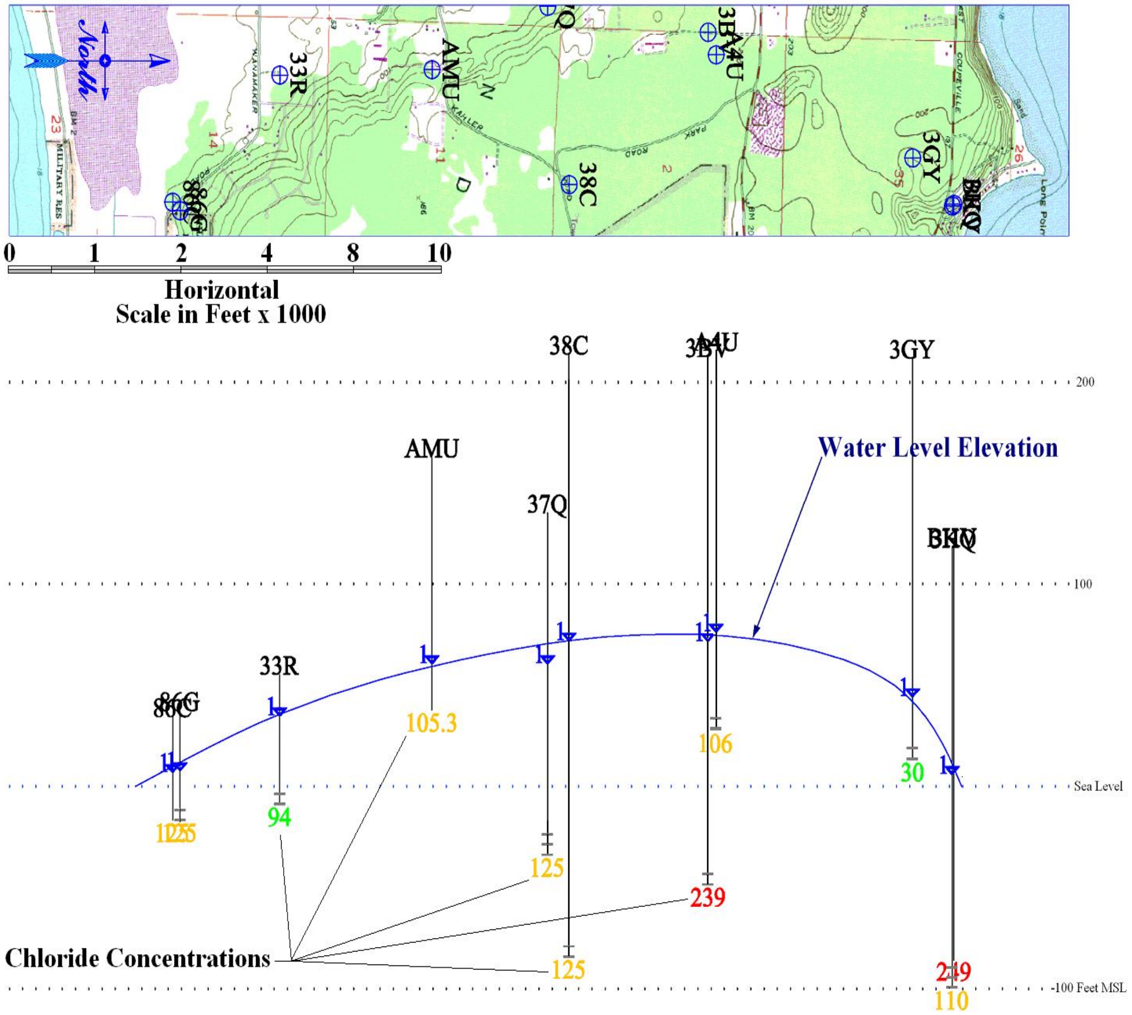

Figure 11.

Figure 11 displays a section of Central Whidbey, with a map of Phase II well locations, and a vertical ‘stick’ diagram of well stratigraphy including elevations of the water table at each well represented by the blue triangles. The diagram shows that the water level elevation data is in good agreement with the conceptual model. Also shown at the base of each well in the stick diagram is the chloride concentration from that well. The elevated chloride concentrations in wells near the center of the island, including wells that are completed (screened) significantly above sea level (such as wells AMU and A4U), represent the anomalous chemistry found in Central Whidbey wells discussed previously. Previous analysis of Central Whidbey that utilized chemistry as the primary analysis tool correctly identified those wells that were completed above sea level as being non-intrusion sources. However, those wells that were completed below sea level remained somewhat in question. Using water level elevation data provides clear differentiation between those wells that are impacted by intrusion and those that are not (false positives).

