PACIFIC groundwater GROUP

CITY OF SEQUIM
2008 HYDROLOGIC
MONITORING REPORT

DECEMBER 2009

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2008 HYDROGEOLOGIC MONITORING REPORT

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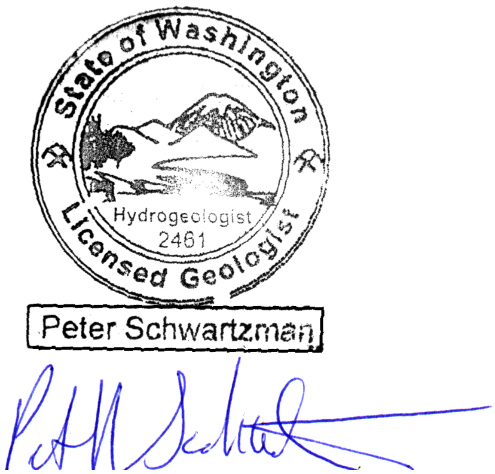
This report, and Pacific Groundwater Group's work contributing to this report, were reviewed by the undersigned and approved for release.



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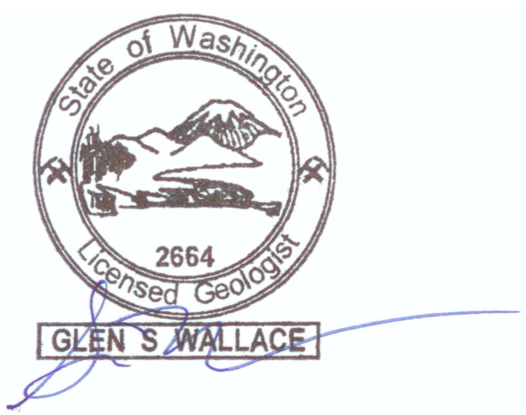

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1.0 INTRODUCTION

The City of Sequim is located on the Sequim-Dungeness Peninsula, which extends off the Olympic Peninsula in Clallam County, Washington (**Figure 1-1**). The City obtains its drinking water from three groundwater sources located east of the Dungeness River and generates Class A reclaimed water from its wastewater treatment plant. Some of the reclaimed water is used for irrigation of City property and augmentation of Bell Creek baseflow, and the City is exploring opportunities for expanding reclaimed water re-use (i.e. "source replacement") and infiltrating portions of the reclaimed water to recharge the groundwater flow system and augment stream baseflows.

The City actively participates in water-resource management on the Sequim-Dungeness Peninsula, and has established a monitoring program designed to document pumping withdrawals, groundwater level trends, and climate trends. Data are shared with interested parties and various governmental agencies. The monitoring program adds to the growing body of hydrologic data and supports evaluation of how observed hydrologic changes relate to changes in groundwater pumping and septic densities (i.e. population-based changes), irrigation practices, and climatic variation. The monitoring is also designed to provide "early warnings" of hydrologic trends of potential concern to water-resource stakeholders.

The scope-of-work for this study was developed to provide a holistic understanding of hydrologic trends and causative factors on the Sequim-Dungeness Peninsula. This report incorporates monitoring data collected by the City and other agencies/organizations over a study area that extends from Siebert Creek (west) to Sequim Bay (east), and from the Olympic Mountain foothills (south) to the Strait of Juan de Fuca (north) (**Figure 1-1**). The City previously sponsored a similar evaluation and produced a report titled, "City of Sequim 2001 Hydrologic Monitoring Report" (PGG, 2002). The report included analysis of groundwater use, climatic trends, irrigation trends, groundwater level trends, and water quality in both City drinking water sources and Bell Creek. At the City's request, this current report updates the understanding of the Sequim hydrologic system with data collected through the end of 2007, and includes a more detailed assessment of changes in recharge due to piping of irrigation ditches along with assessment of trends in snowpack and streamflows, review of water-quality information on local streams and rivers, and the results of preliminary age-dating of groundwater from several of the City's water-supply sources.

Many people at local and regional agencies have provided help in compiling the data for this report. In particular, Anne Soule with Clallam County, John Pearch with the Department of Ecology, Oscar Segura with the Washington Department of Health, and others (e.g. Graysmarsh, City of Sequim) have been instrumental in compiling data for this report.

This work was performed, our findings obtained, and this report prepared, using generally accepted hydrogeologic practices used at this time and in this vicinity, for exclusive application to this study, and for the exclusive use of the City of Sequim. This is in lieu of other warranties, express or implied.

2.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

The following paragraphs summarize the findings of sections 3 through 9 of this report:

1. The surface-water system within the study area includes the Dungeness River and various small, independent streams. Whereas the Dungeness River derives its flow from rainfall and snow-melt in the Olympic Mountains, most small streams derive their flow from groundwater recharge, lowland runoff and (sometimes) irrigation conveyance.

2. The groundwater flow system is regionally comprised of a stratified system of aquifers and aquitards. From top to bottom, these include the: shallow aquifer, upper confining bed, middle aquifer, lower confining bed, lower aquifer, deeper undifferentiated sediments, and bedrock. On a local scale, these broad regional units have variable occurrence, hydraulic properties, and inter-unit relationships.

3. Precipitation trends at the Sequim weather station show no long-term trends over the study period (approximately 1980 through 2007); however, above-average rainfall years occurred between 1996 and 1999 and below-average rainfall years occurred between 1985 and 1989 and between 2000 and 2005. Snowpack at monitoring stations in the upper Dungeness Watershed is estimated to have decreased by 64 to 71 percent between 1960 and 2006 due to warmer temperatures. Temperatures at the Sequim weather gage have increased over time, similar to trends observed throughout the Puget Sound (e.g. 1.6 ^{o}F between 1950 and 2000).

4. Climate change in the Pacific Northwest has been estimated with a variety of global climate models (GCM's). The GCM's predict continued increase in average annual temperature of 1.6 to 5.2 ^{o}F between present and 2040. Rainfall is predicted to exhibit small changes (±12 percent), and GCM's are inconclusive as to increase or reduction. Snowpack is expected to continue its reduction due to warmer winters. Predicted changes in sea level relative to the land surface (which is rising due to geologic forces) range from a relative decline of 5 inches to a relative rise of 14 inches.

5. The Dungeness River exhibits two annual peaks corresponding to the winter rainy season and the "spring freshet" (melting of snowpack). Due to increased temperatures and reduced snowpack, the freshet has moved earlier in the year and exhibits reduced flows, whereas winter flows have increased over time. These trends are expected to continue under GCM projections of climate change. A review of baseflow trends for the small independent streams showed declines on McDonald Creek, Matriotti Creek, Cassalery Creek and Bell Creek which could be attributed to changes in irrigation practices, streambed modifications, or other land-use changes and climatic variations. Data for some streams were too sparse to assess baseflow trends.

6. PGG evaluated groundwater and surface-water use within the study area. Groundwater is used to supply public water systems (Group A and Group B), domestic wells, and irrigation for agriculture and golf courses. Minor amounts are associated with other uses, such as dairy and industrial. Surface water is predominantly associated with irrigation via diversions from the Dungeness River by the Sequim-Dungeness Valley Agricultural Water Users Association (SDWUA).

7. Group A water systems serving 8,458 reported hookups were estimated to withdraw an annual average of about 2.7 million gallons per day (mgd) of groundwater in 2007, of which 1.7 mgd was estimated to be consumptive use (the non-consumptive remainder was estimated to return to the groundwater flow system via septic recharge or irrigation inefficiencies). For the purpose of comparison with other components of the water budget, these estimates translate to 3,020 and 1,910 acre-feet per

year (af/yr). Groundwater withdrawals by the City of Sequim represent 35 percent of all Group A withdrawals. About 82 percent of the withdrawals occur east of the Dungeness River. About 53 percent of Group A withdrawals are estimated from the shallow aquifer, 14 percent from the middle aquifer, and 31 percent from the lower aquifer. The City's Silberhorn Wellfield and their infiltration gallery draw water from the shallow aquifer, whereas their Port Williams Wellfield draws water from the lower aquifer. Data are unavailable to evaluate how Group A withdrawals have changed over time; however, City of Sequim withdrawals have increased from about 0.4 mgd (450 af/yr) in the late 1970's to nearly 1 mgd (1,120 af/yr) after 2005. Pumping from the Port Williams Wellfield has replaced a significant portion of historic pumping from the infiltration gallery and has accommodated a noteworthy share of new water demand associated with population growth.

8. Group B water systems serving 687 reported hookups withdrew an estimated 0.38 mgd (430 af/yr) in 2007, of which 0.21 mgd (240 af/yr) was estimated to be consumptive use. Data are unavailable to evaluate the change in Group B withdrawals over time.

9. Approximately 5,253 domestic wells withdrew an estimated 2.9 mgd (3,250 af/yr) in 2007, of which 1.5 mgd (1,680 af/yr) was estimated to be consumptive use. The number of domestic wells has double between 1993 and 2007, and has increased by 38 percent since PGG's prior "2001 Monitoring Study". Roughly equal numbers of domestic wells are located east and west of the Dungeness River. About 73 to 82 percent of the domestic wells are believed completed in the shallow aquifer, with most of the remainder completed in the middle aquifer.

10. Relative to Group A withdrawals, domestic wells have a slightly lower ratio of consumptive to total use because the consumptive use ratio for Group A systems is skewed by City of Sequim withdrawals. Most of Sequim's reclaimed water is currently discharged to marine water during winter months. About 12 percent is used for irrigation during summer months and 10 percent is used for Bell Creek streamflow augmentation. In the future, reclaimed water use for irrigation (and other upland uses) may increase, and a portion of the City's reclaimed water may be returned to the groundwater flow system for streamflow augmentation.

11. Irrigation diversions from the Dungeness River predominantly occur between April 15 and September 15. Lining of ditches, changes in cropping patterns, and voluntary reductions in use have resulted in a 50 percent reduction in irrigation diversions between the late 1970s and 1999, with respective irrigation-season averages of 110 cfs (33,600 af/yr) and 55 cfs (16,800 af/yr). About 200 miles of irrigation ditches have been mapped, of which about 60 miles have been piped and 13 miles abandoned.

12. The groundwater flow system is recharged from precipitation, leakage from unlined irrigation ditches, unconsumed irrigation water from field applications, seepage losses from "losing" streams (e.g. Dungeness River), infiltration of septic effluent and treated wastewater, and underground "subflow" from higher-elevation areas to the south. Changes in recharge can have a significant affect on groundwater levels.

13. The USGS estimated that recharge from precipitation incident on the land surface averages about 4.8 in/yr over their primary study area (similar to the study area used in this report), amounting to an annualized rate of 26.2 cfs (19,000 af/yr). Variations in precipitation recharge trend with, and are larger than, variations in precipitation itself. High recharge years occurred between 1995 and 1999 followed by low recharge years between 2000 and 2005. Recharge estimated with Sequim climatic data (precipitation and temperature) over the 28-year study period do not suggest a rising or falling tend; however, year-to-year variability in precipitation may obscure the effects of rising temperature. In consi-

dering projected temperature changes between current conditions and 2040, PGG estimated that recharge could be reduced on the order of about 1 in/yr, largely due to increases in evapotranspiration.

14. Land-use changes (e.g. construction of impervious surfaces and compaction of soils) can affect patterns of precipitation recharge; however, the relationship between land-use changes, soil properties, and runoff management (e.g. infiltration vs. surface routing) affect whether changes result in reductions or increases in local recharge. Analyzing how actual combinations of these factors affect precipitation recharge is complex and beyond the scope of this report. However, given that relatively large portions of the study area are occupied by permeable soils, it should not be assumed that urban development has led to a reduction in recharge quantity.

15. The USGS estimates that groundwater subflow into their primary study area from the Olympic Mountain foothills to the south is on the order of 14.5 cfs (10,500 af/yr). The subflow is conveyed within bedrock and (probably to a larger extent) within glacial drift deposits which overlie the bedrock.

16. The USGS estimates that recharge from leaky irrigation ditches averages 23.7 cfs annually (17,200 af/yr) and recharge from unconsumed field applications averages 2.1 cfs annually (1,500 af/yr). PGG estimates that piping of ditches has led to a 9.5 cfs (6,900 af/yr or roughly 36-percent) reduction in irrigation recharge.

17. Groundwater levels in the shallow aquifer have declined at most locations. The greatest declines occurred over several square miles near where Highway 101 crosses the Dungeness River. In this area, groundwater levels declined about 3 to 9 feet from the late 1970s through the mid 1990s and about 8 to 17 feet from 1997 to 2007. Moderate declines were also noted between upper Gierin and Cassalery creeks (1 to 3 feet from the late 1970s through the mid 1990s and from 4.4 to 9 feet between 1997 and 2007) and in the Agnew vicinity (8 feet of decline between 1997 and 2007). The geographic extent of areas with relatively high and moderate rates of groundwater level decline is difficult to delineate due to sparse monitoring locations. Other monitored wells show smaller declines, typically on the order of several feet over the latter 10-year period.

18. Current groundwater level monitoring in the middle aquifer is limited to only 5 wells. Moderate declines between 1997 and 2007 occurred in two areas: 7.7 to 9.7 feet of decline was noted in three wells near Gierin and Bell Creeks (including at the City's Port Williams Wellfield); and 7 feet of decline is noted in a well near Agnew. The geographic extent of these declines could not be accurately delineated due to the sparsity of monitoring locations. The fifth well, near Matriotti Creek, showed 2.2 feet of decline. A sixth well, located near the Highway 101/ Dungeness River crossing, showed 9 feet of decline between the late 1970s and the mid 1990s; however, some question exists as to whether this well is completed in the middle or shallow aquifer.

19. Groundwater level monitoring data are available for only 2 lower-aquifer wells between 1997 and 2007. The data show 9.8 feet of decline at the Port Williams Wellfield, and only 1.8 feet of decline about 1.8 miles to the east-northeast at Graysmarsh.

20. The City monitors onsite wells and nearby domestic wells at its Port Williams and Silberhorn wellfields. At Port Williams, the City monitors water levels in the shallow, middle and lower aquifers along with daily wellfield withdrawals. At Port Williams, groundwater levels in all aquifers declined from 1996 through about 2001 to 2003, and have since remained relatively stable, actually exhibiting a minor rise through 2008. Declines have averaged about 5.5 feet in the shallow aquifer, 9.7 feet in the middle aquifer, and 9.8 feet in the lower aquifer. The observed declines also exhibited year-to-year variation, so that for any particular year, the dry-season or wet-season decline might be several

feet larger or smaller than the average. Seasonal water-level variations are most prominent in the lower (pumped) aquifer, with similar (but muted) variations in the middle aquifer and negligible variation in the shallow aquifer.

21. At its Silberhorn Wellfield, the City monitors groundwater levels in two production wells, one monitoring well, and several nearby domestic wells. The Silberhorn wells completed in the shallow aquifer below a confining unit of glacial till (hardpan) which appears to occur in domestic wells throughout the immediate area. Groundwater levels in Silberhorn wells were stable from 1993 to 1997, declined from 1998 to 2005, and have exhibited a reduced rate of decline from 2006 to 2008. Total decline over this monitoring period is on the order of 15 to 20 feet. Similar trends are exhibited in wells as much as a mile away and on either side of the Dungeness River, as reported above for shallow-aquifer wells in "the area where Highway 101 crosses the Dungeness River". The observed water-level declines do not correlate with annual or seasonal variations in Silberhorn pumping, and annual high water levels are commonly noted during summer peak pumping. Seasonal water-level variations appear to correlate most closely to irrigation diversions; however, not in all years.

22. Groundwater level declines at the Port Williams Wellfield appear to have stabilized to the current level of pumping, as is expected when groundwater withdrawals do not exceed flow through the groundwater system. While a hydraulic connection exists between the lower and middle aquifers, available data are somewhat contradictory regarding the degree and mechanism of connection. Additional data collection, aquifer testing, and/or hydrogeologic characterization may be needed to better understand this connection. Heterogeneity may also be affecting the distribution of drawdown in the lower aquifer. The shallow aquifer appears to have less hydraulic connection to underlying aquifers, and is likely more influenced by recharge than pumping. Trends in wells more distant from the wellfield suggest that influences on the shallow and middle aquifers extend beyond purely Port Williams pumping.

23. Groundwater level declines near the Highway 101 - Dungeness River crossing are on the order of approximately 25 feet over 30 years, and have not stabilized. The declines do not correlate well with long-term patterns in Silberhorn pumping, although pumping from other entities is of similar magnitude and historic patterns are not fully documented. Seasonal water-level variations show some correlation to the timing of irrigation diversions, and respond opposite than typically expected to seasonal pumping patterns. The observed water-level declines may be associated with both pumping and irrigation trends. Given the complexity of the local hydrogeology, additional hydrogeologic characterization, continued (or additional) monitoring of groundwater levels and pumping, and consideration of temporal and spatial patterns in ditch leakage would need to be interpreted to better understand the cause of declines. At minimum, continued monitoring of water-levels and pumping, and documentation of further ditch lining, is strongly recommended.

24. Most other areas with ongoing monitoring exhibited only small to moderate groundwater level decline, with several exceptions: an isolated 6.3-foot decline occurred in the shallow aquifer just east of Cassalery Creek, an isolated 7.7-foot decline occurred in the middle aquifer just south of Bell Creek, and declines of 8.4 and 7 feet in the shallow and middle aquifers (respectively) occurred in the Agnew area. Monitoring is too sparse to determine whether the declines are localized or an expression of more wide spread declines.

25. Hydrologic factors most likely to affect future water-level declines include: reductions in irrigation recharge due to further ditch piping, increases in groundwater withdrawals, and reductions in precipitation recharge due to warming climate and increased evapotranspiration. Water-level responses to

these factors will depend on the relative magnitude of the change, the spatial distribution of the change, and local hydrogeology.

26. Groundwater quality was evaluated based on data collected from public water systems and from specific studies performed by Clallam County and the USGS. Groundwater quality is generally good, although elevated nitrates are noted in several areas. The highest nitrate concentrations and most prominent increases over time occur downgradient (north) of Sequim and in the vicinities of Agnew and Carlsborg. Review of electrical conductivity data shows low incidence of seawater intrusion, with a single intruded well noted near west Sequim Bay. Along with isolated exceedances of maximum contaminant levels (MCL's) for nitrate and conductivity, exceedances were noted for iron and manganese, which are secondary constituents included for aesthetic rather than health concerns.

27. The City of Sequim had samples from its Port Williams and Silberhorn wellfields analyzed for tritium and carbon-14 in order to estimate the age of groundwater reaching these wells. The data suggest that both sources represent a mixture of "modern" (post WWII) and "older" (several thousand years old) water. Further sampling is recommended to confirm the findings, particularly from the Port Williams Wellfield where the lower aquifer was expected to be more isolated from younger sources of recharge (a single isotope analysis is not considered conclusive). Consideration of potential effects of subsurface chemical reactions and analysis for other indicators of "modern" water may also improve our understanding of groundwater age and the timing and movement of groundwater from areas of recharge to areas of discharge.

28. For study-area surface waters, elevated fecal coliform bacterial concentrations have been primary water-quality issues due to the potential for human health impacts and consequent restrictions on shellfish harvesting. A number of parameters including water temperature, nitrate, and dissolved oxygen impair surface water quality due to their influence on stream ecosystems and aquatic life including salmon. Fine sediment (turbidity) is noted as an issue on a number of streams, although study-area streams are not formally listed as impaired for turbidity by the State.

29. Recommendations, presented in Section 10 of this report, include: "filling in the gaps" in areas of sparse or no groundwater level monitoring, increased monitoring in the middle and lower aquifers, additional monitoring in areas of growing groundwater withdrawals or newly piped irrigation ditches, removal of duplicate monitoring locations from the City's water-level monitoring network, a focused hydrogeologic study near the Highway 101 – Dungeness River crossing area (where persistent water-level declines are largest), additional age dating and supplemental analyses to better understand hydraulic connections between shallow and deeper portions of the groundwater flow system, continued groundwater nitrate monitoring, use of monitoring data to further calibrate an existing groundwater flow model of the Sequim-Dungeness Peninsula, and use of monitoring to evaluate needs, opportunities and the performance of new and innovative water-resource management strategies.

3.0 HYDROLOGIC SYSTEM

3.1 SURFACE WATER HYDROLOGY

The Dungeness River is the largest river on the Sequim-Dungeness Peninsula, and supplies water to a variety of irrigation districts through ditch diversions. The river emanates from the Olympic Mountains south of the peninsula, and has a drainage area of about 200 square miles. Streamflows are highest during late spring and early summer due to snowmelt in the upper watershed, and during winter months due to sporadic rainfall events. The lowest flows occur in September and October. Irrigation diversions occur year-round, but are highest during the growing season from mid-April to mid-September. Conservation efforts have supported significant reduction of irrigation diversions without significant loss of irrigated acreage.

East of the Dungeness River, most of the streams are relatively small. Streams such as Bell Creek, Gierin Creek and Cassalery Creek have lowland headwaters on the Sequim-Dungeness Peninsula. In contrast, west of the Dungeness River, larger streams such as McDonald Creek and Siebert Creek have headwaters in the Olympic Mountains or their foothills. The smaller streams are predominantly supplied by groundwater discharge and irrigation tailwater, and have relatively constant flows throughout the year (Thomas et al., 1999). Flow regimes in the larger streams are dominated by snowmelt and rainfall runoff, with highest flows during winter and spring.

The hydrology of the Sequim-Dungeness Peninsula is significantly affected by the many irrigation canals, laterals and tailwater ditches that convey water diverted from the Dungeness River (shown on **Figure 1-2**). Historically, these conveyances were also used to route stormwater away from areas of higher development density. Local changes in the management of this irrigation system are discussed in Section 6.

3.2 GROUNDWATER HYDROLOGY

The regional hydrogeology of the Sequim-Dungeness Peninsula was recently characterized by the U.S. Geological Survey (Thomas et al., 1999). Much of the discussion in this section is summarized from this USGS study. The study describes a stratified system of geographically extensive aquifers and aquitards consisting of a “shallow aquifer” underlain by a fine-grained “upper confining bed”, a confined “middle aquifer”, a “lower confining bed”, a “lower aquifer”, and deeper undifferentiated sediments. Over most of the peninsula, all or some of these six hydrostratigraphic units overlie Tertiary bedrock of sedimentary and volcanic origin. The total thickness of unconsolidated sediments beneath the peninsula ranges from zero feet in the south (where bedrock is exposed on the land surface) to as much as 2,500 feet in the northeast. A conceptual hydrogeologic cross-section is presented on **Figure 3-1**. It should be noted the USGS characterization identified these hydrostratigraphic units from a regional perspective, and local variability and complexities are known to exist.

The shallow aquifer is composed of a variety of geologic materials, including: stream alluvium, glaciomarine drift, glacial outwash, ice contact deposits, and glacial till. The alluvium was deposited by the current Dungeness River along its current floodplain and by the ancestral Dungeness River as a floodplain terrace predominantly east of the existing river channel. The glacial and glaciomarine sediments are associated with the most recent continental glaciation (Vashon stade of the Frasier glaciation), which ended approximately 13,000 years ago. Given the range of geologic materials present, the texture of the shallow aquifer can vary from fine grained to coarse-grained (e.g. from clay and silt to sand and gravel), and can be highly heterogeneous (locally variable) thus potentially supporting multiple water-bearing zones. The thickness of the shallow aquifer generally ranges from 50 to 200 feet, although larger and smaller thicknesses have been observed. The aquifer is generally unconfined but can exhibit local confinement where water-bearing zones occur beneath fine-grained sediments. Groundwater flow directions are generally north, trending to northeast to the east of the Dungeness River (Thomas et al, 1999).

The underlying "upper confining bed" is typically 30 to 110 feet thick, and is mainly composed of pre-Vashon silts and clays with locally discontinuous lenses of water bearing sand and gravel. Beneath the upper confining bed, the "middle aquifer" is typically about 10 to 70 feet thick, and contains pre-Vashon glacial outwash deposits of sand and gravel and coarse-grained interglacial deposits. Although fewer wells are completed in the middle aquifer than the shallow aquifer, wells in the middle aquifer potentially offer higher and more reliable yields due to greater available drawdown in the deeper wells. Larger water systems tend to prefer wells completed in the middle or lower aquifer to wells completed in the shallow aquifer. Groundwater flow directions tend to "fan out" radially beneath the Sequim-Dungeness Peninsula, with northeast flow in the vicinity of Sequim (ibid). Groundwater in the middle aquifer is confined.

The middle aquifer is underlain by the "lower confining bed", composed of till and interbedded clay, silt and fine-grained sand with possible discontinuous lenses of water-bearing sand. Because few wells penetrate this confining unit, the USGS define a broad range for its thickness (10 to 300 feet) with a "typical" thickness of 100 feet. A thickness of about 70 feet is observed at the Port Williams Wellfield. The underlying "lower aquifer" is composed of sand with thin lenses of sand and gravel, silt and clay. Information is limited due to few well completions. The aquifer is present in the northern and eastern portions of the peninsula, and absent in the southern and western portions where bedrock occurs closer to the land surface. It's thickness is believed to range from 10 to 180 feet, with a typical value of about 90 feet. While few wells are completed in this aquifer, it is capable of producing significant amounts of water and serves major water users, including the City of Sequim at its Port Williams Wellfield. Groundwater flow directions in the lower aquifer are believed to be similar to those documented in the middle aquifer. Groundwater in the lower aquifer is confined.

The lower aquifer is underlain by "undifferentiated deposits", which reach thicknesses as great as 1000 feet in the northern peninsula but pinch out against bedrock in southern and southwestern portions of the peninsula. While productive aquifers may exist in the undifferentiated deposits, few well completions occur in this unit. A deep well at the Weyerhauser Seed Orchard (T30N/R4W-9) encountered a fairly transmissive aquifer below 800 feet depth (Robinson & Noble, 1974), although PGG's evaluation of the aquifer test data suggest limited aquifer recharge. In contrast, exploratory drilling at the Port Williams Wellfield to a depth of 852 feet did not encounter significant productive materials beneath the lower aquifer. The underlying bedrock is composed of tertiary sedimentary and volcanic rocks, and is an unreliable source of groundwater because it yields small quantities of water to wells.