One final analysis was performed on the data collected during the Phase II assessment. This analysis involved review of all available data including the various chemical analyses described above, water level elevation, and when available, historical chemistry data for analysis of variations in chemistry over time. Also included in this review was data from other nearby wells that appear to be completed in the same aquifer. For each well in the study, a determination was made based on all available data as to the likelihood that the well was suffering from the impacts of seawater intrusion. Wells were grouped into one of three categories as follows:

Summary Analysis	**# of Wells**
No Indications of Intrusion	242
Inconclusive Indications of Intrusion	101
Positive for Intrusion	36

Figure 12 presents a countywide view of the Phase II Assessment wells, grouped by water level elevations. With a few exceptions on North Whidbey the elevation data closely conforms to the conceptual model. Virtually all the red, orange and yellow data points (lower water level elevations) are located along the shorelines, while the green and cyan data (higher water level elevations) are located inland. Lower elevation data are almost always clustered in groups, indicating that these areas have reduced water level elevations.

Water level elevation data can be used to identify ‘false positives’ in chemistry data, and in addition it can be used to identify ‘false negatives’. Several shoreline areas on South Whidbey and Western Camano have relatively low water level elevations (red and orange data points), but as of now have not experienced any chemical indications of intrusion. These areas can be interpreted as being at risk for intrusion, although intrusion has not yet begun to occur. Larger project proposals in these low water level elevation areas should be evaluated from the perspective of seawater intrusion. Chloride data alone would not have provided this advance warning of pending intrusion problems, but instead could only react after intrusion actually begins to occur.

An additional benefit of using water level elevation as a tool for evaluating seawater intrusion risk is the ability to define areas where intrusion is unlikely to be an issue in the foreseeable future. Areas in Figure 12 with cyan data points have water level elevations more than twenty feet above mean tide. These areas are unlikely to suffer from intrusion, even when substantial withdrawals and drawdown occur.