The groundwater flow system is recharged at the surface from precipitation, irrigation applications to fields, septic system effluent, and seepage losses from unlined irrigation ditches, the Dungeness River and other streams. Additional recharge occurs via subsurface pathways near the foothills of the Olympic Mountains, where groundwater in glacial drift and underlying bedrock discharge into the unconsolidated aquifers described above. Recharge incident upon the land surface flows downward into the various aquifers and aquitards; and eventually discharges into marine waters, the lower reaches of various streams, portions of the Dungeness River, and to wells. Groundwater flow patterns have both horizontal and vertical components. Typically, flow within aquifers is predominantly horizontal whereas flow between aquifers (through aquitards) is predominantly vertical. Downward flow generally occurs in recharge areas, whereas upward flow occurs along discharge areas (e.g. near the coast and lower stream reaches). Vertical flow rates are relatively slow due to the low permeability aquitards between aquifers. Water levels measured at the Port Williams Wellfield indicate downward flow between the shallow, middle and lower aquifers.

4.0 CLIMATE TRENDS

Climate is a key factor affecting surface-water flows and groundwater recharge. Dungeness River flows are largely affected by precipitation in the Olympic Mountains, with snowmelt providing high flows during the spring freshet and sustained baseflow during the summer. Climate based variations in groundwater recharge are typically expressed as variations in groundwater levels, and can affect groundwater-dependent surface-water features such as local streams and wetlands. PGG reviewed climatic data over the study period (and during antecedent years) to support our analysis of groundwater level and streamflow trends.

4.1 DATA SOURCES

Climate data were obtained from online data repositories and other sources. Precipitation and temperature data for Sequim were obtained from the Western Regional Climate Center (WRCC, 2008). Snowpack data were obtained from the Natural Resources Conservation Service (NRCS, 2008). In addition, predictions of climate change were based on published reports for the Washington State and Puget Sound.

Long-term climatic monitoring on the Sequim-Dungeness Peninsula has been performed solely by the City of Sequim. Temperature and precipitation data for Sequim are based on a composite of data from two stations. The first Sequim weather station (station number 457538) was operational from June, 1916 through September, 1980. The station was replaced with a station at a nearby location (station number 457544) in October, 1980. Data from the two stations provide a combined 77-year record. However, because the two stations were not co-located there appears to be a slight discrepancy in temperature records before and after 1980, as discussed in Section 5.3. The shift in station location does not appear to have affected precipitation data.

Snowpack data have been measured on a regular basis since 1949 in the Olympic Mountains, and even longer at other stations in Washington State. Snowpack measurements provide baseline information of water storage for water resource planners. Long term snowpack monitoring data are available from two nearby locations in the Olympic Mountains: Hurricane Ridge (Station 23B03) and Deer Park (Station 23B04). These snow survey locations were originally visited at least once a year on April 1, typically the date with the peak snowpack, but are now more commonly visited several times a year. Hourly to daily data are available from the Dungeness Snotel Station (Station 23B16S; 4,010 ft elevation) from 1998 through 2008. Measurements at snow survey and Snotel stations are converted to snow water equivalent (SWE), the amount of water which would have fallen if precipitation had been rain instead of snow.

Several climate change studies have been conducted that are relevant to Washington State, ranging from analysis of geologic and climate observations to predictive global and local climate models (Mote, et al., 2008a; Mote, et al., 2008b; Miles, 2009). The Washington State Legislature commissioned a study of the impacts of climate change in Washington State (HB1303, 2007). This study included examination of climate models specific to Washington State, and potential impacts of climate change on the hydrology, environment and economy of the state. The study has resulted in two principal documents, an interim report (Miles, et al., 2007), and a final report (Miles, et al., 2009).

4.2 PRECIPITATION

4.2.1 Rain

The rain shadow of the Olympic Mountains has a strong influence on the amount and distribution of precipitation on the Sequim-Dungeness Peninsula. **Figure 4-1**, an isohyetal map of the study area, shows how higher precipitation in the southern study area (closer to the Olympic Mountains) transitions to lower precipitation in the northern study area (closer to the coast). This "rain shadow" effect causes the City of Sequim to have a relatively dry climate with only 15.9 inches of precipitation per year on average between 1980 and 2007 (**Figure 4-2**). Precipitation increases rapidly to the south to 50 inches a year in the Olympic Mountains, and also to the west where the Olympic Mountains produce less of a rain shadow (**Figure 4-1**).

Precipitation varies from year-to-year, and has ranged from 11.35 inches (1994) to 20.51 inches (1997) between 1980 and 2007 (**Figure 4-2**). No clear trend of increasing or decreasing precipitation was observed in the Sequim data over this time period, or when PGG considered a longer time period (1938 through 2007). Between 1980 and 2007, the most significant sustained period of above-average precipitation occurred from 1995 to 1999, and the most significant sustained periods of below-average precipitation occurred from 1985 to 1989 and from 2000 to 2005.

Precipitation varies from month to month with the majority of precipitation falling in November (2.7 inches), December (2.1 inches) and January (2.1 inches) (**Figure 4-2**). Summers are generally dry, with less than an inch of rain falling in a typical July, August or September.

4.2.2 Snow

Snowpack, measured as the snow water equivalent (SWE) has been recorded at an automated Snotel station in the upper portion of the Dungeness Watershed (Station 23B16S; 4,010 ft elevation) since 1998, and manually at Hurricane Ridge (23B03) and Deer Park (23BS04) two to three times a year since 1949. SWE is the amount of water stored in the snowpack expressed as inches of water. SWE does not account for losses due to melting and sublimation from the snowpack. Station locations are shown on **Figure 4-1** and long-term snowpack data are presented on **Figure 4-3**.

Records at the Hurricane Ridge and Deer Park snow survey locations show a long-term decline in SWE. April 1 snow pack measurements are estimated to have decreased 64 percent at Deer Park and 71 percent at Hurricane Ridge from 1950 to 2006 (Mote, et al., 2008). Annual precipitation at Sequim has changed little over the same time period, suggesting little change in total precipitation in the upper portions of the watershed, but that less of the precipitation is falling as snow. This trend is consistent with declining snowpack observations throughout Western Washington (Mote, et al, 2008), and affects seasonal streamflow in the Dungeness River (Section 5.3). Regionally declining snowpacks are mostly attributed to slightly warmer winters. Accordingly, the biggest changes in snowpack in Washington State have mostly occurred at lower elevations closer to the snow line.

Climate models indicate that the trend of decreasing snowpack storage is likely to continue with climate change, as discussed in Section 4.4.

4.3 TEMPERATURE

Figure 4-4 shows mean annual maximum, average and minimum temperatures for Sequim, Washington from 1916 through 2007. Sequim has a temperate climate with mild winters and cool summers. Seasonal temperature variations from 1980 to 2008 are summarized below (WRCC, 2008).

- Sequim averages an annual temperature of 57.7 degrees Fahrenheit (ºF).
- Winter daily temperatures range between 31.2 ºF and 47.1ºF *(average low vs. average high)*.
- Spring daily temperatures range between 37.8 ºF and 56.6 ºF.
- Summer daily temperatures range between 48.9 ºF and 68.7 ºF.
- Fall daily temperatures range between 38.9 ºF and 58.3 ºF.

As discussed above, the Sequim station was moved in October 1980 which appears to have caused a change in the recorded temperature where post-1980 minimum- and average-temperatures biased about about 1 ^{o}C (1.8 ^{o}F) low relative to pre-1980 measurements (**Figure 4-4**). In contrast, a review of measurements from nearby Port Angeles showed no significant temperature shift between pre-1980 and post-1980 records.

Temperature plots show gradually increasing temperatures through the period of record (**Figure 4-4)**. Average annual temperature at Sequim has increased by at least 1 ºC (1.8 ºF) between the start of observations in 1916 and 1980 (**Figure 4-4**). Correcting for the 1980 change in weather station location, the increasing trend appears to continue from 1980 through present.

The observed temperature increases are consistent with temperature changes observed throughout Puget Sound, which has increased approximately 1.3 ºC (2.3 ºF) between 1900 and 2000, 0.9 ºC (1.6 ºF) of which occurred after 1950 (Snover, et al, 2005).

4.4 CLIMATE CHANGE PREDICTIONS

Climate change is increasingly recognized as an influence on long term water budgets and water availability in Washington State (Miles, et al., 2009). Climate change includes variations in many factors including: mean annual and seasonal temperatures, total precipitation, amount of the precipitation falling as snow, and rising sea levels. While climate change is a global issue, the specific effects of climate change vary depending on location.

A number of global climate models (GCMs) have been developed to investigate potential climate change scenarios for the Pacific Northwest (Miles, et al., 2007, 2008). While there are some disagreements between the details of the models, long-term trends in precipitation, temperature, and sea level have been identified (Miles, et al., 2009). GCMs uniformly predict increasing temperatures for the coming decades, with a more pronounced effect at higher elevations than the regional average. The regional climate models also show that the effects of climate change will be felt differently throughout the state depending on the location.

4.4.1 Predicted Temperature Increases

GCMs predict warmer temperatures for the Puget Sound region, including the Sequim-Dungeness area. The predicted temperature trends are (Miles, et al, 2007):

- Mean annual temperatures are expected to increase by between 0.9 and 2.9 ºC (1.6 and 5.2 ºF) by 2040.
- Summer temperatures are expected to increase by between 0.9 and 4.4 ºC (1.6 and 7.9 ºF) by 2040.
- Winter temperatures are expected to increase by between 0.6 and 2.8 ºC (1.1 and 5.0 ºF) by 2040.

Both summer and winter temperature increases will influence the hydrology of the Sequim area, mostly by reducing water storage in the seasonal snowpack and increasing evapotranspiration (ET), particularly during the summer irrigation months. Increases in ET would reduce groundwater recharge rates (if precipitation does not also increase) and increase irrigation requirements. Section 7.3 provides calculations which demonstrate how increased temperatures would increase ET and thus reduce groundwater recharge.

4.4.2 Predicted Changes in Precipitation and Snowpack

GCM predictions of change in precipitation vary depending on the model, ranging from a predicted decrease of 11 percent and a predicted increase of 12 percent by 2040 (Miles, et al., 2009). The average GCM prediction is a slight annual increase of about 2 percent by 2040. Given the annual variability in precipitation (**Figure 4-3**), a 2 percent change in precipitation is not likely to be noticeable. However, GCMs consistently predict wetter falls and drier summers (Miles, et al. 2009; Salathe, et al., 2009).

Changes in snowpack are influenced by both changes in temperature and precipitation. GCMs predict decreased snowpack SWE in the Olympic Mountains as a result of the warmer winters. Statewide, the average spring SWE is predicted to decline by between 26- and 71-percent by 2060 (Salathe, et al.,2009). The decrease in snowpack is one of the more robust features of the climate predictions, and appears to be driven primarily by increasing winter temperature. Snowpack has a strong influence on the hydrograph of the Dungeness River, and decreasing snowpack SWE is expected to change the timing of runoff, as discussed in Section 5.3.

4.4.3 Sea Level Rise

Relative sea level (RSL) change in the Sequim area is a balance between rising absolute sea level (sea level compared to a fixed elevation) and the simultaneous rise of the land surface due to uplift of the Sequim-Dungeness Peninsula (Mote, et. al, 2008). Relative sea level estimates for the northwest Olympic Peninsula in 2050 range from a decline of 5 inches to a rise of up to 14 inches (Mote, et al., 2008).

RSL estimates are based on the difference between absolute sea level rise and uplift of the ground surface, both of which have uncertainty. Absolute sea level is rising, and is expected to continue to rise in response to a combination of melting glaciers and ice caps, thermal expansion of the oceans, changes in salinity, and changes in wind and weather patterns). The Sequim-Dungeness Peninsula is rising due to a combination of plate tectonic forcing and isostatic rebound (crustal uplift as recovery from removal of the weight of ice sheets at the end of the last ice age). Estimates of absolute sea level rise for the Pacific Northwest by 2050 range from 8 to 45 cm (3.1 to 17.7 inches). Surface uplift rates in the Sequim area are approximately 1.5 to 2 mm/yr (0.06 to 0.08 in/yr) (Mote, et al., 2008), suggesting a 2.5 to 3.3 inch rise of the land surface by 2050.

5.0 STREAMFLOW TRENDS

The Dungeness River is the primary drainage in the Sequim area with headwaters in the Olympic Mountains and discharge to the Straits of Juan de Fuca near Dungeness Spit.

5.1 DATA SOURCES

Streamflow data for the Dungeness River were downloaded from the USGS water resources webpage for USGS gauging station 12048000, located 4.8 miles southwest of Sequim, at river-mile 11.8 (USGS, 2008). This station was selected for characterization of Dungeness River instream flows because it is upstream of irrigation diversions.

Streamflow data for independent small streams was summarized by PGG in a technical memorandum entitled "*Assessment of Baseflow in Small Streams of the Dungeness Watershed*" (PGG, 2008a). Data referenced in this memorandum were compiled from Clallam County Streamkeepers, the Jamestown S'Klallam Tribe, Graysmarsh, Ecology and the USGS. The data extended through mid 2007. PGG's interpretation of the data was aided by input from members of the Technical Advisory Group (TAG) for Aquifer Recharge in Clallam County (a working group of the Dungeness River Management Team).

5.2 DUNGENESS RIVER

5.2.1 Dungeness River Flow Regime

The Dungeness River has two annual peaks in flow corresponding to the winter rainy season and the spring freshet. The timing and magnitude of seasonal variations in flow are influenced by the timing of large storms, temperature trends, and the amount of snow available to melt. Simonds & Sinclair (2002) present a statistical summary of historic flows between 1924 and 1996. Historic flows during the winter rainy season (e.g. November through February) typically ranged between 200 and 500 cfs (25^{th} and 75^{th} percentile), with median flows on the order of 300 cfs. Historic flows during the spring freshet (e.g. May through July) typically ranged from about 500 to 900 cfs, with median flows on the order of 600 to 700 cfs (ibid). Peak flows during storm events can reach 5,000 to 7,000 cfs (USGS, 2007). During the late summer and fall (September and October), historic low flows typically ranged from about 120 to 180 cfs, with median flows on the order of 140 cfs.

5.2.2 Changes in Dungeness River Flow

Figure 5-1 presents a comparison of average daily streamflows over two periods: 1938 to 1980 and 1980 to 2007. Winter flows have increased from the earlier to the latter period, presumably due to warmer winters, more precipitation falling as rain rather than snow, and more snowmelt during winter months. Similar trends of increased winter flows and decreased summer flows are observed in snow-fed watersheds throughout the Puget Sound region.

The onset and the decline of the spring freshet has moved earlier in the year and associated early-summer flows have decreased over the 70 years of record. Average flows at the peak of the freshet decreased by approximately 100 cfs between the two time periods. The reduction in freshet reflects the reduced snowpack discussed in Section 4.2.2.

Low flows in the Dungeness River have decreased over time. The lowest flows of the season usually occur between September 25 and 30, and are used herein as the measure of baseflow. Flows during this period are also affected by irrigation diversions (discussed in Section 6.4). Late September baseflows have dropped from an average of about 170 cfs (1938 to 1980) to about 140 cfs (1980 to 2007). This 30 to 40 cfs drop represents a 15- to 25-percent decrease located upstream from irrigation diversion points, thus indicating that less water is available for irrigation.

5.2.3 Future Dungeness River Flows (Climate Predictions)

Climate change is expected to continue the trend of reduced flows during the freshet and summer months, and increased winter flows (Mote, et al, 2008). As discussed above, these changes in streamflow patterns and quantities in the Dungeness River are related to changes in snowpack and storm timing in the watershed. As the temperature warms, the snowline is expected to rise, reducing the size of the snowpack, even if the total amount of precipitation is the same. Because more of the precipitation will be falling as rain in the headwaters of rivers, the spring freshet is expected to decline and seasonal streamflow is expected to shift towards higher winter flows. Declines are therefore expected during the early irrigation season (e.g. April 15 to July 15). It is beyond the scope of this report to make quantitative predictions for changes in the Dungeness River flow regime, but the changes will be sensitive to the amount and timing of seasonal snowpack. Similar trends are anticipated in rivers and streams throughout Washington State.

5.3 SMALL STREAMS ON THE SEQUIM-DUNGENESS PENINSULA

PGG analyzed streamflow data (through mid 2007) from independent streams located on the Sequim-Dungeness Peninsula (PGG, 2008a). Streams included in the analysis were Morse Creek, Bagley Creek, Siebert Creek, McDonald Creek, Matriotti Creek, Meadowbrook Creek, Cassalery Creek, Gierin Creek, Bell Creek, and Johnson Creek. Interpretation of trends included input by members of the TAG, as noted in Section 5.1. PGG's analysis focused largely on changes in baseflow. Conclusions from PGG's 2008 memorandum are summarized below:

- Miscellaneous data from Morse Creek date back to 1997; whereas continuous data were collected at river mile (RM) 6.5 (1966-1976 and 2003-present) and RM 0.5 (2000-2007). No trends in baseflow or total flow were noted over the period of record.
- Flow data for Bagley Creek are limited to miscellaneous data starting in 1988. The data are too sparse to perform meaningful analysis of flow trends over time.
- Miscellaneous data from Siebert Creek date back to 1991; whereas continuous data were collected at RM 3.1 (1952-1969) and RM 1.3 (2002-present). The miscellaneous data are too sparse for trend analysis, and no trends in baseflow or total flow were noted over the limited periods of continuous flow data.
- Continuous data have been collected on McDonald Creek from 2003 through present at RM 3.1. Late summer baseflows declined between 2003 and 2006 from 1.7 cfs to 0.4 cfs. The cause of this decline is unknown, and the short time-period does not lend itself to generalization of long-term trends. It should be noted that the Agnew Irrigation District uses portions of McDonald Creek (above their diversion at RM 3.2) for conveyance, and holds a water right to divert creek flows up to 5 cfs.
- Flow data for Matriotti Creek are limited to miscellaneous data starting in 1986 through present. The data suggest that low flows in the lower reach (below RM 0.5) may have decreased between 1991 and 2007, although the "spotty" nature of the miscellaneous data makes it difficult to draw solid conclusions. The lowest miscellaneous flow measurements at RM 0.3 in 1991 were about 15 cfs; whereas

miscellaneous low flows in 2005 through 2007 ranged from about 0.7 to 5 cfs. Members of the TAG identified several possible reasons for the changes, including: lining of nearby irrigation ditches (reduced groundwater recharge) starting in 2000, changes in conveyance and tailwater management starting in 1995, reduction in leakage from the Cline crossing at RM 3.2 in 1998, and possibly the rerouting work done at RM 5.5 between 1987 and 1994.

- Flow data for Cassalery Creek are largely limited to miscellaneous data starting in 1986 through present. Near the mouth (≤RM 0.6), 1988-89 streamflow data show summer low flows typically ranging from 2 to 4 cfs. In contrast, data collected post-1999 show low flows typically ranging from 1 to 2.5 cfs. TAG members identified that the change in flow regime appears to have occurred in 1999, about the same timeframe that a restoration project was performed on the creek.
- The bulk of the flow data for Gierin Creek were collected by Graysmarsh starting in 1997. The data include continuous data at the Graysmarsh tidegate (starting in 1998) and weekly data at several locations upstream of the marsh. The data do not reveal a conclusive trend in baseflow or high flows.
- Flow data for Bell Creek are limited to miscellaneous data starting in 1986 through present. Flow data from the lower reach shows low flows at RM 0-0.2 typically ranging from 2-3 cfs prior to 1993, and then reducing to between 0.5 to 1.5 cfs after 2001. The sparse timing of the miscellaneous flow data does not allow identification of a "transition period" between these two low-flow regimes; however, several data points from 1998-2001 appear to be more similar to the earlier period than the latter period. The overall range of flows at RM 0-0.2 typically extends from about 2 to 7 cfs prior to 1993, compared to about 0.2 to 4 cfs after 2001. Ecology analyzed changes in streamflow at RM 0.1-0.2 between 1987-97 and 1999-2004, and also noted reductions in flow (Caldwell, 2007). The reasons for these declines are unknown, however it is worthwhile to note that Bell Creek is influenced by irrigation conveyance, stormwater runoff and spring discharge (which is noted to have declined somewhat in recent years). Data from the middle and upper reaches of Bell Creek are too sparse to define trends.
- Flow data for Johnson Creek are limited to miscellaneous data starting in 1986 through present. Johnson Creek is used for conveyance of irrigation tailwater (Highland Irrigation District). Low flows near the mouth of Johnson Creek are typically less than 1 cfs. Although the data suggest a minor reduction in baseflow in this location between the late 1980's and 2006-2007, the data are too sparse to be conclusive or to differentiate trends in natural baseflow from trends in irrigation practices.

6.0 WATER USE TRENDS

Water use is a key component of the water budget capable of affecting groundwater levels and stream baseflows. Water use has been increasing the Sequim-Dungeness area as the population grows, public water systems are expanded, and new domestic (exempt) wells are drilled to meet increased demand. Irrigation diversions from the Dungeness River have decreased over time with conservation activities (e.g. ditch piping), although actual irrigated acreage has changed little. This section provides estimates of changes in water use over the study period.

6.1 DATA SOURCES

Water-use trends are examined from a combination of pumping data, counts of domestic wells, reported sources and numbers of hookups for Group A and Group B public water systems, and gauging of irrigation diversions.

The City of Sequim provided pumping records for production wells in the Port Williams and Silberhorn well fields from 1993 through 2008, in addition to maps of sewered areas in the Sequim vicinity. The Clallam County Public Utility District provided pumping data for the Evergreen and Carlsborg water systems. Public water system information (number of hookups, source capacity, system status, and source locations) were provided by the Washington Department of Health (WDOH) through both data requests and from the Sentry online database. Information on private wells was obtained from the well log database maintained by Ecology.

Groundwater withdrawals for irrigation, stock and industrial use were estimated for the mid 1990's by Tetra Tech FW, Inc. (2003).

Irrigation and agricultural withdrawals from the Dungeness River from 2000 through 2007 were obtained from the Department of Ecology (Ecology, 2008a). Ecology provides online access to daily gauging data for withdrawal points from the Dungeness River into irrigation ditches. Earlier diversions were summarized in the Comprehensive Irrigation District Management Plan (CIDMP) (EES, 2003).

6.2 GROUNDWATER USE

Groundwater use is examined as groundwater withdrawals and as consumptive use. Groundwater withdrawals are simply the amount of water removed from aquifers for use. Consumptive use starts with the groundwater withdrawal but also considers how much of the water is returned to groundwater and how much is lost from the system through evapotranspiration or discharge away from the area.

Groundwater withdrawals for residential use range, in order of increasing system size, from individual domestic wells to Group B water systems to Group A water systems. Group B water systems serve fewer than 15 service connections and fewer than 25 people a day less than 60 days per year (WAC 246-290-020). Group A water systems are community and non-community water systems which serve 15 or more year-round service connections, 25 or more year-round residents for 60 or more days a year, or 1,000 or more people for at least 2 consecutive days per year (WAC 246-290-020). Non-community and transient water systems constitute a small fraction of the systems in the area and are not included in this analysis.

Groundwater is also withdrawn for irrigation (including golf courses), stock (primarily dairy operations), and industrial operations. Estimates of total withdrawals and consumptive use are summarized below, with detailed descriptions in the following sections.

- Group A water systems serving 8,458 reported hookups withdrew an estimated 2.7 mgd (3,030 af/yr) in 2007, of which 1.7 mgd (1,910 af/yr) was estimated to be consumptive use.
- Group B water systems serving 687 reported hookups withdrew an estimated 0.38 mgd (430 af/yr) in 2007, of which 0.21 mgd (240 af/yr) was estimated to be consumptive use.
- Approximately 5,253 domestic wells withdrew an estimated 2.9 mgd (3,250 af/yr) in 2007, of which 1.5 mgd (1,680 af/yr) was estimated to be consumptive use.
- Groundwater pumping for irrigated agriculture and golf courses was estimated at about 0.4 mgd (450 af/yr) during the mid 1990's (later estimates are unavailable). PGG did not estimate the portion of consumptive use for irrigation withdrawals.
- Other water uses (dairy and industrial) were estimated to withdraw about 0.1 mgd (110 af/yr) during the mid 1990's. PGG did not estimate the consumptive portion of these uses.

6.2.1 Public Water Systems

6.2.1.1 *Estimating Residential Water Use*

Pumping records of actual groundwater withdrawals and water use were not readily available for most public water systems or domestic wells. For water systems without pumping records, PGG estimated water use based on the number of hookups and expected volumes of residential water use. Total water use at an individual residential hookup was estimated as the sum of household use and residential irrigation with the following formula:

$$U_T = \text{(Household Use)} + \text{(Irrigation Use)}$$

$$U_T = (U_H) + (A_I * P/E_I) \qquad \text{(Equation 6-1)}$$

Where: U_T = total use (volume/year)
U_H = household use (volume/time)
A_I = assumed irrigated area per residence or hookup (area)
P = plant irrigation requirement (length/time)
E_I = irrigation efficiency (unitless ratio)

Household use is predominantly indoor, but includes other activities such as watering outdoor potted plants, car washing, washing down paved surfaces, etc. Household use is estimated to be about 170 gpd per ERU (equivalent residential unit) based on systems with little residential landscaping (Montgomery Water Group, 1998). Estimated irrigation use is sensitive to assumptions regarding irrigated acreage per residence, irrigation requirements for landscaping, and irrigation efficiency. Although Ecology allows ½ acre of irrigation for the exempt water rights commonly associated with domestic wells, most residential lots in the area are not large enough to support ½ acre of irrigation. An irrigated area of 1/8 acre was assumed for each Group A residence, and ¼ acre for Group B and domestic well residences. A net irrigation requirement of 15.5 inches/year was assumed for lawns based on estimates of water requirements for pasture and turf (Montgomery Water Group, 1998). Because irrigation applications are typically inefficient, actual pumping for irrigation purposes is expected to exceed plant requirements. An efficiency of 75 percent was assumed representative for sprinkler irrigation. Based on these numbers, the average annual water use per residence was estimated to be 362 gpd for Group A systems and 554 gpd for Group B systems and domestic wells. Because these estimates represent annual averages, higher rates of use are likely to occur during the growing season and lower rates of use will occur during the remainder of the year. **Table 6-1** lists the values used in water use calculations.

It should be noted that the domestic and irrigation use assumptions presented above represent PGG's best estimates for residential units. Numbers can vary widely with different land use practices and dwelling occupancy rates. A review of water use by various purveyors in the Sequim vicinity (6 "Group A" water systems) shows use per ERU widely ranging from 173 to 495 gpd (Montgomery Water Group, 1998). Actual water use from public water systems and individual domestic wells can only be quantified through metering and associated data reporting.

The distribution of groundwater withdrawals and consumptive use is described in the sections below.

6.2.1.2 *Group A Water System Withdrawals*

City of Sequim

The City's water supply system consists of three sources: the Dungeness River Infiltration Gallery, the Silberhorn Wellfield, and the Port Williams Wellfield (**Figure 1-1**). Prior to construction of the Infiltration Gallery, the City diverted water directly out of the Dungeness River. In 1953 the City was authorized to withdraw water from the infiltration gallery, and in 1954 a second surface-water diversion was authorized to convey water from the river to the infiltration gallery. Groundwater withdrawals from the Silberhorn Wellfield were authorized in 1975, and pumping from the Port Williams wellfield was authorized in 1996. The City holds water rights to withdraw up to 1,850 acre-feet per year from its three sources combined. Maximum instantaneous withdrawals range from 2,500 gpm at the Port Williams Wellfield to 2,100 gpm at the Silberhorn Wellfield and 718 gpm from the Infiltration Gallery.

The Infiltration Gallery is located east of the Dungeness River in the NE ¼ of the NW ¼, Section 12, Township 29N, Range 4W. It consists of a large-diameter collection well located east of the river, from which horizontal interception pipes extend to about 150 feet from the current stream channel. The interception pipes are buried and set in gravel pack. Until the mid 1980's, the City used to supplement Infiltration Gallery yield by diverting surface water from the Dungeness River into the gravel pack surrounding the laterals. Now that this practice is discontinued, discharge from the Infiltration Gallery flows via gravity to the distribution system. The maximum instantaneous capacity of Infiltration Gallery is unknown; however the City's water right provides a maximum instantaneous allocation (Qi) of 718 gpm (1.03 mgd), and average monthly rates of withdrawal have typically ranged from 0.1 to 0.6 mgd (with a maximum monthly withdrawal of 1.0 mgd.

The Silberhorn wellfield is located in Doctor James Standard Memorial Park, 750 feet west of the intersection of Silberhorn and River Roads (NE ¼, NW ¼, Section 25, Township 30N, Range 4W). Three production wells were constructed between 1975 and 1985; however, Well #1 is no longer in production and is currently used for groundwater level monitoring. Well completions range from 132 to 220 feet below land surface (bls), and instantaneous pumping rates range from about 300 to 370 gallons per minute (gpm) on demand. Drilling information and pumping responses indicate that groundwater occurs under confined conditions at the wellfield. The three wells are tentatively identified as completed in a confined portion of the shallow aquifer (PGG, 1996). Occurrence of glacial till above the completion intervals and the confined nature of the aquifer conform to the USGS description of the shallow aquifer summarized above.

The Port Williams Wellfield is located just north of Port Williams Road, about 500 feet west of its intersection with Brown Road (SE ¼, NW ¼, Section 17, Township 30N, Range 3W). Two production wells were installed in 1995 and 1998, and are both completed in the lower aquifer. Well completions range from 284 to 411 feet bls. While maximum well yields range from 635 to 800 gpm, the wells are currently pumped on demand at instantaneous rates between 600 to 670 gpm. A third production well was installed in 2008 (PGG, 2008b); however, this well has not yet been put into service.

The Port Williams wellfield was constructed in order to shift a portion of the City's pumping withdrawals away from the Silberhorn Wellfield and the Dungeness River Infiltration Gallery towards a deeper groundwater source that has less hydraulic connection with the Dungeness River. Reduced withdrawals from the Infiltration Gallery are beneficial in that they leave more flow in the Dungeness River to benefit fish habitat, and were agreed upon between the City and Ecology in 1997 (Ecology, 1997). Reduced withdrawals at the Silberhorn Wellfield serve to reduce pumping stress on an aquifer with a history of local groundwater level decline (see Section 8.2), and is also likely to benefit Dungeness River streamflow.

The City's water supply system is the largest public water system on the Dungeness Peninsula, with an average daily production of over 0.95 million gallons per day (mgd) accounting for 35 percent of the all Group A water system withdrawals (**Table 6-2**). As of 2007, the system was registered with WDOH as having 2,612 connections, and annual pumping averaged 0.95 mgd. Over the 5-year period between 2003 and 2007, withdrawals were distributed as 43% from Port Williams, 30% from Silberhorn, and 27% from the infiltration gallery.

Figure 6-1 illustrates the historic distribution of pumping between 3 source locations (available data prior to 1993 indicate only total pumping, and do not distinguish between sources). When the Port Williams Wellfield came online in 1996, the City shifted a portion of its pumping from Silberhorn to Port Williams in order to help offset groundwater level declines in the Silberhorn vicinity. The figure shows a reduction in Silberhorn pumping starting in 1996 (Port Williams was offline for much of 1997). However, Silberhorn pumping began to increase towards pre-1996 levels after 2006. Port Williams pumping has remained relatively steady from 2003 through present, with above-average pumping in 1999, 2001 and 2002. Withdrawals from the infiltration gallery decreased from 1992 through 1999, and then began a gentle rise through present. Port Williams pumping has effectively replaced a significant portion of historic pumping from the infiltration gallery and has accommodated a noteworthy share of new water demand associated with population growth. Demand trends are represented by total groundwater withdrawals, which increased from 1978 through 1989, remained relatively stable between 1989 and 2000 (with above-average pumping in 1994 and 1995), and increased again from 2001 through 2007 (**Figure 6-1**).

<u>All Group A Water Systems</u>

There are 41 Group A water systems in the study area. After the City of Sequim, the next largest water systems are the Evergreen Water System (operated by Clallam County PUD), Sunland Water District, Estates Incorporated, and Solmar Water Company systems (**Table 6-2**). Pumping records are available for water systems operated by the Clallam PUD, including the Evergreen and Carlsborg LUD systems (**Figure 6-2**). Water use for all other Group A water systems are estimated using Equation 1, the values listed in **Table 6-1,** and multiplying by the number of connections on file with WDOH (**Table 6-2**). Estimated groundwater withdrawals from *all* Group A water systems totals 2.7 mgd (including City of Sequim).

Many Group A water systems have multiple wells (sources) providing water into their distribution systems, some of which may be more than a mile apart. PGG estimated the withdrawal from each Group-A source by prorating the estimated use by the pumping capacity of each of the wells in the system. These values were then grouped by geographic area. The majority of Group-A pumping in the study area occurs east of the Dungeness River (2.24 mgd), with approximately 18 percent of pumping west of the Dungeness River (0.49 mgd). Significant Group-A pumping occurs near City of Sequim wellfields, with 0.14 mgd of pumping within 1 mile of the Port Williams Wellfield and 0.29 mgd of pumping within 1 mile of the Silberhorn Wellfield. The geographic distribution of Group-A pumping is further discussed with respect to consumptive use in Section 6.3.

PGG reviewed water-use analysis performed by TetraTech FW, Inc. (2003) for the period of 1995 through 1997 to estimate how Group A withdrawals are distributed among aquifers. The TetraTech FW analysis specifies the completion aquifer and estimated annual average withdrawal for all wells with readily available data (estimated pumping from the larger Group A systems was based on 1996 data). PGG reviewed the wells within our study area, and found that Group A pumping in the mid 1990's was roughly distributed as follows: 67 percent from the shallow aquifer, 14 percent from the middle aquifer, and 18 percent from the lower aquifer. Shallow aquifer pumping includes Sequim's Infiltration Gallery and Silberhorn Wellfields. The data considered in TetraTech FW's study did not fully reflect the City's shift in pumping from its shallow aquifer sources to the Port Williams Wellfield, completed in the lower aquifer. Based on a more recent distribution of pumping distribution between the City's sources, adjusted Group A pumping is more likely distributed as follows: about 53 percent from the shallow aquifer, 14 percent from the middle aquifer, and 31 percent from the lower aquifer.

Group B Water Systems

Group B water systems account for a small percentage of the water use in the study area. There are 197 active systems in the study area averaging 3.3 connections per system (687 total hookups). Group B water use per-hookup is expected to be similar to domestic water wells because the smaller Group B systems are less likely to charge for water use, and are more likely to occur in sparsely populated areas where residential parcels are larger. Total withdrawals from Group B systems in the study area are estimated at 0.38 mgd.

6.2.2 Domestic Well Withdrawals

The number of domestic wells in the Sequim-Dungeness Peninsula has increased steadily with population growth in the area. Ecology's online well log database showed 5,253 well logs with completion dates through 2007. As described above, only a small fraction of these wells are Group A or Group B public water systems. For the purpose of this study, PGG assumed that Ecology's well logs are roughly representative of domestic wells within the study area. It should be noted that a portion of *actual* existing domestic wells may not be reported to Ecology; however, a portion of reported wells may no longer be in use.

New wells have increased at a considerable rate within the study area, roughly doubling between 1993 and 2007 (**Figure 6-3**). Since PGG's previous "2001 Monitoring Study", well logs on record increased by 38 percent from 3,853 to 5,253. The USGS estimated that approximately 82 percent of domestic pumping within their primary study area was obtained from the shallow aquifer (Thomas et al, 1999). A review of TetraTech FW data for PGG's study area showed that about 73 percent of domestic wells are believed to be completed in the shallow aquifer and 23 percent in the middle aquifer

New well installations have increased at similar rates both east and west of the Dungeness River (**Figure 6-3**). Between 2001 and 2007, well logs increased by 30 percent (to 2,624) west of the river and by 26 percent (to 2,629) east of the river. **Figure 6-4** compares the geographic distribution of wells over roughly 4 decades since 1980. New wells have been concentrated along the Dungeness River, with greater increases immediately east of the river (including the area surrounding Sequim) than immediately west. New well construction is also apparent in a corridor along Highway 101 west of the Dungeness River and extending into the Agnew area. In the immediate vicinity of the City's wellfields, between 2001 to 2007, well counts have increased by 24 percent (from 228 to 282) within a mile of the Port Williams Wellfield and by 33 percent (376 to 501) within a mile of the Silberhorn Wellfield (**Figure 6-3**).

PGG estimated 2.91 mgd of groundwater withdrawal from domestic wells for 2007 by multiplying the number of wells (5,253) by an assumed average annual pumping of 554 gallons per day (Section 6.2.1.1). This estimate includes 0.81 mgd west of the Dungeness River, 0.84 mgd east of the Dungeness River, 0.10 mgd within a mile of the Port Williams Wellfield, and 0.17 mgd within a mile of the Silberhorn Wellfield.

6.2.3 Non-Residential Water Uses

Groundwater withdrawals for non-residential purposes were estimated by Tetra-Tech Foster Wheeler (2003). The estimate totaled approximately 0.5 mgd, and was developed for a study period between 1995 through 1997. Withdrawals included: agricultural irrigation (0.32 mgd), golf-course irrigation (0.08 mgd), dairy operations (0.09 mgd), and 0.004 mgd for industrial use. More recent estimates of non-residential water use are unavailable; however, growth in these water uses over the past decade is considered unlikely. Commercial water uses are typically supplied by Group A water systems, and are thus included in Section 6.2.1.

Based on the mid-1990's water-use analysis by TetraTech FW (2003), about 75 percent of total irrigation groundwater use is withdrawn from the shallow aquifer and 25 percent is withdrawn from the lower or deep aquifers. Estimated groundwater withdrawals for dairy and industrial operations are entirely withdrawn from the shallow aquifer.

6.3 CONSUMPTIVE WATER USE

PGG estimated consumptive water use associated with sources of residential supply. Water withdrawn by domestic wells and public water systems is either returned to the groundwater flow system through recharge from septic systems and irrigation return flow, or is lost to evapotranspiration or marine discharge (via Sequim's sewer system). Consumptive use includes all uses which do not result in return to groundwater. PGG used data from Group A and Group B water systems, well counts (representing domestic wells), and sewered areas to estimate consumptive residential groundwater use within the study area.

Consumptive use estimates were compiled by square-mile section and mapped on **Figure 6-5**. Consumptive use was estimated for each domestic well or public water system hookup with the following formula:

$$U_C = (\text{Household Consumptive Use}) + (\text{Irrigation Consumptive Use})$$

$$U_C = (U_H * S) + (A_I * P) \qquad \text{(Equation 6-2)}$$

Where:
U_C = consumptive use (volume/time)
U_H = household use (volume/time)
S = Household consumptive use fraction (Sewer connection: yes = 1, no = 0.13)
A_I = assumed irrigated area per residence or hookup (area)
P = plant irrigation requirement (length/time)

Out of the total household use (170 gpd), 13 percent was estimated to be lost to evaporation, leaving 87 percent available to discharge to either septic or sewer systems (Solly et. al., 1993). If a residential unit relies on a septic system or a sewer system that recharges a significant portion of its water through land application or infiltration (e.g. Sunland), PGG estimated consumptive use to be 13 percent of U_H (S = 0.13). If a residential unit is connected to the City's sewer system, the total household use is assumed to be consumptive. The City currently does not currently recharge its Class A reclaimed wastewater; however, it plans to study reclaimed-water infiltration in the near future.

Water use for residential irrigation is largely consumptive; however, a portion of the applied irrigation water infiltrates below the root zone and recharges the underlying groundwater flow system. The consumptive portion of residential irrigation use is equal to the irrigated area (A_I) times the plant irrigation requirement (P). Irrigation applications above the plant requirement predominantly return to the groundwater flow system as irrigation return flow. Irrigation consumptive use is assumed to be the same in sewered and non-sewered areas.

Consumptive water use is higher at residences connected to sewer systems than those with septic systems because septic systems have more return flow to groundwater (**Table 6-1**). Thus, consumptive use estimates presented in **Table 6-1** differentiate between residences connected to sewer and septic systems for both Group A and domestic water systems. Most residences in the Sequim-Dungeness Peninsula are connected to septic systems, with the primary sewer system serving the City of Sequim. PGG estimates that 95 percent of the City of Sequim water-system residences and businesses are connected to sewers based on a comparison of the service areas and parcel maps. An additional 325 connections on Bell Hill served by the Evergreen Group A water system are also connected to the sewer system (Pete Tjemsland, personal communication, 2009). Twenty-two domestic wells located within the Sequim sewered area and are also assumed to be connected to the sewer system (potentially overestimating consumptive water use by a small percentage if they are actually on septic). Local ordinances require residences with available sewer service to connect to the sewer system within 10 years of service availability, or if the septic system fails (Pete Tjemsland, personal communication, 2009). All domestic wells and Group A connections outside the Sequim sewered area are assumed to be on septic systems or on a sewer system that recharges most of its water through land application (e.g. Sunland),.

Most Group A water systems in the study area have multiple well sources which may not be drawn on equally. Consumptive use for each source is estimated by pro-rating the system consumptive use by the capacity of the sources in the system. For example, if a system is served by two sources with capacities of 100 and 200 gpm, the system consumptive use would be split between the sources 33% and 67%. Consumptive use estimates for the Evergreen, Carlsborg, and City of Sequim sources are assigned based on pumping records. For consumptive use calculations for systems with known pumping, the consumptive use is calculated as the recorded pumping at the source times the percent consumptive use per hookup (**Table 6-1**). The Carlsborg system is assumed to consist entirely of Group A hookups to residences connected to septic systems. The consumptive use estimated per square-mile section assumes that all return flow from septic tanks and irrigation occurs within the same section as pumping. This assumption may lead to some errors in the distribution of consumptive use associated with large systems (e.g. City of Sequim) or systems with service areas that straddle section boundaries.

Estimated total consumptive use in the study area is 3.57 mgd, with 1.71 mgd from Group A systems, 0.21 mgd from Group B systems, and 1.65 mgd from domestic wells. **Figure 6-5** shows the distribution of estimated consumptive groundwater use in the study area. Most consumptive use estimated for Group A systems occurs east of the Dungeness River (1.41 mgd), with 18 percent occurring west of the river (0.31 mgd). Consumptive use associated with the City of Sequim withdrawals is estimated at 0.8 mgd, about 47 percent of total estimated Group A consumptive use. Estimated consumptive use within 1 mile of the Silberhorn Wellfield (0.18 mgd) and Port Williams Wellfield (0.09 mgd) are significant, though considerably smaller than the wellfield withdrawals. Domestic and Group B consumptive use also varies by location with 0.84 mgd east of the Dungeness River, 0.81 mgd west of the Dungeness River, 0.17 mgd within a mile of the Silberhorn Wellfield and 0.1 mgd within a mile of the Port Williams wellfield.

6.4 IRRIGATION TRENDS

Irrigation on the Sequim-Dungeness Peninsula was recently described in the Comprehensive Irrigation District Management Plan (CIDMP) (EES. 2003). The following information is summarized from the CIDMP unless noted otherwise.

The Sequim-Dungeness Valley Agricultural Water Users Association (SDWUA) represents seven public and private irrigation organizations. SDWUA members divert water from five diversions on the Dungeness River and one on McDonald Creek. The Dungeness River diversions are on both the mainstem and side channels, at River Miles 11.2, 10.9, 8.8, 8.0, and 7.2. The McDonald Creek diversion is located at river mile 3.2 near Highway 101.

Most of the water is diverted from April 15 to September 15, which is the irrigation season. Peak SDWUA diversions occur in July and August since the warmest, driest weather occurs during those months. After September 15, the SDWUA diverts flow for stockwater purposes only causing diversions to decrease substantially at that time. Implementation of water conservation measures and improved management allowed the SDWUA to meet the requirement of a Trust Water Rights Memorandum of Understanding with Ecology which limits the quantity of water that can be diverted to 50% of the river flow. The SDWUA uses McDonald and Bell Creeks for conveyance of irrigation water. Matriotti Creek was used in the past for conveyance, but this activity is no longer practiced. The SDWUA discharges tailwater from the SDWUA irrigation system into natural waterways, wetlands and/or saltwater bays.

The SDWUA measures flow of water diverted into their systems. Ecology funded installation of flumes which was completed in 2001; however, the CIDMP publishes average annual diversions as far back as 1979. **Figure 5-2** shows historic average irrigation-season diversions based on a compilation of CIDMP data and more recent data from the Ecology gages. The chart shows that diversion since 1999 has been approximately one-half of diversion in the late 1970s. Diversions after 1999 remain relatively stable, ranging between 50 cfs and 65 cfs. Irrigation season diversion was reduced by about 25 cfs over the 1990's decade, which corresponds to the period-of-time the SDWUA members starting focusing efforts on water conservation and reducing diversions. SCWUA past and continuing efforts include ditch lining, changes in cropping patterns and adherence to the Trust Water Right MOU with Ecology. Full implementation of the Dungeness River Agricultural Water Users Association Comprehensive Water Conservation Plan (MWG, 1999) is designed to improve SDWUA operations and conserve an additional 17.5 cfs during peak irrigation season diversions compared to baseline conditions.

Based on GIS coverage of irrigation ditches obtained from the Clallam Conservation District in 2008, about 200 miles of irrigation ditches have been mapped of which about 60 miles of ditches have been piped and about 13 miles of ditches have been abandoned. **Figure 1-2** shows the network of irrigation ditches and when various ditches were piped. The data are grouped into ditches piped before and after the start of year 2000 (some data sets have more detailed chronology). Most of the ditches mapped as "abandoned" or "not used" do not have dates associated with non-use. The Clallam Conservation District indicates that few of the ditches with known piping dates were piped prior to 1990, except for a separate subdistrict of the Highland irrigation District which piped a number of laterals running between the Highland main canal and West Sequim Bay Road, thus creating a pressurized system (Holtrop, 2009). The figure shows that:

- Ditches piped by the Agnew District (far west) largely have unknown dates;
- Ditches piped by the Clallam and Cline districts (immediately west of the Dungeness River) were largely piped after the start of 2000;
- Ditches east of the Dungeness River were variably piped before and after 2000; and,
- More of the abandoned ditches occur east of the Dungeness River

A more complete and accurate representation of the timing of ditch piping is currently under preparation by the Jamestown S'Klallam Tribe (with input from the Clallam Conservation District) under a grant with the EPA.

Additional discussion about how abandonment of ditches affects groundwater recharge is presented in Section 7.2.

7.0 RECHARGE TRENDS

The groundwater flow system is recharged from precipitation, leakage from unlined irrigation ditches, unconsumed irrigation water from field applications, and seepage losses from “losing” stream reaches (e.g. reaches of the Dungeness River). Infiltration of septic effluent and wastewater field application (at the Sunland facility) also recharge the groundwater system; although this recharge originates from groundwater withdrawals and does not provide “new” water to the groundwater system. Finally, the groundwater flow system receives subsurface inflow (“subflow”) from water recharged to the foothills and mountains south of the Sequim-Dungeness Peninsula. This recharge flows through bedrock and overlying sediments before discharging to the groundwater flow system beneath the peninsula.

Changes in recharge can have a significant effect on groundwater levels. This section discusses trends in groundwater recharge from incident precipitation, irrigation and subflow. With the exception of streams used to convey irrigation water, recharge from stream losses is not expected to change substantially[1] and is not addressed in this section. Recharge from septic effluent is expected to increase with groundwater pumping, but the combined effect of pumping and septic recharge remains a net withdrawal from the groundwater flow system, and is included in discussion of consumptive use (Section 6.3). Changes in land use can also affect recharge from incident precipitation. While a formal analysis of how historic land-use changes have affected precipitation recharge was beyond the scope of this project, qualitative considerations are discussed below.

The effect of changes in recharge on the groundwater flow system is discussed in Section 8.3.

7.1 PRECIPITATION RECHARGE

The USGS estimated long-term precipitation recharge over a study area that included much of the Sequim-Dungeness Peninsula (Thomas et al, 1999). The USGS first employed their “deep percolation model” (DPM) (Bauer & Vaccaro, 1987) to estimate recharge over a 1995-1997 study period. The results of the DPM were then used to develop regression equations that associated recharge to composite soil groups (e.g. glacial till, glacial outwash, alluvium), annual precipitation, and land surface slope. In order to estimate the long-term geographic distribution of recharge, the USGS applied the long-term distribution of precipitation to the regression equations[2]. The USGS estimated a long-term average precipitation recharge of 4.8 in/yr (26.2 cfs) over their primary study area and 5.4 in/yr (46.2 cfs) over their entire study area (see Thomas et al (1999) for delineation of study areas).

PGG used the USGS regression equations to estimate trends in precipitation recharge over the primary study area (a similar area was used to evaluate changes in well withdrawals and to quantify consumptive use in Section 6.3). Annual precipitation data from the Sequim gauge between 1980 and 2007 were used to estimate the percentage of the 1980-2007 annual average as a multiplier for each year in the record. This relative variation in precipitation was then applied to the USGS regression equations for the primary study area. The study area was divided into polygons representing specific combinations of composite soil type and “representative precipitation” (the isohyetal map shown on **Figure 4-1** was divided into “bands” of representative precipitation, such that the area between 15 and 20 in/yr precipitation contours was uniformly assigned a value of 17.5 in/yr). The yearly change in recharge for each unique combina-

[1] However, for losing streams with a direct hydraulic connection to the groundwater system, shallow water-level declines can cause increases in stream seepage loss (i.e. recharge).
[2] Thomas et al (1999) employ a long-term precipitation distribution published by the US Weather Bureau in 1965.

tion of composite soil type and representative precipitation value was calculated with the regression equations, and summed up by area to estimate a total change in recharge[3].

Figure 7-1 presents the results of the estimated variation in precipitation recharge for the USGS primary study area over the 28-year period. Variations in annual recharge are more pronounced than variations in annual precipitation (**Figure 4-2**). This is because evapotranspiration consumes a significant portion of annual precipitation and does not exhibit particularly large year-to-year variation. Variation in the remaining portion of precipitation, (that which percolates through the root zone), is relatively larger than variation in total precipitation. The estimated variation in annual precipitation recharge shows no apparent trend over the 28-year period, although it does show above-average recharge estimates from 1995-1999 and below average estimates from 2000-2005.

The USGS regression equations do not consider changes in temperature for estimating recharge. As discussed in Section 4.3, temperature in the study area has increased by 0.9 C between 1950 and 2000. PGG used a proprietary, in-house version of the USGS DPM, along with 1980-2007 monthly average values of precipitation and temperature from the City of Sequim weather station, to perform an evaluation of annual recharge over time that includes actual temperature data. The in-house model used the Blaney-Criddle method for estimating potential evapotranspiration (PET) with monthly plant factors for grass, and performed a daily water balance in a 24-inch deep root zone using available water capacity values of 0.04 and 0.08. Because annual precipitation varies across the study area, three multipliers were applied to the actual monthly precipitation totals to generate three synthetic monthly precipitation records with long-term annual averages of 15, 20 and 25 in/yr. Modeled temperatures were the same as the Sequim station. **Figure 7-1** presents the results of running 28 years of monthly climatic data through PGG's proprietary DPM. (Note that recharge is presented as in/yr rather than integrated over the primary study area as cfs.) Similar to the analysis described above, there is no apparent trend in recharge over the period of interest. As this method takes into account actual changes in temperature over the 28-year period, the results suggest that the effects of temperature change are not observable beneath the natural variation ("noise") in annual precipitation recharge.

Changes in land use can affect groundwater recharge. Construction of impervious surfaces (e.g. buildings, roads, driveways, parking lots) affects the recharge water budget in a number of ways, largely depending on how runoff from these surfaces is routed. Impervious surfaces typically replace vegetated areas, and therefore cause a reduction in water lost to ET and an increase in overall water availability as runoff. Routing of runoff to ditches or streams, and ultimately to marine discharge, will cause a reduction in groundwater recharge. However, in areas with relatively high soil permeability, runoff can be infiltrated into the subsurface on site. Under this practice, if all the runoff is infiltrated to the ground, groundwater recharge can actually increase because the quantity infiltrated includes most of the quantity previously lost to ET. A significant portion of surficial soil in the study area is classified by the USGS as a composite of outwash and coarse alluvium (Thomas et al, 1999, Figure 27). These soils may be able to accommodate recharge from impervious areas (typically accomplished through infiltration ponds, dry wells, French drains, and other methods of direct infiltration). Other portions of the study area have soils derived from till (hardpan) or fine-grained materials that likely could not accommodate full infiltration of generated runoff. It is beyond the scope of this study to estimate whether the distribution of impervious surfaces, soil types, and runoff disposal practices has let to an increase or decrease in precipitation recharge; however, we note that this determination is complex, area-specific, and a net loss or gain across the study area should not be assumed.