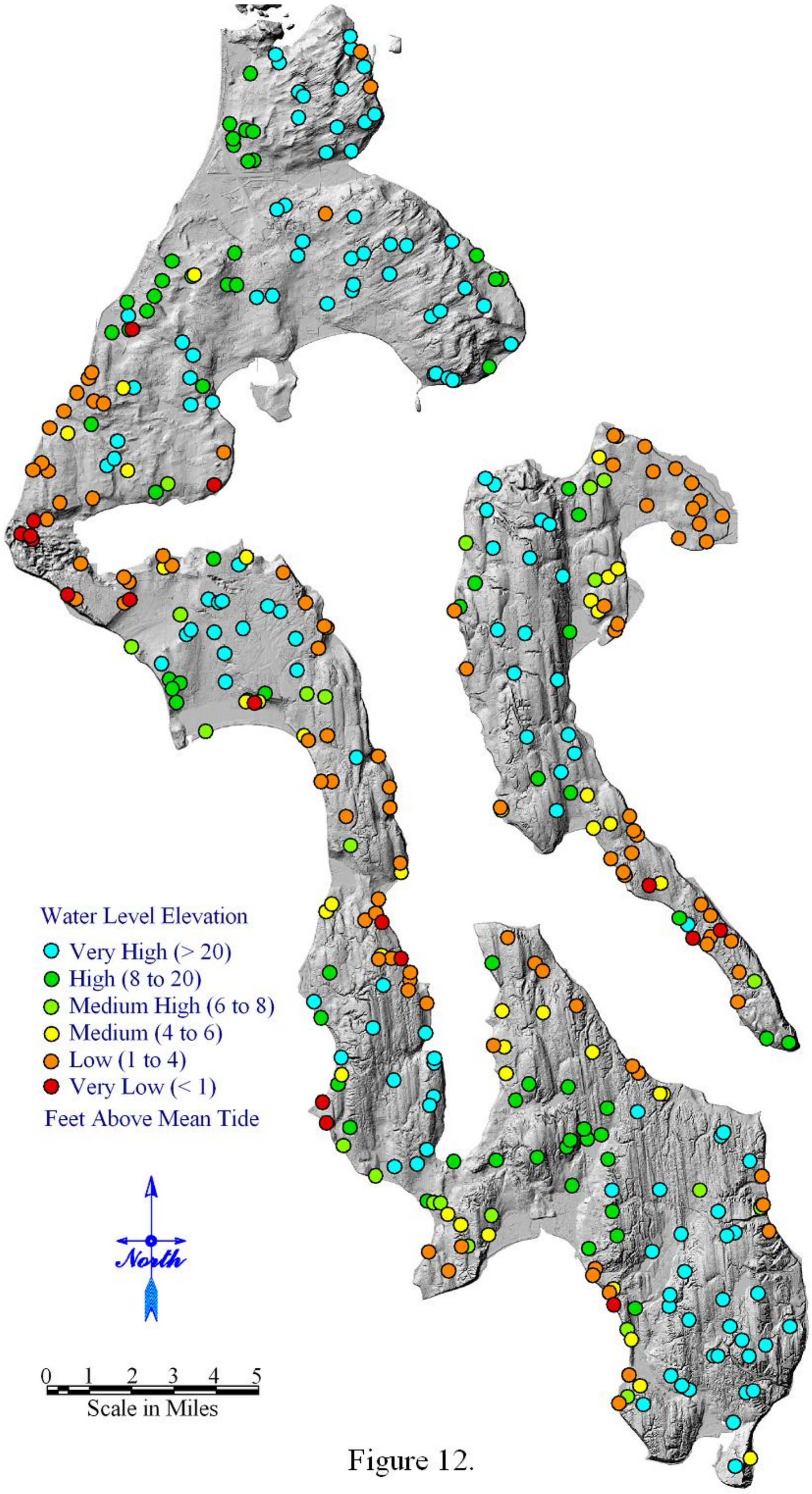
Water Level Elevation
Very High (> 20)
High (8 to 20)
Medium High (6 to 8)
Medium (4 to 6)
Low (1 to 4)
Very Low (< 1)
Feet Above Mean Tide
North
0 1 2 3 4 5
Scale in Miles

Figure 12.

In many cases, water level elevations can be pulled significantly below sea level at a pumping well and yet not induce seawater intrusion, as long as the water level elevations in the aquifer rise high enough between the pumping well and the submarine aquifer outcrop to prevent saltwater from entering into the aquifer.

This situation creates what is known as a 'false interface' and is illustrated in Figure 13. The drawdown cone at the pumping well extends below sea level, which causes the Ghyben-Herzberg predicted interface position to move upward to the well screen. Water level elevations are significantly above sea level in the aquifer between the well and the shoreline (A), result in the predicted interface position falling significantly below the bottom of the aquifer (B), preventing the movement of saltwater to beneath the well, which prevents seawater intrusion at the well.

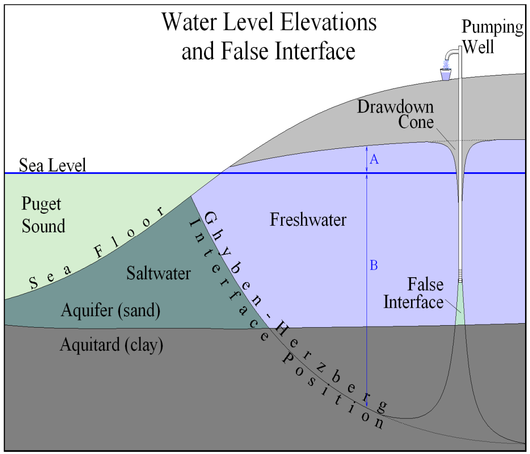

Figure 13.

The important factor in preventing seawater intrusion is not the water level at the pumping well, but instead it is the water level in the area between the well and the shoreline. If water levels in an aquifer are lowered, reducing the pressure above sea level (A), the predicted interface position at (B) will rise until a critical level is reached where the base of the interface rises up to the base of the aquifer. Once the critical rise has been reached, intrusion of the pumping well will occur rather rapidly. Once water level elevations are lowered below the critical level and the seawater interface moves into the base of the aquifer beneath a pumping well, the strategies for mitigation change. From that point forward, attempts to control rather than prevent intrusion are required. Measures such as relocating wells, reducing pumping rates, and raising well intakes (screens) are typically employed.