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[3] The regression equations are written such that precipitation is not paired with the "slope" term – thus change in recharge does not require consideration of slope.

Neither PGG's analysis nor the USGS recharge analysis addressed changes in recharge in the southern foothills and Olympic Mountains, which provides recharge to the study area as subflow through bedrock and overlying glacial drift. Given the likely permeability contrast between bedrock (typically very low permeability) and glacial drift (low permeability till and possible greater permeability outwash), it seems reasonable to assume that the majority of subflow occurs through the glacial drift that overlies the bedrock. Geologic mapping (WDNR, 2008) shows that most of the glacial drift occurs in areas where elevations are less than 3,000 feet, which is typically below the snowline. While the annual snowpack has reduced over time, the lack of a trend in precipitation (rainfall) recharge in the lower-elevation study area may suggest a negligible change in precipitation recharge to the glacial drift in the foothills south of the study area. If the majority of subflow entering the study area occurs in the glacial drift, no substantial changes in subflow are expected over the study period.

7.2 IRRIGATION RECHARGE

Thomas et al (1999) reported estimates of irrigation recharge resulting from percolation of unconsumed field applications (5 cfs during the irrigation season) and losses from leaky irrigation ditches (30 cfs during the irrigation season, 20 cfs off-season, and 23.7 cfs annual average). Thomas' estimates of ditch recharge were based on analyses by Montgomery Water Group (1993), which pre-date most of the recent conservation activities to pipe the ditches. In 1996 there were about 200 miles of irrigation ditches. Piping of ditches results in reduced seepage losses (and associated recharge), and supports similar reductions in irrigation diversion from the Dungeness River. **Figure 1-2** shows the network of irrigation ditches and when various ditches were piped.

Although about 60 miles of ditches had been piped (and 13 miles abandoned) as of 2008, estimates of reduced ditch leakage are not readily available (pers. comm.. Joe Holtrop, 2009). PGG estimated reductions in irrigation recharge based on the distribution of piped ditches (**Figure 1-2**) and the distribution of irrigation recharge estimated by the USGS. PGG obtained the USGS GIS coverage of estimated average annual precipitation and irrigation recharge, and resolved this recharge distribution to the grid of the "2008 Dungeness Groundwater Model" (PGG, 2009). The annual irrigation recharge distribution totals 26.3 cfs and is presented (as of 1993) on **Figure 7-2** along with model grid cells that include piped ditches. Irrigation recharge associated with model cells containing piped ditches, totals 9.5 cfs; thus suggesting that ditch recharge has decreased by 40 percent since recharge was estimated by Montgomery Water Group in 1993. Field applications are estimated to remain relatively unchanged over the recent ditch lining period (pers. com. Joe Holtrop, 2009).

Some of the ditches have been piped in the vicinities of the Silberhorn and Port Williams wellfields. At Silberhorn, two ditch reaches south of the wellfield were piped after 2000 and the remaining surrounding reaches were likely piped prior to 2000 although they are dated as "unknown" on **Figure 1-2** (pers. comm.., Joe Holtrop, 2009). The total reduction in annual average recharge associated with these five reaches is 0.6 cfs (0.38 mgd) based on the method of estimation outlined above. In the vicinity of Port Williams Wellfield, ditches were generally piped prior to 2000, including the (upgradient) Highline Irrigation Ditches marked as "unknown" (near West Sequim Bay Road). Piped ditches surrounding the Port Williams Wellfield are more geographically dispersed than those surrounding the Silberhorn Wellfield, and the applicable reduction in irrigation recharge is more difficult to estimate.

7.3 IMPACTS OF CLIMATE CHANGE

In order to assess the sensitivity of recharge to changes in temperature associated with projected climate change, PGG ran its version of the DPM using 20 in/yr of precipitation (divided into monthly values proportional to long-term monthly averages) and three sets of monthly temperature values: 1) long-term averages calculated for 1980-2007, 2) long-term averages plus the midpoint value of predicted 2040 increases (ranging from 1.7 ^{o}C during the winter to 2.7 ^{o}C during the summer), and 3) long-term averages with maximum predicted 2040 temperature increases (ranging from 2.8 ^{o}C during winter to 4.4 ^{o}C during summer). The mechanism for reduced recharge under higher temperatures is increased evapotranspiration of precipitation from plants, soils, and other surfaces. The predicted change in monthly recharge is shown on **Figure 7-3**. For an annual precipitation of 20 in/yr, recharge estimated under the mid-point 2040 temperature increase (7.5 in/yr) was 0.8 in/yr (10%) less than recharge estimated under the long-term averages (8.3 in/yr). Furthermore, recharge estimated under the maximum 2040 temperature increase (6.9 in/yr) was 1.4 in/yr (17%) less than recharge estimated under the long-term averages.

These estimates were performed with PGG's DPM under specific assumptions (e.g. 20 in/yr precipitation, no runoff, grassy vegetation, 24 inch root zone, no shallow perching layers, available water capacity – 0.04); whereas, actual conditions in the study area vary considerably. Nevertheless, these estimates indicate that groundwater recharge is sensitive to the degree of temperature change predicted for 2040. In areas where annual precipitation is less than 20 in/yr, predicted recharge reductions would likely be less in absolute terms (i.e. less reduction in in/yr) but greater in relative terms (i.e. greater than 10% and 17%). In areas where annual precipitation is greater than 20 in/yr, predicted recharge reductions would likely be greater in absolute terms but less in relative terms. In areas with shallow perched groundwater, recharge reductions would likely be greater in both absolute and relative terms, because perched groundwater remains accessible to the root zone longer into the summer season and is therefore more susceptible to evapotranspiration under higher summer temperatures.

8.0 GROUNDWATER LEVEL TRENDS

Groundwater level trends indicate hydrologic responses to changes imposed on the groundwater flow system. Factors capable of affecting groundwater levels include: changes in pumping stress, changes in recharge, and changes in surface-water bodies with hydraulic connections to groundwater (e.g. streambed scouring or siltation, varying the water level of an impoundment, etc.). When such changes are imposed, the groundwater flow system responds and water levels adjust to reach a new equilibrium with the changed condition(s). While the factors affecting groundwater levels are often not directly monitored, their influence is directly expressed in groundwater level trends.

This section summarizes groundwater level trends in aquifers on the Sequim-Dungeness Peninsula based on available monitoring data. Discussion includes: data sources, observed trends, and interpretation of observed trends. PGG's interpretation considers hydrogeologic conditions as well as trends observed in the hydrologic factors that influence groundwater levels (Sections 4 through 7).

8.1 DATA SOURCES AND MONITORING PRACTICES

Groundwater level monitoring data were obtained from the City of Sequim, Graysmarsh, Department of Ecology, Clallam County, and Clallam County PUD and the United States Geological Survey (USGS). The monitoring practices of each of these organizations are summarized below:

<u>*City of Sequim*</u> performs automated daily monitoring at two production wells and two dedicated monitoring wells at its Port Williams Wellfield; manual monthly monitoring of production wells and one dedicated monitoring well at its Silberhorn Wellfield; and manual monthly monitoring in a network of 5 private wells adjacent to the two wellfields. Two of these wells (AAF 397 and AAF 398) were used in the USGS monitoring study (Thomas, 1997).

<u>*Graysmarsh*</u> collects manual water level measurements at 5 production wells on a daily to monthly basis depending on the well, with data available from 1997-1998 through 2007.

<u>*Department of Ecology and Clallam County*</u> cooperatively collect water-level data at numerous monitoring wells and private domestic wells with some records extending back to 1975. This study uses data from 13 of the monitored locations. Sampling interval varies widely between locations from monthly to yearly. For records extending in to the 1980s and 1970s, data gaps of several years are often present in the early 1980s. Ecology and Clallam County have also collected water levels at numerous other wells within the study area, but with shorter data records or from time intervals not useful for this study.

<u>*Clallam County PUD*</u> collects manual water level measurements at eight wells 1 to 2 times a month with data from May, 2005 through 2008. PUD water levels were not used in this study due to the short data record.

<u>*The USGS*</u> have conducted both miscellaneous and focused water-level monitoring in Sequim area wells. Whereas miscellaneous monitoring may include one or two measurements, focused monitoring included multiple measurements over discrete time periods (e.g. 1978-79, 1994-97). Many of the wells monitored by the USGS are now monitored by the Department of Ecology and Clallam County.

Table 8-1 summarizes the well characteristics and periods of record for the 33 wells included in the current study. **Figure 8-1** shows the locations of the monitored wells. The data set includes 25 shallow aqui-

fer wells (78%), 4 middle aquifer wells (13%) and 3 lower aquifer wells (9%). This distribution is similar to the general distribution of wells in the area as a whole where 73 percent of wells are completed in the shallow aquifer, 25 percent are completed in the middle aquifer and less than one percent in are completed in deeper aquifers. Group A production wells are biased to deeper aquifers with 11 percent completed in the Lower aquifer, 10 percent in the middle aquifer and 80 percent are completed in the Shallow aquifer. The few monitored wells in the Middle and Lower introduce some bias to the data in that only small portions of the study area are represented. Most of the deeper wells are located in or around the Silberhorn and Port Williams wellfields, and water-level data in these areas may be over-represented relative to the rest of the study area.

Water level monitoring includes both manual measurements collected with an electronic sounding tape, and automated measurements collected with pressure transducers. Manual water level measurements were collected only when wells were visited by one of the agencies listed above, and intervals between measurements range from daily in some well field measurements to years at wells which are only used for long term monitoring. Water level measurements with pressure transducers are usually collected several times a day, while manual measurements are usually collected on a less-frequent basis, usually days or months.

Maintaining a long-term monitoring network at private wells requires the cooperation of many well owners. Water level data is available from many wells in the study area, but many have records which were too short, or from a time interval with limited utility for the current study. In many cases, excellent water level data was available from earlier measurements in private wells, but monitoring at the well was discontinued at the well owner's request. Water level records with fewer than 5 years of data were not used in this study because the goal was to investigate long-term trends. If the end of the monitoring record was close to 2007, or if the well is in an area with sparse data, or from the middle or lower aquifer, the data were included in this report to help fill data gaps, even if the data was less complete for recent years.

8.2 WATER LEVEL TRENDS

PGG evaluated water-level trends by plotting water levels as "departures" from the first measurement on record for each well. **Figure 8-2a,b** presents departure hydrographs for all of the monitored wells, and **Figure 8-1** presents representative hydrographs on a study-area map. Positive water level departures indicate that water levels have risen since the initial measurement. For plots of manual water-level data PGG removed measurements collected when well pumps were running; however, some of the measurements may by influenced by recovery from pumping or by pumping in nearby wells. For automated water-level data, PGG plotted the minimum depth to water (i.e. closest to static) for each day when multiple measurements were available.

The USGS conducted water-level monitoring in the Sequim area from 1978-1980 and again from 1994-1997, and mapped water-level changes between these two periods. Several of the wells used in the USGS study are now monitored by local agencies. **Figure 8-3** presents the water-level changes from the USGS study and subsequent water level changes (between 1997 and 2007) drawn from the hydrographs shown in **Figures 8-1** and **8-2**. Water-level changes over the most recent decade were estimated by considering trends in both maximum and minimum seasonal water levels.

The following sections discuss water-level trends first grouped by aquifer and then by geographic area. Most water level plots show a combination of seasonal variation and long-term trends. Seasonal trends are influenced by seasonal variations in recharge (from precipitation and irrigation) and pumping, whereas long-term trends are influence by long-term variations in these factors. Water levels in the shallow aquifer generally show greater seasonal variability than water levels in the middle or lower aquifers. While this study focuses predominantly on long-term trends, seasonal variations are considered where they provide insight into the hydrologic factors affecting groundwater levels at specific sites.

8.2.1 Shallow Aquifer

In the shallow aquifer, water-level changes between the late 1970's and the mid-1990's showed declines at most locations, with several isolated instances of rising trends. Declines in all wells with monitoring data over this approximately 15-year period ranged from 1 to 9 feet (**Figure 8-3**). Between 1997 and 2007, water-level declines ranging from 1 to 17.4 feet occurred at all 24 monitored locations. The following observations describe the geographic distribution of observed water-level declines in the shallow aquifer:

- In the area between upper Gierin and Cassalery creeks (including the Port Williams Wellfield), declines of about 3 feet were observed between the late 1970s and the mid 1990s. Declines increased to about 4 to 9 feet between 1997 and 2007, with the largest declines (8-9 feet) occurring at sites west of the wellfield, and smaller declines occurring at the wellfield and to the northwest (**Figure 8-3**). Recent hydrographs show most of the decline occurring prior to 2002 followed by apparent stabilization (**Figure 8-1**).
- Near where Highway 101 crosses the Dungeness River, significant water-level declines have occurred over both time periods. The area extends over at least 3 square miles where data are available (sections 24, 25 and 26 of T30NR4W) and is surrounded by areas with limited or no water-level monitoring. Water levels declined by 8 to 17 feet from 1997 through 2007, an acceleration from the 3 to 9 feet of decline observed from the late 1970s to the mid 1990s (**Figure 8-3**). Water level variations do not correlate well with seasonal pumping patterns, as annual high water levels are typically observed during summer peak pumping (**Figure 8-2a**).
- In the Graysmarsh area, water-level declines are relatively small, with maximum declines of about 2 feet observed between 1997 and 2007 (**Figure 8-3**). Several trends show stabilization post 2000 (**Figure 8-2b**).
- A single shallow-aquifer well in the Agnew area shows about 8 feet of decline between 1997 and 2007, with relatively stable water levels between the late 1970s and the mid 1990s.
- Little data are available to evaluate trends in the Carlsborg area. Comparison of static water levels at LUD Well #10 at the time of drilling (June 1990, 38 ft bgs) to water levels collected by Clallam County PUD (April, 2007, 40.3 ft bgs) suggest little or no decline near Carlsborg. It is not clear if the same measuring point was used for these measurements, but would likely be within a few feet of each other if different.
- Data are also fairly sparse in other portions of the study area, such as along Bell Creek, along the middle reaches of Matriotti Creek, and in various coastal areas (**Figure 8-3**).

8.2.2 Middle Aquifer

Very little data are available to evaluate water-level declines in the middle aquifer before the 1990s (**Figure 8-3**). Only three wells, located far apart, are shown in the USGS report (Thomas, 1997). Between the late 1970s and the mid 1990s, these wells suggest a slight rise in water levels (about 2 feet) near Agnew and a significant decline (9 feet) about a mile east of where Highway 101 crosses the Dungeness River. The third well is located south of the study area for this report, and showed a rise of 1 foot.

It should be noted that aquifer designations near the Highway 101 – Dungeness River crossing exhibit some degree of uncertainty. The well showing a 9-foot decline in this area is 276 feet deep, and was classified by the USGS as completed in the middle aquifer. At this location, the USGS estimate the thickness of the shallow aquifer as 150 feet. In contrast, about a mile closer to the Dungeness River at the Silberhorn Wellfield, the USGS estimate the shallow aquifer to be 200-250 feet thick. The Silberhorn production wells range from 172 to 220 feet deep, and are therefore interpreted as completed in the shallow aquifer. As noted in Section 3.2, the shallow aquifer can contain multiple water-bearing zones separated by aquitard materials, and the Silberhorn production wells are all completed under confined conditions below a till aquitard. The similarity in groundwater level declines between these shallow- and middle-aquifer wells may indicate parallel trends and significant hydraulic connection between aquifers, but may also suggest that all monitored wells with similar trends in this area are in fact all completed in the *same* aquifer. The till aquitard noted in Silberhorn area wells may have complicated the USGS interpretation of aquifer designations.

Five middle-aquifer wells were monitored between 1997 and 2007, and showed water-level declines ranging from 1 to 8 feet (**Figure 8-3**). Only one of these wells (near Agnew) was also previously monitored by the USGS.

- Near Agnew, water levels declined by about 7 feet near from 1997 to 2007, in contrast to a 2 foot rise from the late 1970s to the mid 1990s (Thomas, 1997).
- In the vicinity of Gierin and Bell Creeks, monitoring in 3 wells showed declines ranging from 7.7 to 9.7 feet. A decline of 9.7 feet at the Port Williams Wellfield shows stabilization after 2001 (**Figure 8-1**). Well AAF386, about a mile east of the wellfield, shows 9.2 feet of decline without apparent stabilization (**Figure 8-2b**). Well AAB741, located south of Bell Creek about 2 miles from the wellfield, shows a 7.7-foot decline. The data record for Well AAB741 only extends through 2003, and the late-time data are two sparse to discern stabilization vs. continued decline (**Figure 8-1**).
- Well ABA539 near Matriotti Creek has a very sparse record. A decline of 2.2 feet is suggested, but is considered highly uncertain (**Figure 8-1**).

It should also be noted that large portions of the study area have no current water-level monitoring in the middle aquifer (**Figure 8-3**).

8.2.3 Lower Aquifer

The USGS did not include monitoring for any lower-aquifer wells in their late 1970s to mid 1990s analysis. Water level monitoring in the lower aquifer between 1997 and 2007 was performed at the Port Williams Wellfield (discussed below) and at Graysmarsh. The USGS interpret both wells as completed in the lower aquifer (Thomas et al, 1999). Whereas 9.8 feet of decline was observed in the lower aquifer at Port Williams, only 0.8 feet of decline was observed about 1.8 miles away at Graysmarsh (**Figure 8-3**). Relatively few wells are completed in the lower aquifer, and water-level monitoring is non-existent in other portions of the study area.

8.2.4 City of Sequim Wellfields

PGG performed a detailed analysis of water-level trends at they City's Port Williams and Silberhorn wellfields. Monitoring at both wellfields is conducted in production wells and dedicated monitoring wells. In order to provide the most up-to-date analysis for the City's wellfields, PGG extended the study period of record through 2008 (rather than 2007). **Figures 8-4** and **8-5** present hydrographs from onsite wells at the two wellfields along with average monthly and annual pumping withdrawals.

Water levels at the Port Williams wellfield declined in all three aquifers between 1996 and 2001-2003, and appear to have remained relatively stable through 2007 (**Figure 8-4**). Pumping withdrawals occur from production wells PW-1 and PW-2 in the lower aquifer (pumping was initiated at the wellfield in 1996)[4]. PGG analyzed static water levels in Well PW-1 for declines over the period of record. At the time of drilling (September 1995), PW-1 had a static water level of 55.2 feet below land surface (bls). Both pumping and groundwater level monitoring were initiated in 1996, so pre-pumping seasonal water-level variations are unknown. However, the wellfield was not pumped during much of 1997, and a water-level variation of about 5 feet was noted during the non-pumping period. Over the period of record, seasonal high groundwater levels declined from about 54 feet bls in 1997 to about 60-62 feet bls (a 6-8 foot decline). Seasonal low groundwater levels declined from about 58 feet bls in 1997 to about 68-72 feet bls (a 10-14 foot decline). Relatively stable water levels are observed from 2001 through 2008, with a slight rising trend noted in the final two years. Over this stable period, the average daily static water level (63.8 feet bls) indicates an average decline of 9.8 feet below the highest noted static water levels in 1997.

Port Williams Monitoring Well MW-3 is completed in the middle aquifer, with a data record that begins after pumping was initiated in 1996 (**Figure 8-4**). Relative to the highest wet-season water levels in 1997 (37.4 feet bls), water-level declines of about 7-9 feet are noted in subsequent wet-season highs. Relative to a late-1997 average seasonal low water-level of 39.7 feet bls, subsequent average seasonal low water levels show declines ranging from about 8-11.5 feet. Relatively stable water levels are observed from 2001 through 2008, with a slight rising trend noted in the final two years. Over this stable period, the average daily static water level (47.1 feet bls) indicates an average decline of 9.7 feet below the average wet-season high static water levels in 1997.

Seasonal water-level variations in middle-aquifer Well MW-3 closely mimic the pattern of variation observed in lower-aquifer Well PW-1 (**Figure 8-4**). While the patterns are similar, the range of variation in Well MW-3 is about one half the range of variation in Well PW-1. The City also monitors middle-aquifer Well AAF386, located about 4700 feet east of the Port Williams Wellfield. As shown on **Figure 8-6**, seasonal water-level variations in Well AAF386 are very similar to those in Well MW-3 with a slightly reduced range of variation. Comparison of hydrographs from these two wells on **Figure 8-6** shows similar trends, although Well MW-3 has a slightly steeper rate of decline during the first years of Port Williams pumping (1996-2001) and definitive stabilization after 2001, whereas Well AAF386 has a gentler rate of decline between 1996-2001 and continues to decline very gradually after 2001.

Port Williams Monitoring Well MW-1 is completed in the shallow aquifer, with a data record that begins after pumping was initiated in 1996 (**Figure 8-4**). Relative to the highest wet-season water level in 1997 (4.6 feet bls), water-level declines of about 4-6 feet are noted in subsequent wet-season highs. Relative to the 1997 seasonal low water-level of 6.8 feet bls, subsequent average seasonal low water levels decline about 5-7 feet. Relatively stable water levels are observed from 2001 through 2005, with a minor rise between 2006 and 2008. The MW-1 data suggest that water-level declines in the shallow aquifer are only about 60 percent of the declines observed in the middle and lower aquifers. In addition, seasonal variation in the shallow aquifer is much less pronounced than in the middle and lower aquifers. The shallow aquifer tends to exhibit seasonal highs in the summer months (coincident with irrigation recharge), whereas the middle and lower aquifers exhibit seasonal lows in the summer months (coincident with periods of high groundwater withdrawals).

Figure 8-6 compares hydrographs from Well MW-1 with shallow-aquifer wells AAF381 and AAF382, located about 1,500 feet west of the Port Williams Wellfield. All 3 wells have similar trends. However, whereas stabilization and a late-record rise is observed in MW-1 after 2001, the other two wells exhibit a

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[4] A new production well "PW-3" was installed at the Port Williams Wellfield in 2008, but is not yet in operation.

continued (but very gentle) decline. In addition, MW-1 exhibits more short-term variation than the other wells, including a more pronounced short-term rise in 2006 and 2007.

Water levels at the Silberhorn Wellfield are monitored in two production wells (Well 2 and Well 3) and one monitoring well (Well 1)[5] (**Figure 8-5**). All 3 wells are interpreted to be in the shallow aquifer; however, they are completed beneath till-like materials which are inferred to cause the completion aquifer to function (at least locally) as a confined aquifer (PGG, 1996). Although the data exhibit considerable noise from short-term variations, a fairly stable trend is noted between 1993 and 1997, followed by a declining trend between 1998 and 2005, followed by a trend towards stabilization (or a much more gentle rate of decline) between 2006 and 2008. Water level declines at the wellfield from 1997 to 2007 range from -12 to -17 feet. As shown on **Figure 8-3**, similar declines are noted in monitoring wells as much as a mile away (and on the other side of the Dungeness River), suggesting that water level declines are not localized to the area immediately around the wellfield. **Figure 8-3** also shows that water levels in nearby wells on both sides of the river declined 6 to9 feet between the late 1970s and the mid 1990s.

Water-level variations at the Silberhorn Wellfield show a seasonal pattern that does not correlate well with pumping. Seasonal low water levels from 2000 to 2008 typically occur between December and March, with high water levels often observed during the summer peak pumping season (**Figure 8-7**). Water levels also do not correlate well with flow events in the Dungeness River, but appear to correlate well with seasonal irrigation diversions in most years. (Ditches operated by the Independent Irrigation District are closest to the Silberhorn Wellfield.) However, during some years (e.g. 2000 and 2005), irrigation diversions appear to show poor correlation to groundwater level trends.

8.3 INTERPRETATION OF WATER LEVEL TRENDS

Water levels reflect the cumulative impact of several factors including precipitation recharge, irrigation recharge and pumping from wells. As discussed in the preceding sections, each of these factors has changed over time in the Sequim area. Changes in these factors impose new stresses on the hydrologic system. The influence that new stresses exert on groundwater levels is a function of their magnitude (relative to the overall water-budget for the groundwater flow system), their spatial distribution (whether they are regionally dispersed or locally concentrated), and specific hydrogeologic conditions in the area under change.

8.3.1 Relative Changes in Key Hydrologic Factors

The largest permanent change in key hydrologic factors in the study area is associated with reduction in recharge from leaky irrigation ditches. Consumptive groundwater withdrawals for residential (domestic and municipal) supply is estimated to have increased by about one third the change in irrigation recharge over the period from 1980 to 2007. Estimated variations in precipitation recharge are larger than changes in irrigation recharge, but are not long-lasting and snow no significant long-term trend. Whereas changes in recharge are predominantly imposed on the shallow aquifer (with secondary impacts on underlying aquifers), changes in pumping directly influence the shallow, middle and lower aquifers.

Precipitation Recharge

Precipitation recharge, estimated on an annual basis, has not exhibited a long-term change over the study-period. However, precipitation recharge varies year-to-year due to natural variations in precipitation. Based on USGS regression equations, study-area recharge over time is estimated to vary by around

[5] Well 1 is currently out of service.

±12,000 af/yr around a long-term average of about 19,000 af/yr (**Figure 7-1**). Similar to precipitation trends, above-average precipitation recharge occurred between 1995 and 1999, and below-average precipitation recharge occurred between 2000 and 2005. Total recharge to the study area is estimated to be about 58,000 af/yr, based on 19,000 af/yr of precipitation recharge, 18,700 af/yr of irrigation recharge, 10,500 af/yr of groundwater subflow, and 9,800 af/yr of flow losses from the Dungeness River[6]. Compared to the other factors considered, the range in variation for precipitation recharge reflects the largest stress imposed on the groundwater flow system within the study area; however, it is also relatively geographically dispersed.

The variation in precipitation recharge is neither long-lived nor consistent; however, its magnitude alone (e.g. a change of about 15,000 af/yr from the 5-year period 1996-1999 to the 6-year period 2000-2005) suggests that it should have a significant influence on groundwater levels. Nevertheless, water levels generally do not show a strong response to changes in precipitation recharge. Only three wells in the shallow aquifer (AAB 746, AAB 749, ACA594) had a noticeable positive response to the 1995-1999 high recharge years (**Figures 8-2a,b**). The response observed in these wells may be related to the fact that they are located in areas of lower aquifer permeability, as identified by the USGS (Thomas, 1997). Lower permeability materials tend to show a greater response to changes in recharge than high permeability materials where water is able to more quickly migrate away.

While recharge variations are large relative to pumping and changes in irrigation recharge, they do not exert an influence on groundwater levels that is consistent, and they do not appear to be the primary cause of the observed water level declines.

Irrigation Recharge

Recharge from leaky irrigation ditches has declined by an estimated 6,900 af/yr since 1993. Leakage from the ditches was estimated by Montgomery Water Group (1993), and exhibits significant spatial variation due to variations in soil permeability. Reductions in irrigation leakage due to ditch piping are also variably distributed over the study area. **Figure 7-2** shows how irrigation recharge was applied to the 2008 Groundwater Flow Model (PGG, 2009) and which model cells are associated with lined ditches. The piping has occurred in multiple sectors of the study area; however, the most concentrated reductions in recharge occur along a north-south strip immediately west of the Dungeness River, south of Highway 101 in the Silberhorn Wellfield vicinity, and within the Sequim city limits. One area of particularly high recharge immediately north of Highway 101 has yet to be piped.

Reduced recharge from leaky irrigation ditches (6,900 af/yr) is smaller than the magnitude of variation in precipitation recharge (e.g. 15,000 af/yr). However, once ditches are piped, irrigation recharge is permanently lost from the groundwater flow system. Depending on the time required for groundwater levels to equilibrate to changes in recharge, the timing of variation in precipitation recharge may have less influence than a continued trend of permanent recharge reductions through ditch lining. This is definitely the case over the long-term, as precipitation exhibits no observable long-term trend. In addition, recharge from irrigation ditches is more geographically concentrated than precipitation recharge. Ditch piping is likely to cause more pronounced groundwater declines adjacent to retired ditches, but is also expected to extend regionally as local declines propagate outwards to surrounding areas. Hydrogeologic conditions near a particular ditch may dictate how associated local and regional declines are distributed.

Groundwater Pumping

[6] TTFW reported personal communication with Bill Simonds (USGS) indicating that net losses from the river are on the order of 12 to 15 cfs (TTFW, 2003)

Groundwater pumping on the Sequim-Dungeness Peninsula has generally increased with population throughout the study period. Consumptive groundwater use for residential water supply in 2007 is estimated to total 3,820 af/yr, as summarized on the table below. Data are unavailable to quantify how withdrawals for all three categories of residential use have changed over the study period; however, existing data suggest that total withdrawals in 1980 were about 40 percent of withdrawals in 2007[7]. Assuming a similar ratio for consumptive use suggests that consumptive use may have increased by about 2,300 af/yr between 1980 and 2007.

	Estimated Total Withdrawal	Withdrawal from Shallow Aquifer	Withdrawal from Middle Aquifer	Withdrawal from Lower Aquifer	Estimated Total Consumptive Use
Domestic Wells	3,251 af/yr	~53% (1,723 af/yr)	~14% (455 af/yr)	~31% (1,008 af/yr)	1,681 af/yr
Group B Public Water Supply	426 af/yr	not estimated	not estimated	not estimated	235 af/yr
Group A Public Water Supply	3,027 af/yr	~78% (2,361 af/yr)	~22% (666 af/yr)	not estimated	1,906 af/yr
Total Residential	6,704 af/yr	~61% (4,084 af/yr)	~17% (1,121 af/yr)	~15% (1,008 af/yr)	3,823 af/yr

Whereas changes in recharge are imposed on the shallow aquifer with secondary effects in lower aquifers, changes in pumping are imposed directly on all aquifers. The table above summarizes estimates of residential groundwater withdrawals by aquifer. It should be noted that pumping from the middle and lower aquifers to supply homes with septic systems effectively transfers a portion of the pumped water into the shallow aquifer. While withdrawals from the shallow aquifer are estimated as about 61 percent of total withdrawals, *consumptive use* from the shallow aquifer is considerably less due to transfer of septic discharge associated with wells completed in the middle and lower aquifers[8]. On a per aquifer basis, consumptive use associated with pumping from the middle and lower aquifers is considerably higher than 61 percent, as a much smaller portion of septic recharge is likely to affect the water budget for these deeper aquifers.

The change in total consumptive residential groundwater use is estimated to be about one third of the change in recharge from leaky irrigation ditches, and less than one sixth the scale of observed variation in precipitation recharge. If the shallow aquifer supplies less than 50 percent of the total consumptive use associated with residential groundwater pumping, net consumptive withdrawal from the shallow aquifer represents less than one sixth the water-budget change associated with changes in irrigation recharge. Thus, changes in pumping are likely to have less influence on shallow-aquifer water levels than changes in ditch recharge and variations in precipitation recharge. Conversely, changes in pumping are expected to have more influence on middle-aquifer and lower-aquifer water levels. The extent to which changes in a given aquifer affect changes in adjacent aquifers depends on the degree of hydraulic connection provided by intervening aquitards. Trends in the shallow aquifer can cause trends in the middle aquifer, and vice versa. The extent of interconnection between aquifers is best analyzed through a groundwater flow model, as recently developed by PGG (2009). However, the current "2008 Groundwater Flow Model" has not been rigorously calibrated to datasets that reflect the interconnection between aquifers and related uncertainties remain (ibid).

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[7] Domestic well withdrawals in 1980 are estimated to comprise about 40 percent of 2007 domestic withdrawals (Figure 6-3). City of Sequim (which constitutes about 35 percent of the current Group A pumping) also withdrew about 40 percent of current withdrawals in 1980 (Figure 6-1).

[8] For instance, returning just 1/4 of the pumping from the middle and lower aquifers into the shallow aquifer (via septic discharge) reduces the consumptive use from the shallow aquifer from an assumed 61 percent to 47 percent.

It is also important to note that the spatial distribution of pumping withdrawals can vary from diffuse (in areas of low density development) to concentrated (e.g. at municipal wellfields). Diffuse pumping is likely to cause diffuse (i.e. regional) patterns of drawdown, whereas concentrated pumping is expected to cause pronounced drawdown near the pumping center along with some degree of diffuse regional drawdown.

8.3.2 Interpretation of Trends by Area

A few areas within the overall study area have sufficient data to perform a detailed interpretation of groundwater level trends. These are areas near the Port Williams Wellfield and at the Highway 101 – Dungeness River crossing, where the City (and others) have performed intensive monitoring over time and the City has performed aquifer testing at their wellfields. For these areas, PGG evaluated how changes in pumping and recharge have interacted with the local hydrogeology to produce the observed trends. In both cases, this detailed analysis has illustrated that the hydrogeologic framework is complex and that existing characterization does not capture all of its salient features. For other areas, where water-level monitoring is sparser and hydrogeologic conditions are not as well documented, PGG's interpretation is limited to comparing water-level trends with the distribution of pumping and piped irrigation ditches.

Port Williams Vicinity

Groundwater levels are monitored at the Port Williams Wellfield in all three aquifers. As noted previously, pumping was initiated at the wellfield in 1996. Water levels declined between 1996 and 2001/2003, stabilized, and have more recently exhibited a minor rising trend (**Figure 8-4)**. This type of response is expected for development of a new groundwater supply. New pumping will draw down water levels until sufficient gradients toward the wellfield are created to satisfy the pumping withdrawal. Groundwater declines will cease once a new equilibrium is reached between wellfield pumping and the overall groundwater flow system. This condition appears to have been achieved. The minor rise observed from 2005 through 2008 may be associated with reduced withdrawals after heavier pumping in 2001 and 2002.

Groundwater withdrawals at Port Williams average 450 af/yr (0.4 mgd); however, the wellfield is a supplemental source permitted to withdraw up to 1,850 af/yr (the combined annual allocation for the City's three sources). Although the City is unlikely to serve their entire demand through Port Williams withdrawals, their current water right provides capacity for future growth, and the City will likely look towards additional pumping at the wellfield to meet future demand. Based on the water-level response to Port Williams pumping thus far, increased future withdrawals will likely lead to additional declines followed by stabilization at a new equilibrium. The decline is a natural response to new pumping, and stabilization indicates that the groundwater flow system is capable of meeting the wellfield withdrawals.

Average declines at the wellfield thus far are approaching a "trigger" established under a water-rights Settlement Agreement signed by the City, Ecology and Graysmarsh. The agreement states that if declines in the middle aquifer exceed 10 feet, the City shall notify Ecology and Ecology shall issue a response[9]. The City has already notified Ecology of this condition, and has requested that Ecology respond after reviewing this monitoring report. At the time that the Settlement Agreement was developed, the 10-foot middle-aquifer trigger was believed to be conservative and unlikely to be reached (similar "triggers" for the lower aquifer were set at 35 to 50 feet, and only 9.8 feet of average decline has been observed thus far). Further discussion of the connection between the lower and middle aquifers follows. However, stabilization of

[9] While the average middle-aquifer decline is estimated at 9.7 feet, this "Tier 2" trigger has been exceeded during some years due to year-to-year variations.

water levels in response to pumping indicates that withdrawals are not "over-drafting" the groundwater flow system. As long as groundwater level declines associated with the City's pumping are not impairing neighboring water users, it appears safe to allow further incremental increases in withdrawals along with continued monitoring and data reporting.

The 9.8 feet of decline observed in the lower aquifer is consistent with aquifer properties estimated from aquifer testing at the wellfield (PGG 1995, 1998, 2008b). The "2008 Groundwater Flow Model (PGG, 2009) represents the lower aquifer with these properties and predicts 12 feet of drawdown after stabilization to 0.4 mgd of pumping. However, thorough review of the available data reveal various details which suggest that the lower aquifer is more complex that previously understood and that the degree of hydraulic connection with the middle aquifer is not yet well defined. Prior characterization of the hydrogeologic framework (e.g. Thomas et al, 1999) was based on limited wells penetrating the lower aquifer. As more data become available, our understanding of the groundwater flow system improves. The following observations reflect the hydrogeologic complexity associated with these deeper portions of the groundwater flow system, and suggest that our understanding would benefit from further data collection and interpretation.

1. Drawdowns associated with Port Williams pumping predicted with the 2008 Groundwater Flow Model are similar to those observed at the wellfield. However, the model predicts that lower-aquifer drawdown would be more widespread than observed under existing monitoring. Graysmarsh Well #8, located about 1.5 miles east-northeast of the wellfield is interpreted as completed in the lower aquifer (pers. comm.., Miller, 2007) and has declined by only 0.8 feet between 1997 and 2007. In contrast, the model predicts stabilized drawdown at Well #8 of about 5 feet. Assuming that hydrogeologic interpretation that Well #8 is completed in the lower aquifer is correct, other factors would be responsible for the lack of observed drawdown in that well. Possible factors include: aquifer heterogeneity (variations in aquifer texture) that "shields" the Well #8 vicinity from drawdown propagation, or leakage from adjacent aquifers that satisfies the Port Williams groundwater withdrawal before drawdown can propagate as far as Well #8.

2. During aquifer testing on Port Williams Well PW-1, water-levels were monitored in two lower-aquifer wells: one on the Graysmarsh property and another about 4000 feet west of the wellfield (PGG, 1995). While drawdown and recovery curves from wells near the wellfield closely matched predicted responses for a non-leaky, infinite, confined aquifer (Theis, 1935), the two distant monitoring wells showed no drawdown even though 1.8 to 4.2 feet was predicted. PGG interpreted this (lack of) response as indication that some combination of aquifer heterogeneity and/or aquitard leakage was influencing the test results.

3. Lower-aquifer water levels monitored at the Port Williams wellfield exhibit a strong (10-foot) seasonal fluctuation that correlates to seasonal variations in pumping. A very similar seasonal variation and long-term decline trend is observed in the middle aquifer at onsite monitoring well MW-3 (**Figure 8-4**). Seasonal variations in the middle aquifer are about half the magnitude of seasonal variations in the deep aquifer. The similarity of these seasonal and long-term trends seems to reflect hydraulic connection between the two aquifers. However, groundwater elevations in the two aquifers differ by about 15 feet. This head difference suggests that the lower confining bed provides significant resistance to flow between the two aquifers. These two conclusions appear to be contradictory. Preliminary experimentation with the 2008 Groundwater Flow Model suggested that an vertical aquitard permeability (Kv) on the order of 0.0008 ft/d was needed to maintain a significant head difference between the two aquifers; however, Kv values of 0.008 to 0.016 ft/d were needed to for long-term drawdown in the middle aquifer to approach about half the drawdown in the lower aquifer. The fact that the model cannot simultaneously simulate a significant head difference between the two aquifers *and* similarity in water-level trends between the two aquifers indicates that the conceptual model that

extends the regional hydrogeology (e.g. Thomas et al, 1999) to the local conditions may need to be revisited.

4. Trends in the shallow aquifer do not show seasonal variations similar to the middle or lower aquifers (**Figure 8-4**). This suggests that the shallow aquifer has less hydraulic connection to the middle aquifer than the connection between middle and lower aquifers. It also suggests that factors influencing groundwater levels in the shallow aquifer may differ from those affecting water levels in the middle and deep aquifers. These differences are illustrated on **Figure 8-6**. The hydrograph for shallow-aquifer well MW-1 (located at the wellfield) shows mid-summer water-level rises that may correspond to irrigation activity. In addition, whereas water-levels in MW-1 stabilize after 2000 and show a minor rise after 2005, water levels in two shallow aquifer wells about ¼-mile away show continued gentle declines. This suggests that other factors besides Port Williams pumping have some affect on shallow aquifer groundwater level trends (e.g. other pumping withdrawals and/or changes in irrigation and other sources of recharge).

5. Trends in the middle aquifer noted at the Port Williams Wellfield tend to closely follow trends in the lower aquifer (**Figure 8-4**). However, trends in the middle aquifer appear to be fairly widespread; whereas pumping drawdowns in the lower aquifer do not appear to affect more distant wells (see points 1 and 2 above). As shown on **Figure 8-3**, middle-aquifer water level declines between 1997 and 2007 cover a large area, with similar declines noted 1 to 2 miles away from the Port Williams Wellfield. A hydrograph of middle-aquifer Well AAF386, located a mile east of the wellfield, shows similar seasonal variation to Port Williams Well MW-3; however, two differences are noted: 1) whereas MW-3 shows a pronounced decline prior to 2001 followed by stabilization, AAF386 shows a more continuous, gradual decline, and 2) whereas MW-3 shows a greater water-level rise following 2005 than AAF386 (**Figure 8-6**). These differences suggest that other factors, besides pumping at the Port Williams Wellfield (e.g. other pumping or changes in the distribution of recharge), may be affecting nearby water levels in the middle aquifer.

6. It is worth noting that while groundwater is withdrawn from the Port Williams Wellfield at an average annual rate of 0.4 mgd (450 af/yr), other Group A systems and domestic wells within a mile of the wellfield are estimated to withdraw about 0.14 mgd (160 af/yr) and 0.1 mgd (110 af/yr), respectively. These two categories of withdrawal comprise 60 percent of total Port Williams pumping, and are expected to influence observed water-level trends. Ditch lining in the wellfield vicinity, predominantly prior to 2000 (**Figure 1-2**), is also expected to affect water-level trends.

7. Preliminary isotope analysis for age dating suggests that the groundwater drawn from the lower aquifer at the Port Williams Wellfield may be a mixture of old and recent water (Section 9.3). If confirmed with additional sampling, this would suggest a higher degree of hydraulic connection between the shallower and deeper portions of the groundwater flow system than implied by the current conceptual model.

In summary, groundwater level declines at the Port Williams Wellfield appear to have stabilized to the current level of pumping, as is expected when groundwater withdrawals do not exceed flow through the groundwater system. While a hydraulic connection exists between the lower and middle aquifers, available data are somewhat contradictory regarding the degree of connection. Additional data collection, aquifer testing, and/or hydrogeologic characterization may be needed to better understand this connection. Heterogeneity may also be affecting the distribution of drawdown in the lower aquifer. The shallow aquifer appears to have less hydraulic connection to underlying aquifers, and is likely more influenced by recharge than pumping. Trends in wells more distant from the wellfield suggest that influences on the shallow and middle aquifers extend beyond purely Port Williams pumping. Indeed, other withdrawals within a mile of the wellfield comprise an additional 60 percent of the wellfield pumping, and changes in irrigation recharge also occur nearby.

Highway 101 – Dungeness River Crossing

Water-level declines near the Highway 101 – Dungeness River crossing appear to extend over an area of several square miles on either side of the Dungeness River. As noted in Section 8.2.1, declines have ranged from 8 to 17 feet between 1997 and 2007, preceded by 3- to 9-foot declines between the late 1970s and the mid 1990s[10]. Wells exhibiting declines are interpreted as completed in the shallow aquifer beneath a glacial till confining unit. Local stresses on the groundwater flow system capable of causing decline include:

- Pumping at the Silberhorn Wellfield
- Pumping from nearby public and domestic water systems; and,
- Changes in recharge from piping of irrigation ditches.

The City of Sequim has used the Silberhorn Wellfield for water supply since 1975. PGG evaluated pumping and water-level declines at the Silberhorn Wellfield in 1996, as declining water levels had forced a number of nearby residents to deepen their domestic supply wells in the early 1990s. To help mitigate declining water levels, the City of Sequim reduced pumping at the wellfield in 1996 as it brought the Port Williams Wellfield into service. Reduced pumping continued through 2005, and has more recently increased back to quantities withdrawn in the early 1990's (**Figure 8-5**). However, water levels in the Silberhorn area continued to decline from 1997 through 2005 despite reduced annual pumping loads. In addition to the fact that long-term water-level declines do not correlate well with changes in pumping, seasonal high groundwater levels tend to occur during maximum (summer) seasonal pumping withdrawals (**Figure 8-7**). Both of these observations suggest that other changes in the hydrologic system may be contributing to the water level declines.

Other pumping in the area is significant relative to Silberhorn withdrawals, as summarized in the table below. Whereas Silberhorn pumping has averaged 0.26 mgd (290 af/yr) from 1993 through 2008 and was 0.35 mgd (390 af/yr) in 2007, other Group A water systems within a 1-mile radius of the wellfield had 2007 withdrawals on the order of 0.29 mgd (330 af/yr). Just over half of this Group A pumping is associated with the Clallam County PUD Evergreen System (**Figure 6-2**). In addition, domestic wells within a 1-mile radius are estimated to withdraw about 0.17 mgd (190 af/yr). Compared to the sum of Group A and domestic *gross* withdrawals (520 af/yr), associated consumptive use is estimated to be 0.35 mgd (390 af/yr) or more[11]. Therefore withdrawals from other Group A systems and domestic wells are expected to have a similar degree of influence on the groundwater flow system as pumping from the Port Williams Wellfield.

Groundwater Use	Gross Withdrawal	Consumptive Use
Silberhorn Pumping (2007)	0.35 mgd (390 af/yr)	0.35 mgd (390 af/yr)
Other Group A Systems and Domestic Withdrawals within 1 mile of Silberhorn Wellfield (2007)	0.46 mgd (520 af/yr)	0.35 mgd (390 af/yr)

[10] An isolated middle-aquifer decline of 9 feet is noted in the area where highway 101 crosses the Dungeness River (Figure 8-3). As noted above, preliminary hydrogeologic interpretation suggests that this well may be completed in the shallow aquifer. Further evaluation would be needed to confirm this or ascertain whether similar declines are noted in the shallow and middle aquifers.

[11] Consumptive use may be more than 350 af/yr locally because the Clallam PUD Evergreen System may supply wells over an extended area.

In comparison with pumping withdrawals, lining of irrigation ditches near the Silberhorn Wellfield is estimated to have reduced local groundwater recharge by about 0.38 mgd (430 af/yr). Ditch lining on the west side of the Dungeness River is also significant (**Figure 1-2**), although PGG did not calculate associated reductions in recharge. As discussed above, seasonal water-level trends at the Silberhorn Wellfield exhibit good correlation to seasonal irrigation diversions during some (but not all) years. In contrast, seasonal pumping patterns generally exhibit an inverse correlation to water-level trends. This suggests that recharge from irrigation ditches may exert a stronger influence on seasonal water-level variations than pumping. Additional study would be needed to better understand these causative factors.

Interpretation of the data collected to date suggest that hydrogeologic conditions in the vicinity of the Highway 101 – Dungeness River crossing are somewhat complex, and the mechanisms for groundwater level decline are not fully understood. Many of the wells in the area are completed beneath a till confining unit, and aquifer testing at the Silberhorn Wellfield showed a confined aquifer response (PGG, 1996). Under confined conditions, drawdown from pumping is expected to propagate relatively far out into the aquifer, and declines on either side of the river are consistent with expected pumping responses from an aquifer that is partially isolated from the river by an overlying confining unit. However, declines on either side of the river could also be explained by reduced irrigation recharge on both sides of the river, and the noted correlation between irrigation diversions and Silberhorn water-levels suggests that irrigation recharge has a greater influence on water-level trends than pumping. If this is the case, a mechanism for changes in irrigation recharge (which reaches the shallow aquifer *above* the confining unit) to exert greater influence on water levels *below* the confining unit is required.

Variations in irrigation recharge could exert a strong influence on groundwater levels below the confining unit if the unit were local in extent, and was absent in more distant areas where ditch recharge is a significant contributing factor to the water budget. However, if changes in irrigation recharge were responsible for most of the observed decline, similar declines would be required in areas where the confining layer was absent. These "source areas" would be functioning under unconfined conditions, would probably be better connected to the Dungeness River, and declines on the order of 20 feet would therefore be less likely. Pumping drawdowns are more capable of creating decline beneath a confining unit, and the combination of both factors may be influencing the observed declines. Although long-term variations in Silberhorn pumping do not correlate well to long-term water-level trends, other local pumping occurs at a similar magnitude and associated changes over time are unknown.

Declines near the Dungeness River crossing are on the order of approximately 25 feet over 30 years, and have not stabilized. If these declines are to be better understood, additional hydrogeologic characterization, continued (or additional) monitoring of groundwater levels and pumping, consideration of temporal and spatial patterns in ditch leakage and associated interpretation is recommended. At minimum, continued monitoring of water-levels and pumping, and documentation of further ditch lining, is strongly recommended.

Other Areas

Water-level declines in other areas are typically small to moderate compared to the declines discussed above. A few exceptions are noted below, and are described qualitatively in terms of documented groundwater withdrawals and ditch piping:

- An isolated 6.3-foot water-level decline in the shallow aquifer just east of Cassalery Creek (**Figure 8-3**) may be associated with similar order declines noted near the Port Williams Wellfield; however, available data are too sparse to assess whether these declines are continuous over intervening areas.

Consumptive groundwater use is not estimated to be particularly high in that square-mile section (**Figure 6-5**). An upgradient reach of irrigation ditch was piped prior to 2000 (**Figure 1-2**); however piping of irrigation ditches is not particularly concentrated in this area.

- An isolated 7.7-foot water-level decline in the middle aquifer just south of Bell Creek (**Figure 8-3**) is of unknown origin. Two Group A water systems withdraw about 0.03 mgd from this square-mile section (**Table 6-2**) and domestic well withdrawals are moderate (**Figure 6-5**). The area includes a relatively high density of piped irrigation ditches (**Figure 1-2**). Because groundwater levels are not monitored in the shallow aquifer, the influence of reduced ditch recharge is difficult to interpret. While similar magnitude middle-aquifer declines are noted at the Port Williams Wellfield (approximately 2 miles to the northwest), it seems less likely that almost 8 feet of drawdown from the Port Williams Wellfield has propagated this far from the pumping center. Available monitoring points are too sparse to characterize the continuity of declines between areas.
- Declines of 8.4 and 7 feet in the shallow and middle aquifers (respectively) are noted in the Agnew area, west of McDonald Creek (**Figure 8-3**). A single Group A system withdraws 0.07 mgd from this square-mile section (**Table 6-2**), and domestic well withdrawals are moderate (**Figure 6-5**). Ditch lining has also occurred in the area of decline (**Figure 1-2**).

8.3.3 Factors Influencing Future Hydrologic Changes

The same factors considered in interpretation of historic water-level changes have the potential to cause future change: precipitation recharge, irrigation recharge and pumping withdrawals. As discussed above, water-level responses to these factors will depend on: 1) the relative magnitude of the change, 2) the spatial distribution of the change, and 3) local hydrogeology. The largest near-term change could be associated with lining of irrigation ditches. About 6,900 af/yr out of 17,200 af/yr of irrigation recharge has been lost due to ditch piping since the early 1990's, leaving as much as 10,300 af/yr of future potential reduction. The other two factors are the same order of magnitude but smaller. Consumptive groundwater use is currently on the order of 3,800 af/yr. City of Sequim doubled its pumping over 30 years from 1978 to 2008 (**Figure 6-1**). A similar growth rate would increase total pumping by about 4,000 af/yr by 2040. Long-term average precipitation recharge is estimated to be 19,000 af/yr over the study area. If climate change (warming) caused a reduction of about 15 percent, precipitation recharge would decline by about 2,900 af/yr. These three factors combined represent about one third of the current total estimated recharge for the study area[12].

Whereas precipitation recharge is distributed over the area, the spacing of un-piped irrigation ditches varies greatly. Water-level declines resulting from piping would be greatest in areas of closely spaced ditches. Groundwater withdrawals can be widely distributed (as with multiple single-residence domestic wells) or concentrated (as with large public water-system wellfields). Drawdown distributions will depend on the intensity and concentration of pumping, along with the aquifer pumped. Hydraulic connection between aquifers dictates that pumping in a given aquifer will cause some degree of (subdued) decline in overlying or underlying aquifers. Groundwater level declines in the shallow aquifer would lead to some baseflow reduction in streams that are hydraulically connected to the groundwater flow system. Whereas gaining streams (e.g. many of the small independent streams in the study area) would gain less water, losing streams (e.g. the Dungeness River) would lose more water to the shallow aquifer, partially offsetting the reduction in recharge. The 2008 Groundwater Flow Model (PGG, 2009) could be used to estimate the affects of these changes, although further calibration of the model is recommended to better

[12] Total recharge, including ditch leakage for 1993, was estimated on the order of 58,000 af/yr (Section 8.3.1). Ditch lining between 1993 and 2008 has reduced total recharge to an estimated 51,100 af/yr.

represent the degree of hydraulic connection between shallow and deeper portions of the groundwater flow system.