There is one additional conclusion that can be drawn from examination of the water level elevation study results: risk for intrusion is highest near the shoreline, and decreases as you move inland. In some cases, wells currently showing signs of intrusion may exhibit intrusion problems even if they were the only wells completed in that particular aquifer. In these cases, the problem is not so much one of over-drafting the aquifer, but rather one of poor selection of well location. These wells were initially installed into the zone of diffusion, and thus experienced elevated chlorides from the day they were installed.

Figure 14 presents an example of this situation, with an aquifer with high freshwater flow discharging a substantial amount of water to the Puget Sound. Some of this freshwater discharge could be utilized as a water source, if the resultant movement of the interface could be tolerated. Two wells are shown in Figure 14 - a shoreline well with its well screen positioned at the base of the aquifer and an inland well with an elevated

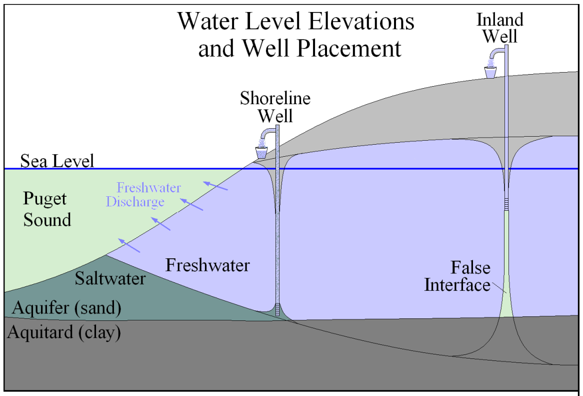

Figure 14.

screen. As in the previous example, pumping of the inland well, even at a substantial rate, will not result in intrusion of the inland well. In contrast, the shoreline well will suffer from intrusion, even when pumped at a relatively low rate. Depending on the specific aquifer conditions and the distance of the second (inland) well, pumping of that well may induce drawdown on the near-shore well. Such drawdown would result in a worsening of intrusion problems for the near-shore well. Although the aquifer has significant capacity for additional withdrawals, the poor placement and subsequent intrusion of the near-shore well would be interpreted as a degradation of water quality, resulting in limiting future withdrawals from this aquifer in the immediate area. In fact, given the above-described scenario, the Washington Department of Ecology (DOE) would not approve a water right application for the inland well, based on the degradation of water quality it would cause on the shoreline well.

A loss of capacity can occur in aquifers that are not subject to seawater intrusion, where well construction can pose a limitation on the ability to utilize the resource. Take for example a well being constructed to supply water for a particular purpose; the well is drilled into a one hundred foot thick, highly productive aquifer. Due to the aquifer's high productivity, it is only necessary to drill twenty feet into the aquifer in order to achieve the desired well production rate and the well is completed at that depth. Years later several new wells are completed for other purposes, and these withdrawals result in a lowering of the water table in the aquifer, and a reduction in the production capacity of the existing well. In this situation, the aquifer is capable of supplying additional water to new wells, but in so doing these withdrawals would impair the ability of the existing well to produce water. Under these circumstances, DOE would require that the existing well fully penetrate the aquifer, or in other words, the existing well owner could only claim an impairment if his well was screened at the base of the aquifer, allowing for full utilization of the resource.

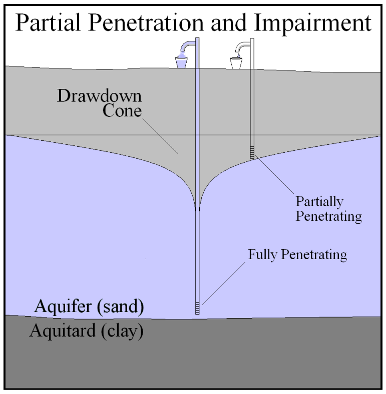

Figure 15.

Seawater intrusion can be viewed as an inverted version of the partially penetrating well construction situation described above. An aquifer that could otherwise produce a significant quantity of water could be rendered useless due to "intrusion", caused by poor well placement and construction (too close to the shore, and/or too deep). If maximizing the use of groundwater resources is a desired goal, then a solution to this problem, similar to the fully penetrating solution described above, will need to be devised and implemented. Phase III of the Watershed Planning process aims to address this problem.