9.0 WATER QUALITY

This section summarizes spatial distributions and temporal water-quality trends from readily available groundwater and surface-water quality information. The data reflect sampling of groundwater supply sources and sites along local streams, as reported by involved agencies and organizations. This section does not attempt to summarize water-quality issues associated with local contaminated sites (such as leaking underground storage tanks or landfills), and the reader is referred to Washington Department of Ecology databases for information regarding known and suspected contaminated sites. This section also presents the results of isotopic analysis for groundwater age dating from recent samples collected by the City of Sequim at its two wellfields.

9.1 DATA SOURCES

Groundwater Data

Groundwater data was compiled from the Washington Department of Health (DOH), the USGS, and Clallam County:

- DOH provided a download of analytical data for all Group A water quality systems in the study area including samples from 352 Group A[13] water systems with data from as early as 1975 (DOH, 2008).
- Clallam County provided nitrate data from 125 samples, including some continued monitoring of USGS monitoring wells (Anne Soule, personal communication, 2008).
- Groundwater data from USGS monitoring include results from 510 nitrate and specific conductance analyses from 1979 to 1996 (Thomas et al, 1999).

The discussion below focuses on data from the DOH. USGS and Clallam County data are used to supplement the analysis of nitrate and conductivity of groundwater.

Surface Water Data

Surface-water quality is summarized from existing compilations of water-quality data including: data summaries from the Streamkeepers of Clallam County (Streamkeepers, 2004, 2007); surface-water quality reports from the Department of Ecology (Sargeant, 2002 and 2004); and the WRIA 18 Watershed Plan (EDPU, 2005).

9.2 GROUNDWATER

Water quality in Group A systems is generally good, with only isolated exceedances of maximum contaminant levels (MCLs). The following sections discuss nitrate concentrations, electrical conductivity, and MCL exceedances in the data considered.

[13] Group A water systems have 15 or more service connections or regularly serve 25 or more people 60 or more days per year, and are required to collect water quality samples on a regular basis.

9.2.1 Nitrate

Nitrate is a common constituent in groundwater that can originate from both natural and anthropogenic sources. Nitrogen compounds such as ammonium and nitrate are important nutrients for plant and bacterial growth. Nitrate is generally the dominant form of nitrogen in groundwater with lesser amounts of ammonium and nitrite which convert to nitrate through bacterial processes. High nutrient concentrations in groundwater may indicate contamination by animal waste or sewage, nitrogen-rich fertilizers, or industrial discharges. Nitrate is regulated in groundwater with an MCL of 10 mg/L.

Figure 9-1 summarizes nitrate data in 1980, 1996 and 2005-2007[14]. Nitrate values in the study area ranged from non-detect to 20.1 mg/L and have generally been increasing since 1980. Nitrate values in Group A water systems ranged from non-detect to 16.6 mg/L, with only 2 of 2132 samples exceeding the MCL. Among the Group A water systems, 35 samples exceeded the 4.99 mg/L DOH trigger for nitrate; 2 samples exceeded the MCL (10 mg/L). Six of these exceedances occurred at the Carlsborg Mobile Estates Group A system since 2005, which shows an increasing trend from 3mg/L to over 9 mg/L since 2003.

The highest nitrate concentrations and most prominent increases over time occur downgradient (north-northeast) of Sequim and in the vicinities of Agnew and Carlsborg. Recent data are largely lacking south of Highway 101. Areas with elevated nitrate concentrations in **Figure 9-1** generally occur near high densities of domestic wells (**Figure 6-4).** This similarity could reflect a correlation with increased densities of residential development (and associated septic loading) and/or a bias inherent in sampling density.

Clallam County found that nitrate concentrations in the Agnew and Carlsborg areas tended to occur as locally elevated hot-spots near or above the MCL, surrounded by lower concentrations generally less than 5 mg/L (Soule, 2004). Ecology found a statistically significant increase in nitrate concentrations at 3 of 8 wells from 1980 to 2002 near Agnew and Carlsborg, with one well showing a declining trend (Sinclair, 2003).

The USGS estimated that about 47 percent of nitrogen loading was attributed to fertilizers, manure lagoons and application, and 20 percent of the loading was attributed to septic systems (Thomas et al, 1999). The USGS found that residential areas with higher septic system density had statistically significant increases in nitrate over nitrate concentration in natural grasslands and forests (background). Nitrate concentrations beneath agricultural areas were higher than background, but were not considered statistically significantly higher.

9.2.2 Conductivity

Electrical conductivity, sometimes referred to as specific conductance, is an indicator of total dissolved solids in water and water hardness, and can also provide an indicator of seawater intrusion. Increasing electrical conductivity values indicated increasing concentrations of dissolved minerals producing harder water, or elevated chloride from saltwater interaction. Conductivity data suggest soft to moderately hard water in the Sequim-Dungeness Peninsula, and do not indicate widespread seawater intrusion.

PGG reviewed conductivity data from 153 samples in the DOH database as a screen for saltwater intrusion, and other forms of contamination (DOH, 2008). Conductivity values in the DOH data range from 114 to 860 umhos/cm, with an average of 338 umhos/cm. The highest value, associated with the West Sequim Bay Water System, had *both* elevated conductivity and chloride values, suggesting possible sea-

[14] Data from Clallam County and DOH were extracted into time-slices from 1979-1980, 1995-1996, and 2005-2007 for use in Figure 9-1.

water interaction or presence of connate saline water in the aquifer. The system's chloride concentrations averaged 176 mg/l, which is about 10 times higher than the dataset average of 18 mg/l, but well below the secondary MCL for chloride of 250 mg/l.

The USGS reports an average specific conductance of 312 umho/cm ranging from 167 to 712 umhos/cm from 74 samples collected in 1996 (Thomas et al, 1999). Specific conductance was slightly higher in the Middle Aquifer (404 umhos/cm) than the Shallow Aquifer (294 umhos/cm). These values are similar to conductivity values from the DOH database.

PGG also reviewed a 1993 study that evaluated chloride and conductivity in 49 wells located in 13 coastal areas of eastern Clallam County (Forbes, 1993). Areas sampled within PGG's study area included: Agnew, Washington Harbor, Port Williams, Old Town, near the mouth of McDonald Creek, W. Anderson Road/W. Marine Drive, Fairview and Dungeness. Some (13) of the wells were outside of PGG's study area (e.g. in south Sequim Bay and on the Miller Peninsula). Approximately 20 wells had been previously sampled by the USGS in 1978-79. Within PGG's study area, only one well (on the west side of Sequim Bay) had high chloride and conductivity (260 ppm and 1200 umhos/cm). The study presented the following conclusions:

- Seawater intrusion is not a pervasive problem in Clallam County at the present time, and there appears to have been little if any significant change in chloride content in wells that were last sampled in 1978-79.

- No new areas of potential impact from seawater intrusion were discovered in Clallam County. However, data from previous studies and this work indicate that elevated chlorides in the west and east coast of Sequim Bay, the community of Blyn at the south end of the Bay, and Diamond Point on Miller Peninsula.

- Water wells located along the coastline between Dungeness and the entrance to Sequim Bay appear to be remarkably resistant to intrusion. Based on our knowledge of the hydrogeology, this appears to be due to the fact that groundwater is being produced from confined aquifers with a relatively high hydraulic (sometimes artesian) head.

9.2.3 MCL Exceedances

There were relatively few exceedances of groundwater maximum contaminant levels in the study area between 2002 and 2007. 18 out of 352 systems had exceedances of the MCL, including:

- Fourteen systems (36 samples) had exceedances of the secondary MCL for manganese (0.05 mg/l);
- Seven systems had exceedances of the secondary MCL for iron (0.3 mg/l);
- One system had exceedances of the MCL for specific conductivity (700 umhos/cm); and,
- Two water systems MCL for nitrate (10 mg/L).

Iron and manganese are naturally occurring, and commonly elevated in Washington State soils and groundwater due to the regional geology of the area (San Juan, 1994). Elevated iron and manganese present an aesthetic rather than health concern in most cases.

Several MCL exceedances were noted in the WDOH data for volatile organic compounds (VOC); however these were related to by-products of disinfection by chlorination (e.g. trihalomethane, dibromochloromethane, chloroform, and bromochloromethane) and are likely unrelated to subsurface conditions.

9.3 GROUNDWATER AGE DATING

The City of Sequim had samples from its Port Williams and Silberhorn wellfields analyzed for tritium and carbon-14 in order to estimate the age of groundwater reaching these wells. A positive detect for tritium means that some portion of the water comes from recent (post "H-bomb") water. If there is no detect, then the water is completely older than 1944. The Carbon-14 age represents the "average age" of the groundwater. If the groundwater flowpath involves mixing, this value is an average age of all the various waters that get mixed in the aquifer. The samples were taken in April 2008 and sent to Beta Analytic Laboratories of Miami, FL for Carbon-14 analysis and to Isotech labs of Champagne, IL for tritium analysis. Laboratory results are summarized below:

Source	Apparent C14 Age (Fraction Modern)	C13/C12 Ratio	Tritium (TU)	Tritium Std. Dev. (TU)
S05-Port Williams	1840 +/- 40 BP (Fmdn 0.7949 +/- 0.0040)	-14.2 o/oo	5.21	0.31
S02-Silberhorn	1350 +/- 40 BP (Fmdn 0.8449 +/- 0.0042)	-10.6 o/oo	3.20	0.29

The tritium age dating suggests that there is some component of modern (post world war 2) water at both wellfields. This is indicated by values in excess of 1 tritium unit (TU). Port Williams had a higher tritium measurement than Silberhorn, but that doesn't mean it is more "modern" (i.e. younger). Tritium levels in the atmosphere were highest in the 1960's - so a higher tritium value could mean that the water was recharged during a time of high atmospheric tritium and then went through some radioactive decay underground.

The Carbon-14 age dating provides "apparent" ages. They are called apparent because they can be influenced by mixing with more modern water or they can be affected by chemical reactions in the subsurface. The apparent ages are 1840 years for Port Williams and 1350 years for Silberhorn. If there are no significant chemical reactions in the subsurface, this would signify that the average age between the "modern" water (shown by the tritium values) and the older water is 1840 and 1350 years. This means that some amount of modern water is mixing with water that is older than 1840 and 1350 years. How much older depends on the amount of mixing. For example, if the mixing were 50/50, then the "old" water would be 2x older than the apparent age (i.e. 3,680 and 2,700 years). Further analysis by an isotope geochemist might support better assessment of the mixing ratios based on consideration of the tritium values.

If chemical reactions have occurred in the subsurface, the apparent ages of 1,840 and 1,350 years are *maximum* values (pers. com., Hood, 2008). That is, possible chemical reactions make the apparent ages go older, not younger. If chemical reactions have occurred, the mixed groundwater may have average ages that are younger than the reported values. The most common reactions in the subsurface are carbonate dissolution, methane production ("methanogenesis"), interactions with buried organic carbon and sulfide oxidation (ibid). Because there is no limestone in the area, carbonate dissolution is unlikely to be affecting the accuracy of the dating. Methanogenesis is also highly unlikely because the Carbon-13 numbers are in normal ranges (ibid). The likelihood of interactions with buried carbon and sulfide oxidation is unknown. Groundwater could potentially move through pockets of organic-rich materials (e.g. buried peat deposits) that could cause either reaction. Neither of the water sources produces sulfur smelling water; however, Ann Soule (hydrogeologist for Clallam County) notes that a number of wells on the Sequim-Dungeness Peninsula do exhibit sulfur-smelling water (Soule, pers. com., 2008). Further geochemical analysis would be needed in order to better assess (or rule out) the potential for dating errors due to interactions with buried organic carbon and/or sulfide oxidation

Overall, the age-dating results indicate that both samples appear to be a mixture of "modern" (post WWII) and "older" (>1,840 and >1,350 years), and that these dates represent "average" values for the mixed waters. If interactions with buried organic carbon or sulfide oxidation have significantly affected the samples, the mixed water samples would have a younger affective age than the reported values.

The occurrence of younger water in the lower aquifer at Port Williams is unexpected, given that USGS characterization of the groundwater flow system includes two overlying regional aquitards. In general, more than one age-dating analysis should be performed to characterize groundwater residence times in a given aquifer, especially to rule out the possibility of laboratory error. Confirmation of the presence of younger water in the lower aquifer would suggest that the aquitards that overlie the lower aquifer do not provide a continuous low-permeability restriction to downward groundwater flow, and that areas may exist that provide more rapid communication between shallow groundwater and the lower aquifer. Additional sampling, at minimum for tritium analysis, would be needed to better assess this possibility.

9.4 SURFACE WATER

Surface water quality is monitored in the Dungeness River and smaller streams by Ecology, the Jamestown S'Klallam Tribe and Streamkeepers on a regular basis. The Jamestown S'Klallam Tribe is preparing a report on the current status of surface-water quality in the Sequim area expected available in early spring, 2009 (Hansi Hals, personal communication, 2009). Surface-water quality can impact not only the immediate stream environment, but also on the health of salmon populations, near-stream groundwater and the near shore environment in the Strait of Juan de Fuca, Dungeness Bay and Sequim Bay. Elevated fecal coliform bacterial concentrations have been the primary water quality issues in study-area surface waters due to the potential for human health impacts and consequent restrictions on shellfish harvesting. A number of parameters including water temperature, nitrate, and dissolved oxygen impair surface water quality due to their influence on stream ecosystems and aquatic life including salmon. Fine sediment, while not a water quality parameter, can clog stream beds and increase water turbidity adversely affecting stream ecosystem health. Silted stream bottoms adversely affect salmon spawning habitat, and increased turbidity can reduce available light for aquatic plant and animal life.

A summary of the water quality rating for each of the streams and descriptions of water quality issues from the State of the Waters report (Streamkeepers, 2004), the WRIA 18 Watershed Plan (EDPU, 2005), Streamkeepers water quality summaries (Streamkeepers, 2007), and the Washington State Waster Quality Assessment Report (Ecology, 2008b) are presented in **Table 9-1**. Select water quality parameters are discussed in the following sections.

9.4.1 Fecal Coliform

Fecal coliform exceedances are a primary surface-water quality issue in the study area in monitoring to date (**Table 9-1**). Elevated fecal coliform counts are reported for 8 of 10 of the monitored drainages in the Sequim area. Fecal coliform indicates the presence of feces in contact with water at some point upstream of the sampling point. Detections of fecal coliform can also indicate the presence of viruses and other pathogens present in feces that are not commonly tested for.

Elevated concentrations in the study area are generally considered to result from many non-point source activities in the area including leaky septic systems, animal access to creeks and irrigation ditches, and other animal waste. Elevated coliform counts in Dungeness Bay resulted in restrictions on shellfish harvesting. Elevated coliform in the Dungeness River and tributaries are considered the primary source for the elevated coliform in Dungeness Bay, and Ecology completed two a total maximum daily load (TMDL) studies to begin addressing the problem (Sargeant, 2002 and 2004). Changes in use and maintenance of septic systems, animal access to waterways, and agricultural practices have reduced coliform levels in the Dungeness River and Matriotti Creek, although levels remain above target levels outlined in the *Clean Water Strategy for Addressing Bacteria Pollution in Dungeness Bay and Watershed* (Streeter, 2004).

9.4.2 Nitrate

Nitrate is a basic nutrient in the fresh and saltwater bodies required for plant growth and ecosystem health. However, excessive nitrate can cause human health effects and adversely effect surface water ecosystems by promoting algal blooms and other changes. Similar to groundwater, elevated nitrate in surface waters can come from residential and agricultural fertilizers, septic systems, animal waste, and certain types of crops which fix nitrogen in soil. The state regulates nitrate in surface waters for human health effects at 10 mg/l. However, concentrations below 10 mg/l have the potential to adversely affect stream ecosystems. PGG did not conduct an exhaustive analysis of nitrate concentrations, but relies on evaluations of stream health provided in the documents listed in Section 9.1 which may list nitrate as impairing water quality based on habitat concerns, even if concentrations are below the MCL for human health. Nitrate is listed as a concern for surface water quality in 4 of 10 streams on the Sequim-Dungeness Peninsula, including Cassalery Creek, Matriotti Creek, McDonald Creek and the Dungeness River (**Table 9-1**) (Streamkeepers, 2007; EDPU, 2005). Nitrate was not measured at all water quality monitoring stations and may be elevated in other areas.

Ecology collected 72 nitrate samples between 2001 and 2007 at station 18A050 near the Dungeness River mouth, which averaged 0.053 mg/l with a maximum of 0.143 mg/l. Nitrogen values at this station vary seasonally with a peak between November and January and lowest values in summer months.

9.4.3 Temperature

Water temperature is an important indicator of stream health because it influences the health and type of biota. Warm temperatures can adversely affect salmon spawning, and promote growth of disease causing organisms and algae. Human activities can affect water temperature through changes in streamside vegetation, and changes to streamflow through diversions and inputs from commercial outfalls and stormwater.

Temperature is listed as degrading stream health at 6 of 10 streams in the study area, including Cassalery Creek, Cooper Creek, Dungeness River, Matriotti Creek, McDonald Creek, and Meadowbrook Creek (Streamkeepers, 2004, 2007). Dungeness River temperature at station 18A050 varies daily and seasonally with a summer high in July and August between 13 and 16.5 degrees C and a low in January and February with temperatures just above freezing (Ecology, 2008b).

9.4.4 Dissolved Oxygen

Dissolved oxygen is the oxygen present in water and available for fish and other aquatic species. Dissolved oxygen concentrations can be reduced by increases in water temperature, presence of decaying organic matter in streams, and types of in-stream biota. Low dissolved oxygen impairs aquatic life in streams (Streamkeepers, 2004). Dissolved oxygen is listed as an impairing water quality at 5 of 10 streams in the study area including Bell Creek, Cassalery Creek, Cooper Creek, Meadowbrook Creek and

Siebert Creek (**Table 9-1**) (Ecology, 2008b). Dissolved oxygen is listed as a concern for water quality at Bagley Creek and Matriotti Creek (Ecology, 2008b).

9.4.5 Conductivity

Electrical conductivity is the ability of water to conduct electricity, and is a measure of the concentration of dissolved ions. Conductivity in the Dungeness River ranges from 81 to 170 umhos/cm with an average of 129 umhos/cm, which is in the expected range for fresh water (Ecology, 2008b). These conductivity values are also generally lower than the range for groundwater discussed in Section 9.2.2, suggesting lower total dissolved solids concentrations in the Dungeness River than in groundwater.

9.4.6 Turbidity and Fine Sediment

Turbidity is a measure of the suspended material in water and an important water quality parameter because of the potential for fine sediment clog stream beds, block sunlight from aquatic vegetation, and otherwise adversely affect stream health. The Streamkeepers note fine sediment as an issue at 7 of 10 streams in the study area based on repeat observations of channel conditions (Streamkeepers, 2004). They cite stormwater runoff, bank erosion, and land use practices as contributing to increased fine sediment and turbidity levels in study area streams, although factors vary by stream. No study area streams are listed as impaired for turbidity in the State Water Quality Assessment Report (Ecology, 2008b).

10.0 RECOMMENDATIONS

The following recommendations are offered to guide future monitoring efforts along with related studies to better understand the structure and function of the groundwater flow system:

1. Existing monitoring efforts have been useful in documenting hydrologic trends on the Sequim-Dungeness Peninsula and should be continued to guide water-resource management decisions. The City's monitoring program includes several nearby monitoring points that appear to provide duplicate data. Specifically, the Sequim Test Well and Well MW-1 are both located at the Port Williams Wellfield in the shallow aquifer, and wells AAF381 and AAF382 are located across the street from one another (**Figure 8-1**), about ¼ mile west of the Port Williams Wellfield. Monitoring of all four wells is specified in the water rights settlement agreement for the Port Williams Wellfield. However, with Ecology's approval, PGG recommends that the Sequim Test Well and Well AAF382 be dropped from the monitoring network.

2. The current monitoring network includes broad areas with no monitoring points, or that were monitored previously by the USGS and are no longer monitored (**Figure 8-3**). Monitoring is extremely limited in the middle and lower aquifers, although groundwater withdrawals are likely shifting to these aquifers. The City's responsibilities are associated with monitoring conditions near their wellfields. However, if the City or other entities have resources for additional monitoring, we recommend that the network could be expanded to include:

    - "Filling in the gaps" in shallow aquifer monitoring, including re-establishing some of the wells historically monitored by the USGS in areas with sparse or no current monitoring;
    - Locations in the shallow aquifer *surrounding* areas of noted declines to establish the geographic extent of the decline. Areas include the Highway 101 – Dungeness River crossing, and the area between the headwaters of Gierin Creek and mid Cassalery Creek;
    - Locations in the shallow aquifer where extensive ditch piping has recently occurred or will be occurring in the future;
    - Areas of increasing groundwater withdrawals (e.g. Carlsborg);
    - Areas in the middle and lower aquifers surrounding areas where declines are noted, and in other areas to establish background trends.

3. Groundwater declines near the Highway 101 – Dungeness River crossing present the greatest concern. If a better understanding of this situation is desired, PGG recommends that further study include: installation of dataloggers in some of the monitoring wells to obtain better time-resolution of groundwater responses, monitoring of additional wells surrounding the area of documented decline, further hydrogeologic characterization of the area (e.g. hydrogeologic cross sections, water-level mapping, assessment of vertical gradients), and monitoring or observation of flow conditions and changes in nearby irrigation ditches.

4. Stabilization of groundwater levels in the vicinity of the Port Williams Wellfield indicates that the groundwater flow system has established equilibrium with current pumping. Future increases in pumping will shift this equilibrium and cause further decline (which is likely to stabilize). Although average declines at the wellfield have not reached the "trigger" established in the water-rights settlement agreement, the trigger has been reached in some years. The City should work with Ecology to

review the conclusions of this report, and continue its commitment to monitoring in the Port Williams area.

5. Understanding the hydraulic connection between the shallow aquifer and deeper aquifers is important for predicting the impacts of future increases in deep pumping, and could be aided by additional age-dating isotopic analysis. Preliminary analysis suggests mixing of old and recent water in the lower aquifer; however, this is based on a single sample from the Port Williams Wellfield. This single analysis should be repeated. Use of tritium or other indicators of recent human influence such as methylene blue active substances (ingredients in detergent), nitrate or PCPP (personal care products and pharmaceuticals) could be useful in mapping areas where recent water has made its way into deeper portions of the groundwater flow system. Additional geochemical and hydrogeologic analysis could be employed to evaluate ratios of mixing between older and recent waters, and further applied to assess hydraulic connections between adjacent aquifers.

6. As groundwater quality data suggest increasing nitrate concentrations over time, the County's efforts to monitor nitrate appear to be useful and warranted. Nitrate data collected from public water system testing, sampling associated with building permits, and focused monitoring in problem areas is encouraged. Hopefully, Clallam County will continue its efforts to track nitrate concentrations over time.

7. Existing and future monitoring data would likely be useful for further calibration of the 2008 Groundwater Flow Model (PGG, 2009). Better calibration of the model to hydraulic connection between shallow and deeper portions of the groundwater flow system is needed to improve predictions of pumping impacts on surface-water features. As the ability to predict such impacts improves, decisions regarding new water rights and associated mitigation requirements will be easier to make.

8. Monitoring can be used to evaluate the need for new and innovative water-resource management strategies, to establish baseline conditions, and to assess the effects of these strategies. Strategies currently under consideration in the area include aquifer recharge with source water from the Dungeness River and with Class A reclaimed water (explored in detail in a recent AR feasibility study by PGG et al, 2009), focusing new water-supply development on deeper aquifers that exert less flow impacts to streams, various mitigation strategies to offset impacts of new water-supply development (currently under discussion in the instream flow and water management rule-making process for the Dungeness watershed), and aquifer storage and recovery (ASR) in deeper aquifers.

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Table 6-1. Water Use Assumptions

Parameter	Group A on Sewer	Group A on Septic	Domestic or Group B on Sewer	Domestic or Group B on Septic
Domestic Use				
Assumed Return from Domestic Use (%)	0%	87%	0%	87%
Assumed Domestic Consupmtive Use (%)	100%	13%	100%	13%
Domestic Use Per Hookup (gpd)	170	170	170	170
Domestic Consumption Per Hookup or Well (gpd)	**170**	**22**	**170**	**22**
Irrigation Use				
Irrigation Acres (acres)	1/8	1/8	1/4	1/4
Irrigation Consumptive Demand (in/yr)	15.5	15.5	15.5	15.5
Irrigation Consumptive Demand Per Hookup (gpd - annualized)	144	144	288	288
Irrigation Efficiency (%)	75%	75%	75%	75%
Irrigation Application to Meet Efficiency (gpd - annualized)	192	192	384	384
Irrigation Return Flow (gpd - annualized)	48	48	96	96
Summary Totals				
Amount Withdrawn per hookup or well (gpd)	362	362	554	554
Return Flow Per Well or Hookup (gpd)	48	340	96	244
Consumptive Use Per Well or Hookup (gpd)	314	166	458	310
Consumptive Use Per Hookup (%)	87%	46%	83%	56%
Sequim Water System Consumptive Use				
Sewered Consumptive Use per Hookup (%)	87%			
Non-Sewered Consumptive Use per Hookup (%)	46%			
Sewered Connections (%)	95%			
Average Consumptive Use Per Hookup (%)	85%			

Note: Withdrawal amounts for the Sequim Water system in this table are only used to estimate the percent consumptive use. Consumptive use from the Port Williams and Silberhorn well fields in Figure 6-5 is based on City of Sequim pumping records combined with the percent consumptive use from this table.

Table 6-2. Estimated Group A Water System Withdrawals

Source Locations on Map [1]	Water System Name	System ID	Number of Connections	Withdrawals (gpd)	Consumptive Use (gpd)
1	AGNEW MOBILE HOME PARK	518	14	5,068	2,327
2	ALDERWOOD EAST	1265	15	5,430	2,493
3	BUENA VISTA ESTATES	9155	15	5,430	2,493
4	HAPPY VALLEY ESTATES	30975	16	5,792	2,660
5	OLYMPIC VIEW	5151	16	5,792	2,660
6	PALO VERDE	2315	16	5,792	2,660
7	TROWBRIDGE COURT CONDO ASSN	339	16	5,792	2,660
8	RESORT AND MARINA	36421	17	6,154	2,826
9	BRANDT POINT	16190	19	6,878	3,158
10	OLYMPIC VIEW MOBILE PARK	19110	22	7,964	3,657
11	LORA LEE ESTATES	36991	25	9,050	4,156
12	MEADOWBROOK VILLAGE	10774	26	9,412	4,322
13	CEDAR GROVE MOBILE PARK	36836	28	10,136	4,654
14	DEYTONA	19184	28	10,136	4,654
15	MADRONA RIDGE HOMEOWNERS	50085	28	10,136	4,654
16	FOREST RIDGE	25949	30	10,860	4,987
17	JAMESTOWN	6344	41	14,842	7,314
18	DUNGENESS GOLF COURSE AND MT VISTA	20453	45	16,290	8,312
19	WOODLAND HEIGHTS	98182	45	16,290	7,480
20	GREEN ACRES MOBILE HOME PARK	29358	49	17,738	8,145
21	CARLSBORG MOBILE ESTATES	29	51	18,462	8,478
22	BAYWOOD VILLAGE MOBILE HOME PARK	36754	52	18,824	8,644
23	FLAURAS ACRES PROPERTYOWNER	25600	53	19,186	8,810
24	SUNLAND SHORES INC	85257	53	19,186	8,810
25	DUNGENESS BEACH	20350	69	24,978	11,969
26	LEE	46658	71	25,702	11,802
27	WEST SEQUIM BAY INC	54192	76	27,512	12,634
28	VISTAS INC	58144	90	32,580	14,961
29	SUN MEADOWS	4511	115	41,630	19,117
30	DUNGENESS HEIGHTS	20425	129	46,698	21,610
31	CARLSBORG LUD 10 12 13 14	307	156	78,152 *	35,950
32	MAINS FARM PROPERTY OWNERS	50400	156	56,472	25,932
33	DUNGENESS BAY PLAT	20300	161	58,282	26,763
34	MONTERRA	55990	182	65,884	30,254
35	DUNGENESS MEADOWS	20445	184	66,608	30,586
36	PARKWOOD MOBILE HOME COMMUNITY	2699	209	75,658	34,742
37	SOLMAR WATER COMPANY	81315	290	104,980	48,207
38	ESTATES INC	8166	315	114,030	52,363
39	SUNLAND WATER DISTRICT	85260	828	299,736	137,639
40	EVERGREEN CLALLAM COUNTY PUD 1	24181	580	388,632 *	273,117
41	SEQUIM, CITY OF	77620	1,188	951,604 *	805,940
Totals			**5,519**	**2,719,778**	**1,714,603**
Totals (mgd)				**2.72**	**1.71**

* Based on total reported annual 2007 pumping.

Consumptive Use By Area

Area	**gpd**	**mgd**
Group A Wells within 1 mile of Silberhorn	**182,433**	**0.18**
Group A Wells within 1 mile of Port Williams	**88,943**	**0.09**
Group A wells East of the Dungeness River	**1,408,029**	**1.41**
Group A wells West of the Dungeness River	**306,696**	**0.31**

[1] Please see number on Figure 6-2 for location of Group A water source.

Table 8-1. Monitoring Well Summary

Well Name and/or Ecology Unique Well ID	Location Source	Aquifer	Well Log	Period of Record	Data Type	Water Level Data Source
AAB 741	County	Middle	Yes	1978-2003	Manual	Ecology (discontinued)
AAB 742	County	Shallow	Yes	1978-2004	Manual	Ecology (discontinued)
AAB 745	County	Shallow	Yes	1989-2008	Manual	County and Ecology
AAB 746	Parcel or Address	Shallow	Yes	1989-2008	Manual	County and Ecology
AAB 747	County	Shallow	Yes	1989-2008	Manual	County and Ecology
AAB 748	County	Middle	Yes	1990-2007	Manual	County and Ecology
AAB 749	County	Shallow	Yes	1989-2007	Manual	County and Ecology
AAB 850	County	Shallow	Yes	1975-2004	Manual	Ecology (discontinued)
AAF 381	Parcel or Address	Shallow	No	1996-2008	Manual	City of Sequim
AAF 382	Parcel or Address	Shallow, Middle	Yes	1996-2008	Manual	City of Sequim
AAF 384	County	Lower	Yes	1995-2008	Manual	City of Sequim
AAF 385	EIM	Shallow	No	1996-2008	Manual	City of Sequim
AAF 386	Parcel or Address	Middle	Yes	1996-2008	Manual	City of Sequim
AAF 391	Parcel or Address	Shallow	No	1996-2008	Manual	City of Sequim
AAF 392	Parcel or Address	Shallow	No	1996-2008	Manual	City of Sequim
AAF 393	Parcel or Address	Shallow	Yes	1996-2008	Manual	City of Sequim
AAF 396	Parcel or Address	Shallow	Yes	1996-2008	Manual	City of Sequim
ABA 539	Parcel or Address	Middle	Yes	2000-2008	Manual	County and Ecology
ACA 594	County	Shallow	No	1978-2005	Manual	County
ACA 599	County	Shallow	No	1978-2005	Manual	County
AGQ 685	County	Shallow	Yes	2004-2008	Manual	County and Ecology
Graysmarsh (AAB 744)	County	Shallow	Yes	1978-2008	Manual	Ecology
Graysmarsh Well 1	County	Shallow	No	1998-2006	Manual	Graysmarsh
Graysmarsh Well 2	County	Shallow	Yes	1997-2007	Manual	Graysmarsh
Graysmarsh Well 4	County	Shallow	Yes	1997-2007	Manual	Graysmarsh
Graysmarsh Well 8 (AAF 387)	County	Lower	Yes	1997-2007	Manual	Graysmarsh / City of Sequim
Sequim Port Williams MW-1 (AAF 397)	County	Shallow	Yes	1996-1999	Manual / Continuous	City of Sequim
Sequim Port Williams MW-3 (AAF 398)	County	Middle	Yes	1996-1999	Manual / Continuous	City of Sequim
Sequim Port Williams PW-2 (AAF 961)	DOH	Lower	Yes	1999-2008	Manual / Continuous	City of Sequim
Silberhorn Well 1 (AAF 388)	PNS	Shallow	Yes	1993-2008	Manual	City of Sequim
Silberhorn Well 2 (AAF 389)	DOH	Shallow	Yes	1993-2008	Manual	City of Sequim
Silberhorn Well 3 (AAF 390)	DOH	Shallow	Yes	1993-2008	Manual	City of Sequim

Table 9-1. Summary of Surface Water Quality Evaluations

Drainage	Streamkeepers Avg. CCWQI Site Rating [1]	State of the Waters (2004) Rating and Issues [2]	WRIA 18 Watershed Plan (2004) Drainage Water Quality Summary	2008 Clean Water Act 303(d) List [3] Category 4 and 5	Category 2
Bagley Creek	4.4	*Compromised:* fecal coliform; sediment	"Bagley Creek is classified as a Class AA water body. It also is listed for aesthetic beneficial use. The creek is on the 303(d) list for fecal coliforms; other nonpoint issues listed by the Dungeness River Area Watershed Management Plan include vegetation removal, animal access, sedimentation, and highway runoff. Ecology states that there are runoff and erosion problems from the bluffs. Nitrates were elevated in 1992. "	Fecal coliform	Dissolved oxygen; fecal coliform; pH
Bell Creek	2.7	*Impaired:* fecal coliform; sediment	"Bell Creek is designated as a Class AA water body. It is listed on the Clean Water Act Section 303(d) list of impaired waterbodies, based on elevated fecal coliform counts. Water quality has been most impacted to date by unrestricted animal access in the watershed; however, there is increasing concern about stormwater as urban/rural development occurs in the watershed. Stormwater runoff due to land development has increased significantly."	Dissolved oxygen; fecal coliform	Fecal coliform; pH; temperature
Cassalery Creek	3.6	*Compromised:* fecal coliform; sediment; temperature; nitrate; low streamflows reduce flushing through the system.	"Cassalery Creek is designated as a Class AA water body. It is listed on the Clean Water Act 303(d) list for fecal coliform contamination. Other nonpoint issues listed by the Dungeness River Area Watershed Management Plan include nutrients, lack of vegetation, and animal access. The PSCRBT (1991) reported that water quality in Cassalery Creek is adversely affected by direct animal waste input due to unrestricted animal access to the channel. Nitrate results are suggestive of increased nutrient loading, but the accuracy is in doubt (Streamkeepers). Temperature sampling indicated a high of 14.9C, a low of 8.0 C, and an average of 11.3C."	Dissolved oxygen; fecal coliform	Dissolved oxygen
Cooper Creek	--	*Compromised:* fecal coliform; sediment; temperature.	"Cooper Creek is classified as a Class A water body."	Dissolved oxygen; fecal coliform	pH
Dungeness River	5	*Healthy to Compromised:* fecal coliform; sediment.	"The State of Washington classifies the Dungeness River and its tributaries from the mouth to its confluence with Canyon Creek as Class A (Excellent) under WAC 173-201 A. All portions of the river above Canyon Creek are classified as Class AA (Extraordinary). Dungeness River water quality problems are affecting critical and depressed salmon stocks in the river, as well as shellfish in the bay. Ecology found numerous problems in the Dungeness River associated with excessive sediments and nutrients, dissolved oxygen and temperature problems in some segments."	Instream flow; fecal coliform	pH; mercury; thallium
Gierin Creek	--	*Impaired:* fecal coliform; data are limited.	"Gierin Creek is designated as a Class AA water bodyNonpoint issues listed by the Dungeness River Area Watershed Management Plan include bacteria and nutrients, animal access, residential development, channelization and lack of a vegetative buffer. Water quality is adversely affected by direct animal waste input due to animal access to the channel, although animal access issues are thought to be generally corrected downstream of Holland Road. Animal access to the stream remains a concern upstream of Holland Road. "	--	--
Matriotti Creek	--	*Compromised:* fecal coliform; dissolved oxygen; temperature; sediment.	See Dungeness River, above.	Fecal coliform	Dissolved oxygen; pH
McDonald Creek	--	*Impaired:* dissolved oxygen; sediment; fecal coliform; potential nitrate issues	"McDonald Creek is classified as a Class AA water body. It also is listed for aesthetic beneficial use and irrigation conveyance. Elevated bacteria from the Agnew ditch is also noted. Wilson (1988) indicated elevated coliform bacterial contamination. McDonald Creek serves as conveyance for portions of Agnew Ditch, where past water quality samples have indicated high bacterial levels. In August 1993, six temperature monitors were installed. Water temperature was poor at RM 2.0, 4.3, and 6.5, and fair at RM 0.1 and 8.3. Temperature thresholds were substantially exceeded only at RM 2.0, just downstream of a large residential development."	--	--
Meadowbrook Creek	--	*Impaired to Highly Impaired:* fecal coliform; sediment; temperature; dissolved oxygen.	"Water temperature in Meadowbrook Creek exceeds optimal levels for salmon spawning and rearing (Joel Freudenthal). It is classified as a Class A water body."	Dissolved oxygen; fecal coliform	Dissolved oxygen; fecal coliform; pH
Siebert Creek	4.7	*Healthy:* fecal coliform, west fork water quality compromised, possibly by leachate from old landfill.	"Siebert Creek is classified as a Class AA water body. Nonpoint issues listed by the Dungeness River Area Watershed Management Plan include a major source of sedimentation from a logging road on the East Fork, some vegetation removal, and an old landfill leachate and sedimentation at Emery Creek. Primary land uses are commercial timber, Olympic National Park (the uppermost 20% of the watershed), and private woodlots."	Dissolved oxygen	Fecal coliform; pH

1 Streamkeepers CCWQI data from http://www.clallam.net/streamkeepers/assets/applets/CCWQI_10-25-07.pdf 2/2/2009. Value in table is average site rationg of all sites on stream.

2 State of the Waters Report (2004).

3 Washington State Water Quality Assessment Report, 303(d) impairment list. Categories 4 and 5 are impaired by specific issues or pollutants; Category 2 is waters with concern of impairment.

Clallam County Water Quality Index (CCWQI) site-rating scale: 5 - 4.5 = Healthy; 4.4 - 3.5 = Compromised; 3.4 - 2.5 = Impaired; 2.4 - 1.5 = Highly impaired; <1.5 = Critically impaired.

Healthy: Ecologically intact; no known significant impacts to human health or salmonid populations or lifestages.

Compromised: Showing signs of degradation; slight exceedance of human health-based water quality standards; impacts to one or more salmonid life-stages.

Impaired: Not likely to support self-sustaining salmon populations; exceedance of human health-based water quality standards.

Highly Impaired: Highly adverse to salmon and possibly life-forms; substantial exceedance of human health-based water quality standards.

Critically Impaired: Unable to support a variety of once-native life forms; exceeding any human health-based water quality standard by 100% or more.

K:\Peter\Dungeness_AR\GIS\mxds\SequimMonitoringStudy\Fig1_StudyArea.mxd

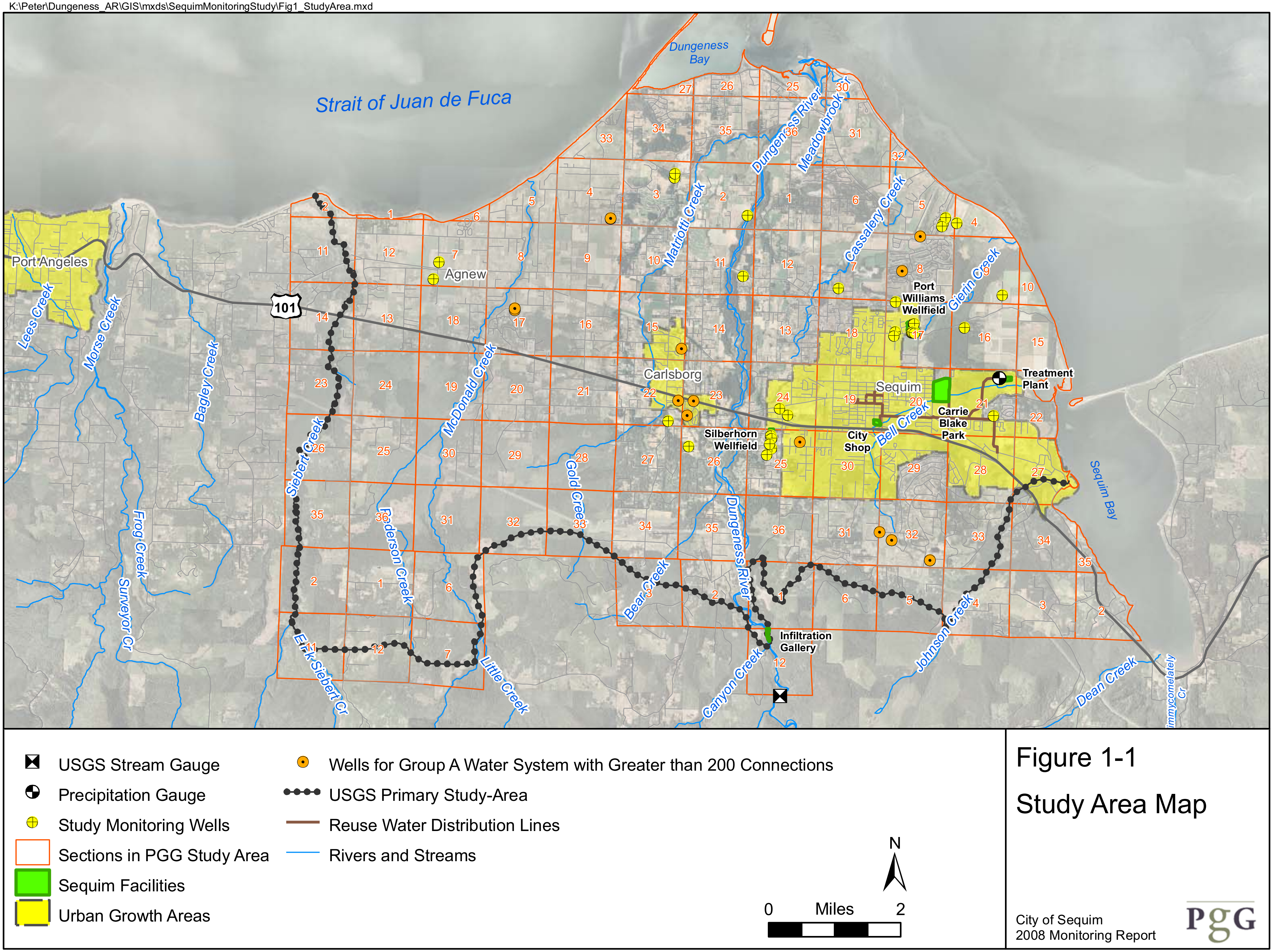


Figure 1-1

Study Area Map

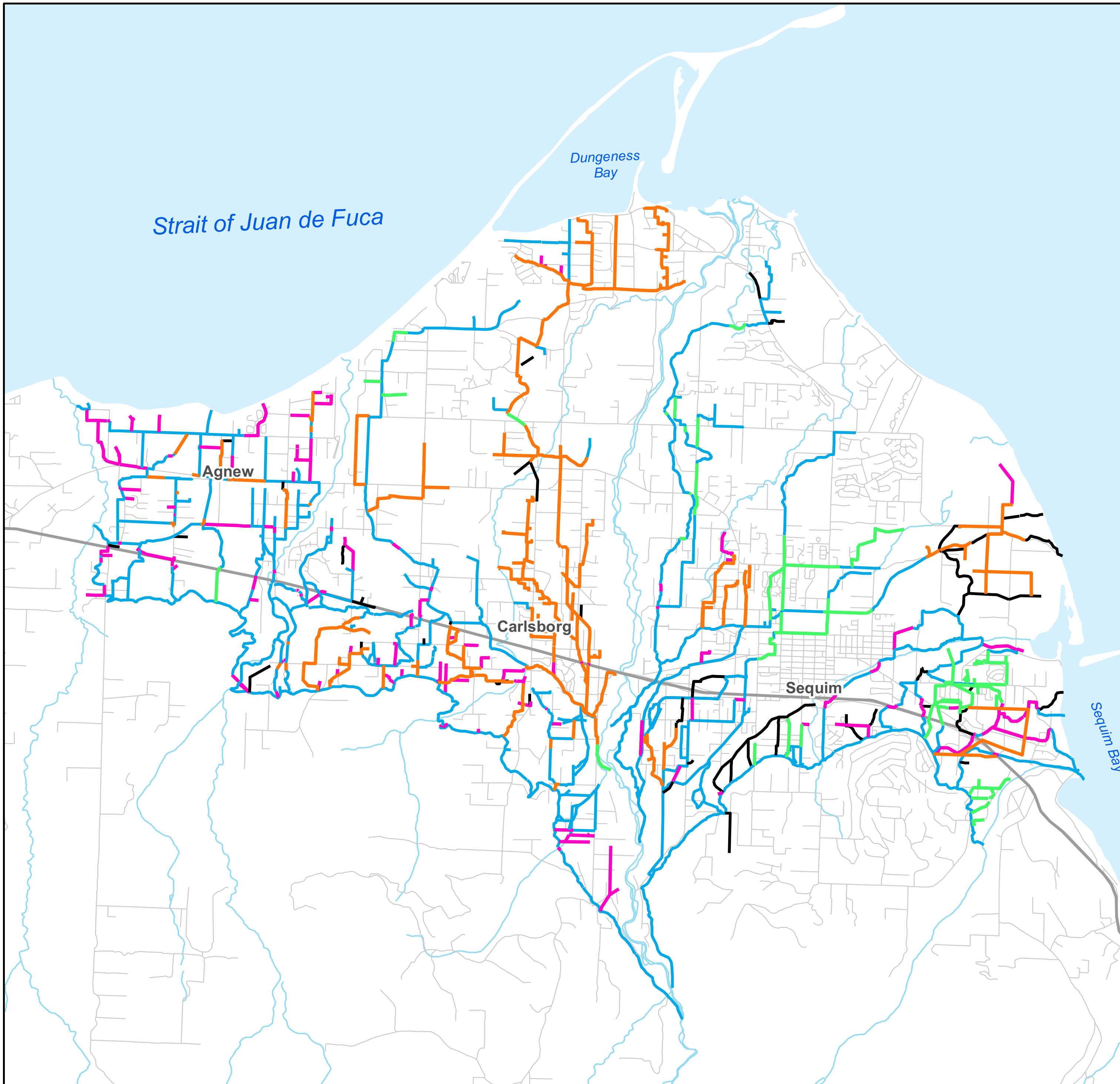
City of Sequim
2008 Monitoring Report

PGG

Figure 1-2

History of Irrigation Ditch Piping

City of Sequim
2008 Monitoring Report



Ditch Piped Before 1/1/2000
Ditch Piped After 1/1/2000
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Abandoned Ditch/Pipe or Not Used
Open Ditch
Rivers and Streams

Data Source:
Clallam Conservation District 2008

N

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Feet

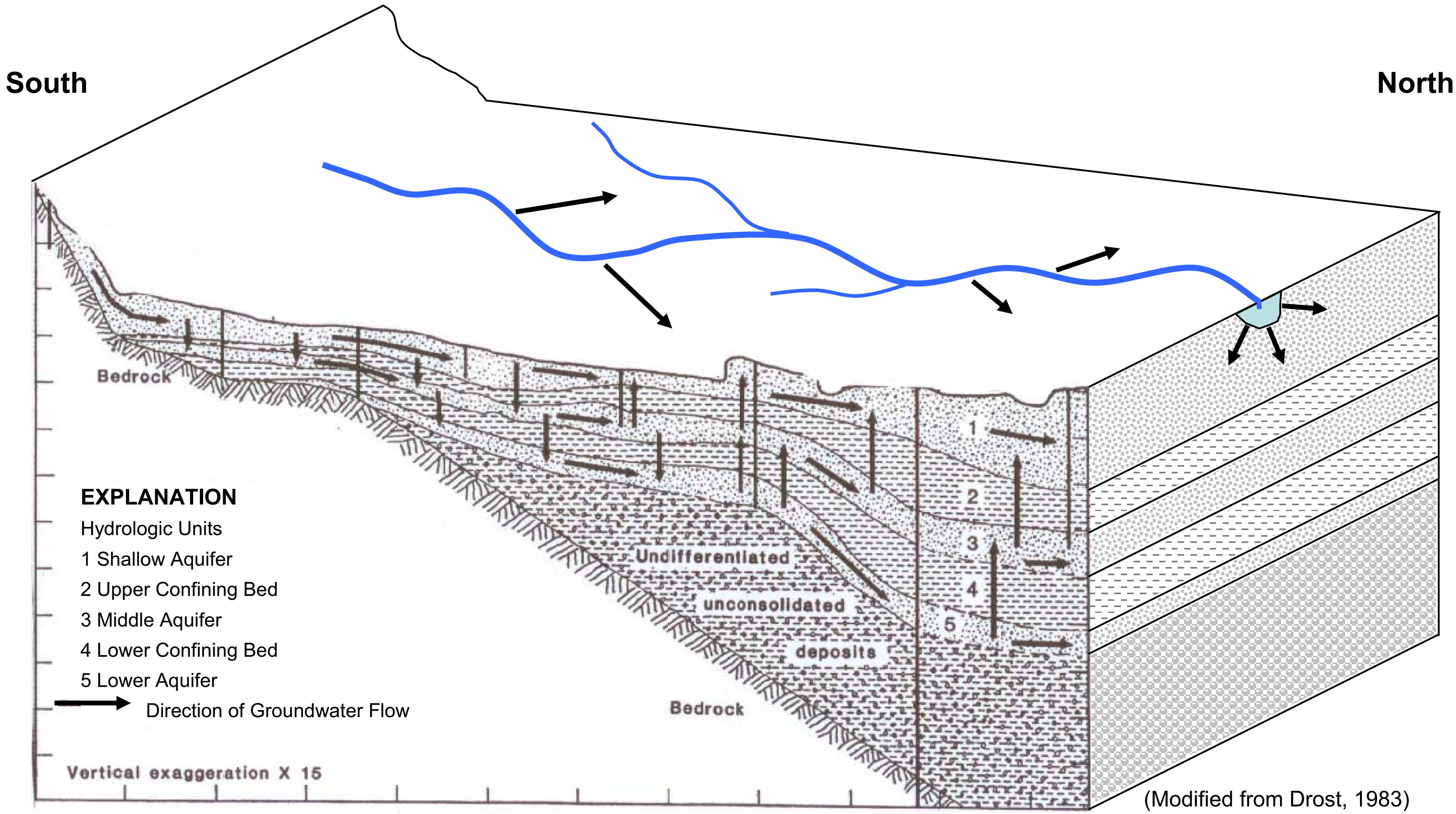


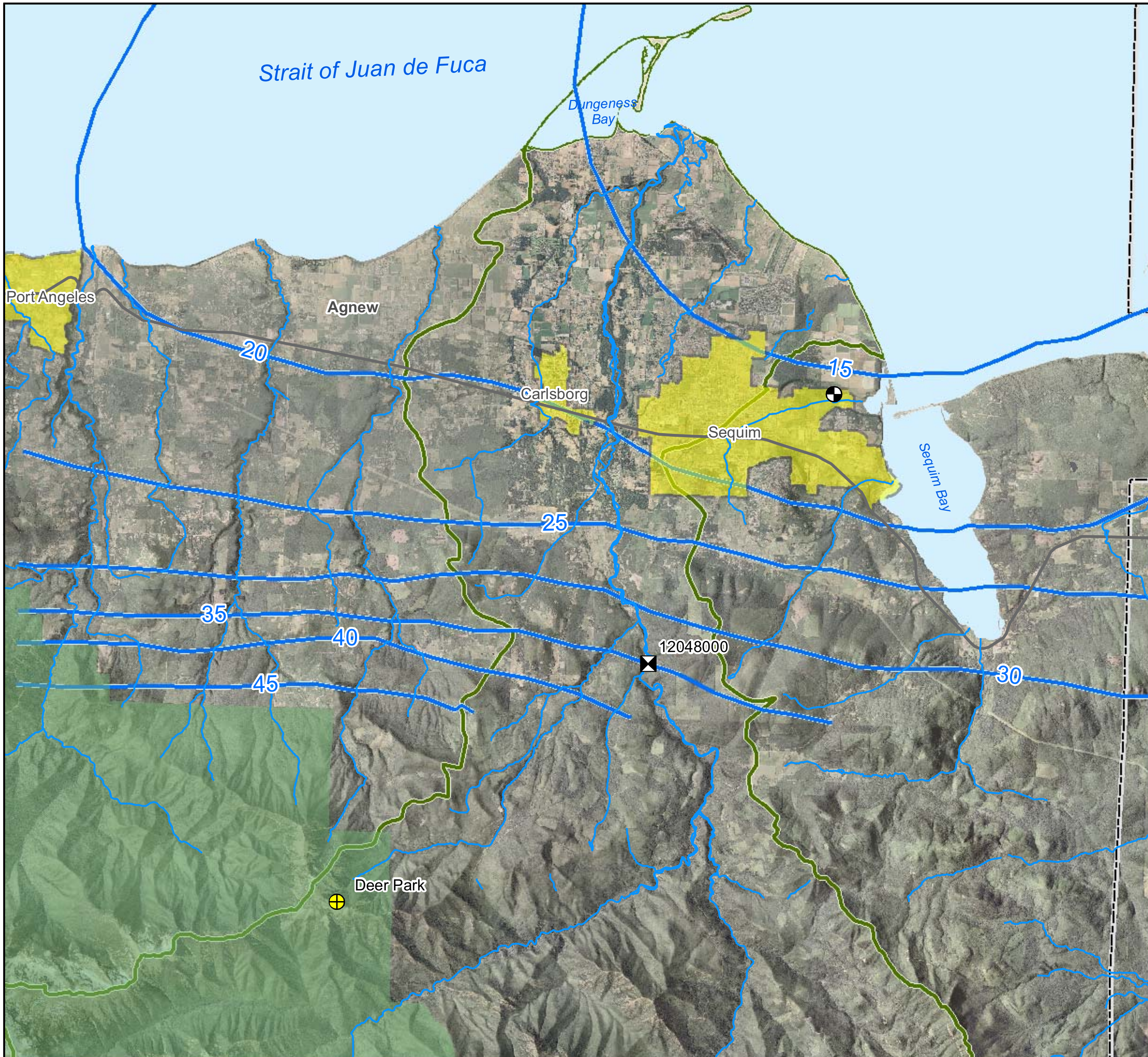
Figure 3-1
Conceptual Diagram of Groundwater Flow System

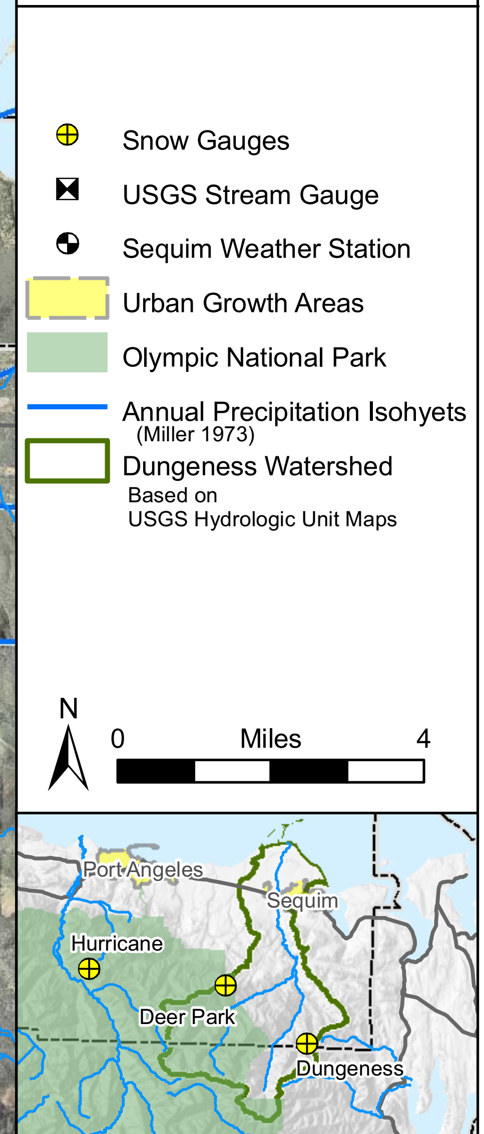
City of Sequim
2008 Monitoring Report

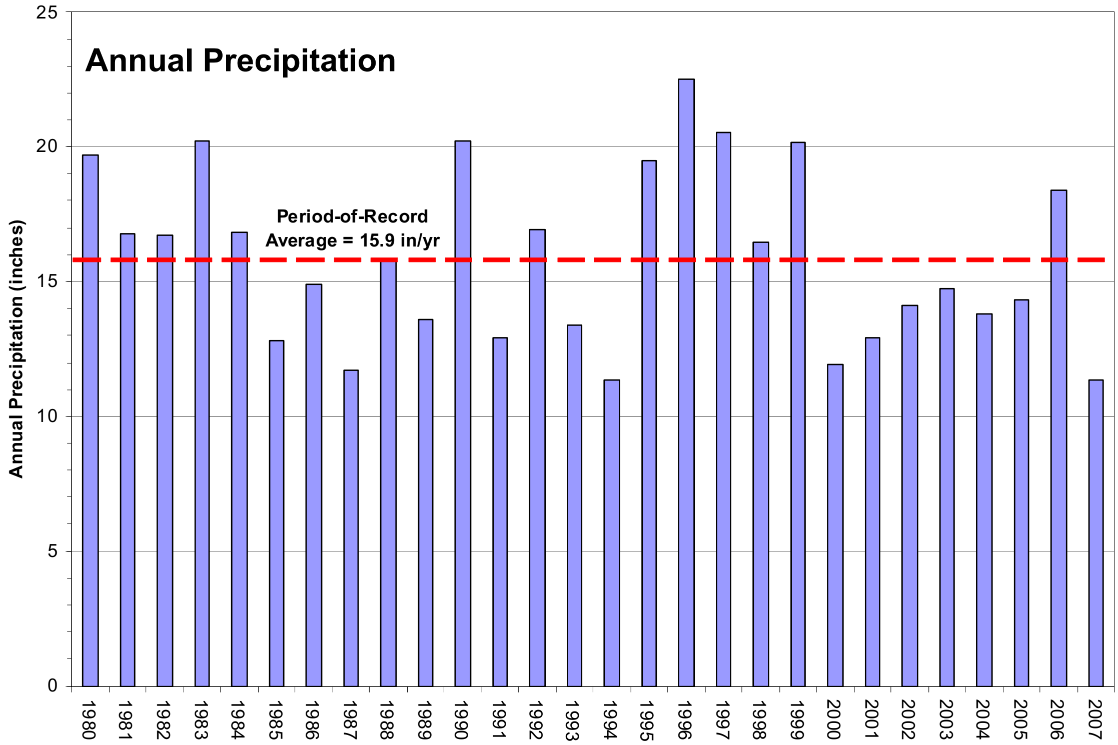
PGG

Figure 4-1
Climate Gauges and Precipitation Distribution

City of Sequim
2008 Monitoring Report







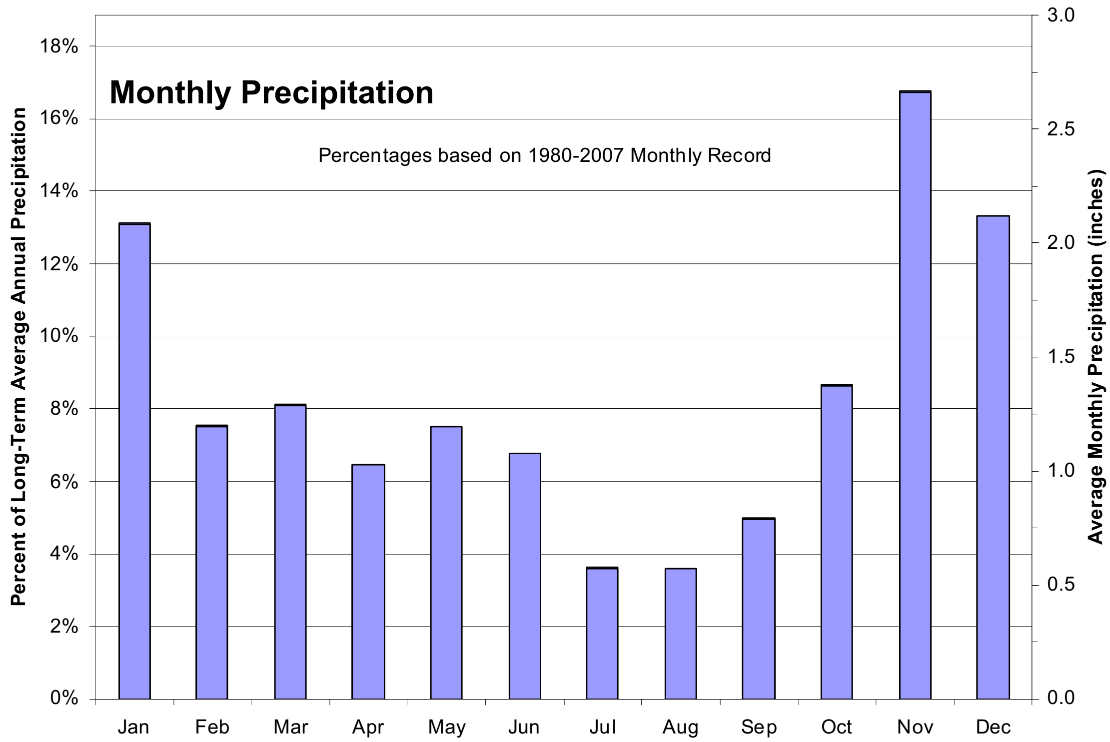


Figure 4-2
Annual and Monthly Precipitation at Sequim

City of Sequim
2008 Monitoring Report

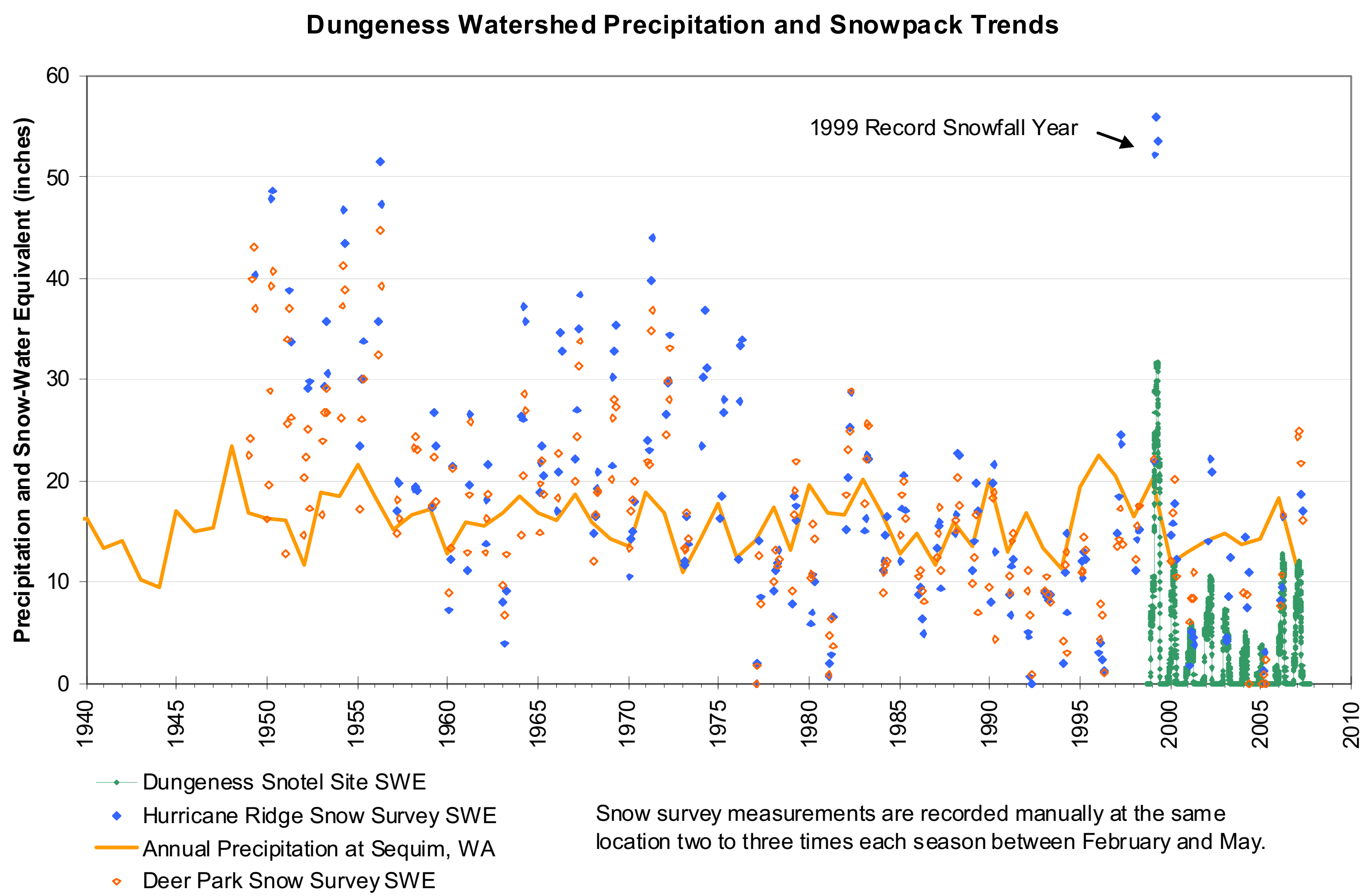


Figure 4-3
Trends in Sequim Precipitation and Dungeness Watershed Snowpack

City of Sequim
2008 Monitoring Report

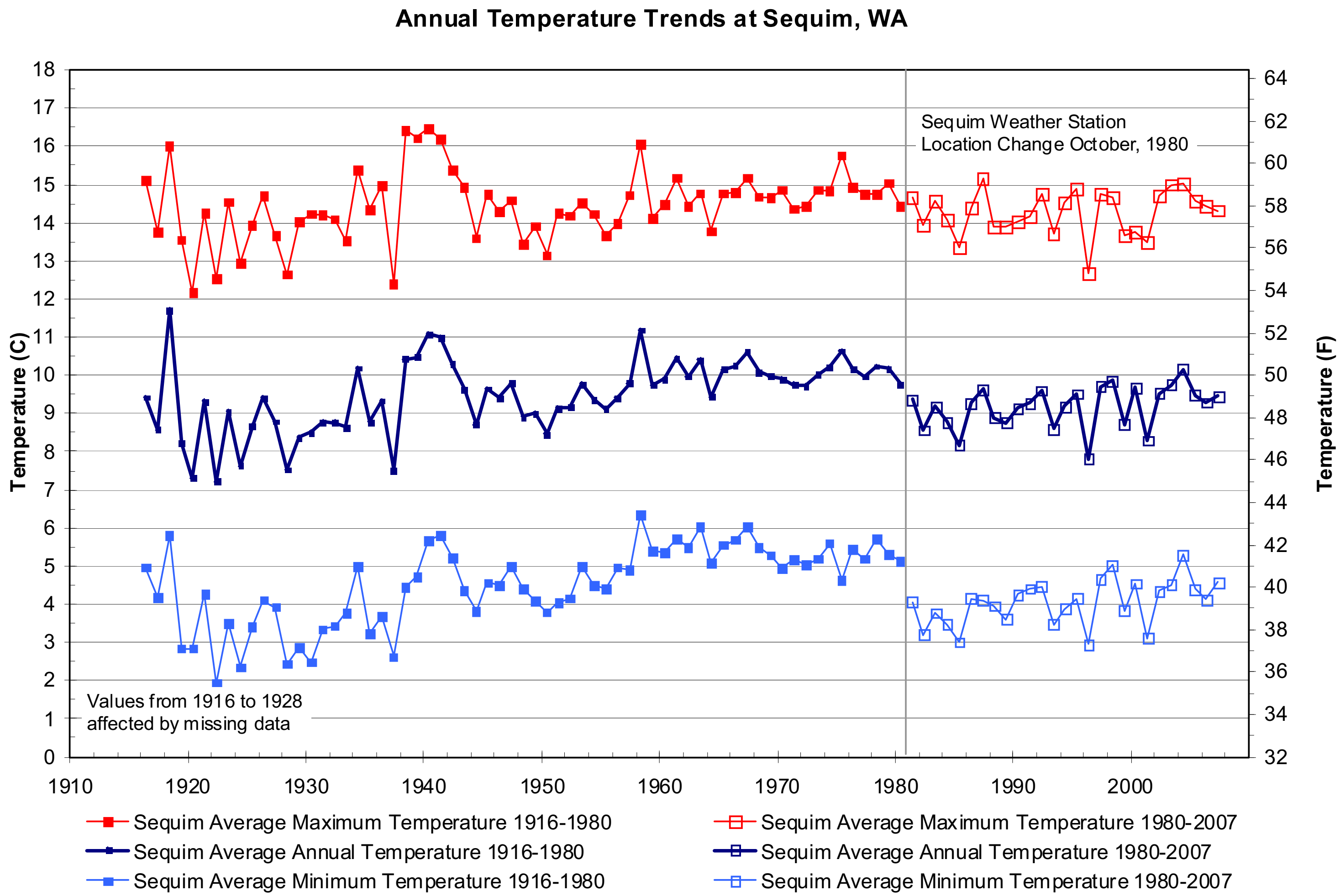
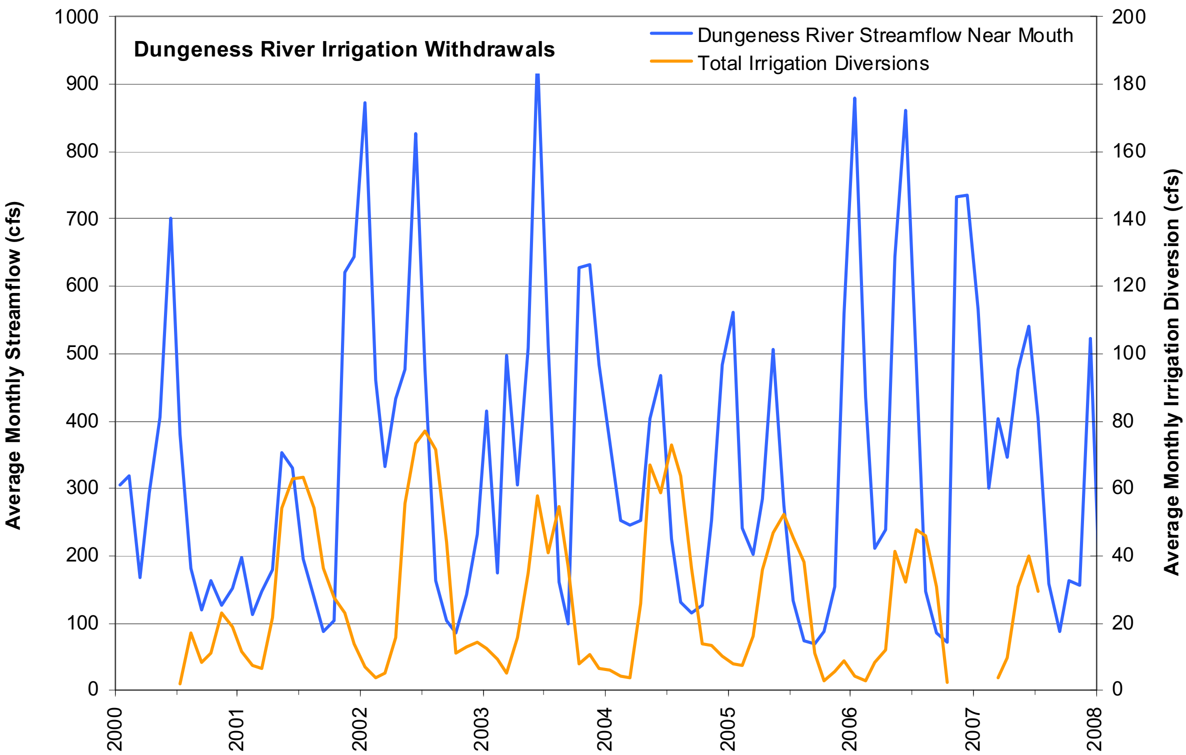


Figure 4-4
Sequim Annual Temperature Trends

City of Sequim
2008 Monitoring Report

PGG



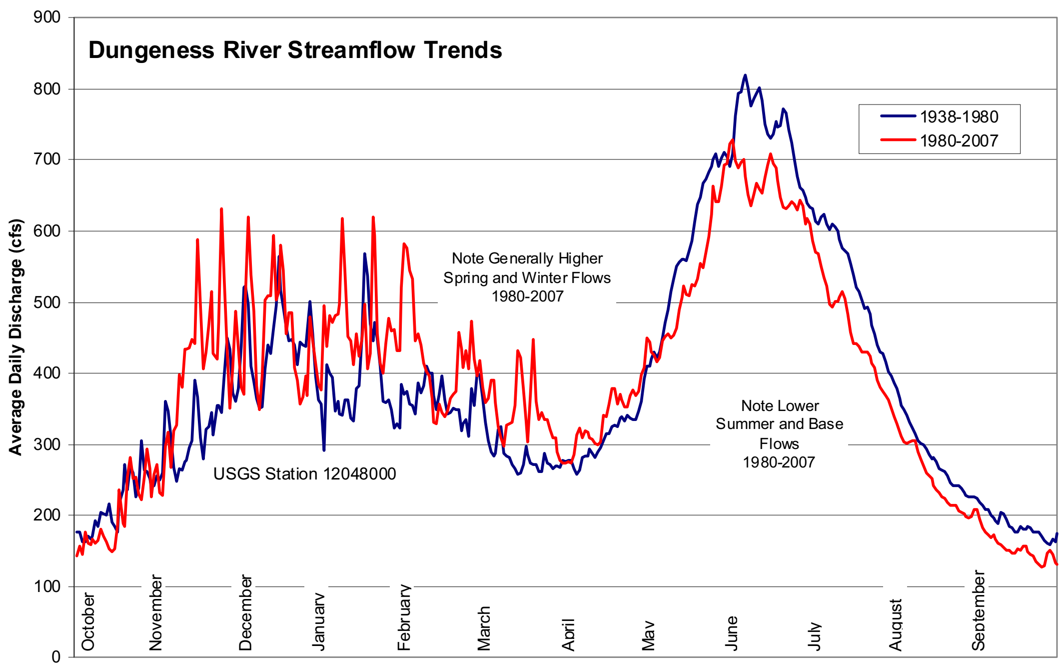


Figure 5-1
Dungeness River Streamflow Trends and Irrigation Withdrawals

City of Sequim
2008 Monitoring Report

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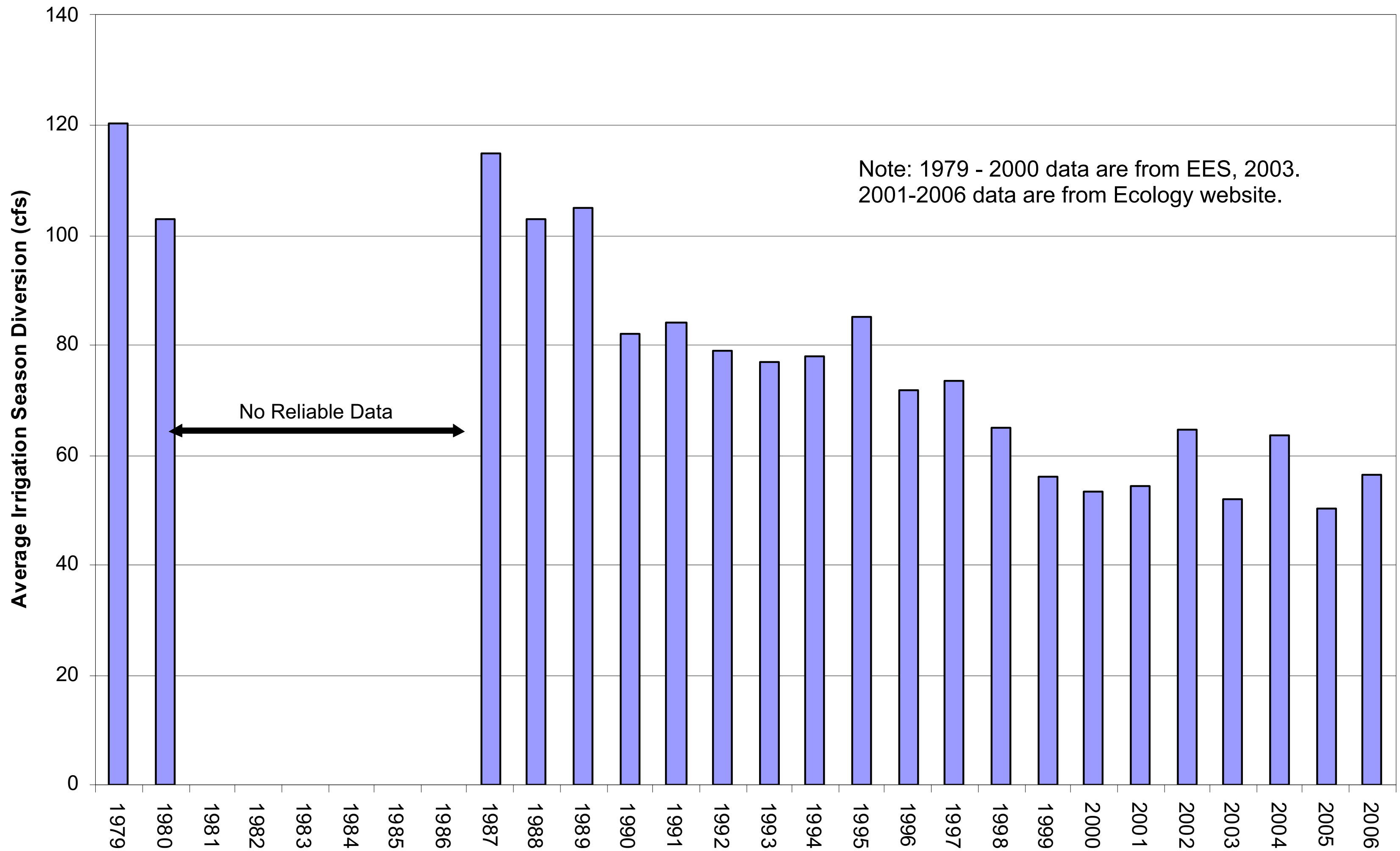

Figure 5-2
Historic Average Irrigation-Season Diversions from Dungeness River

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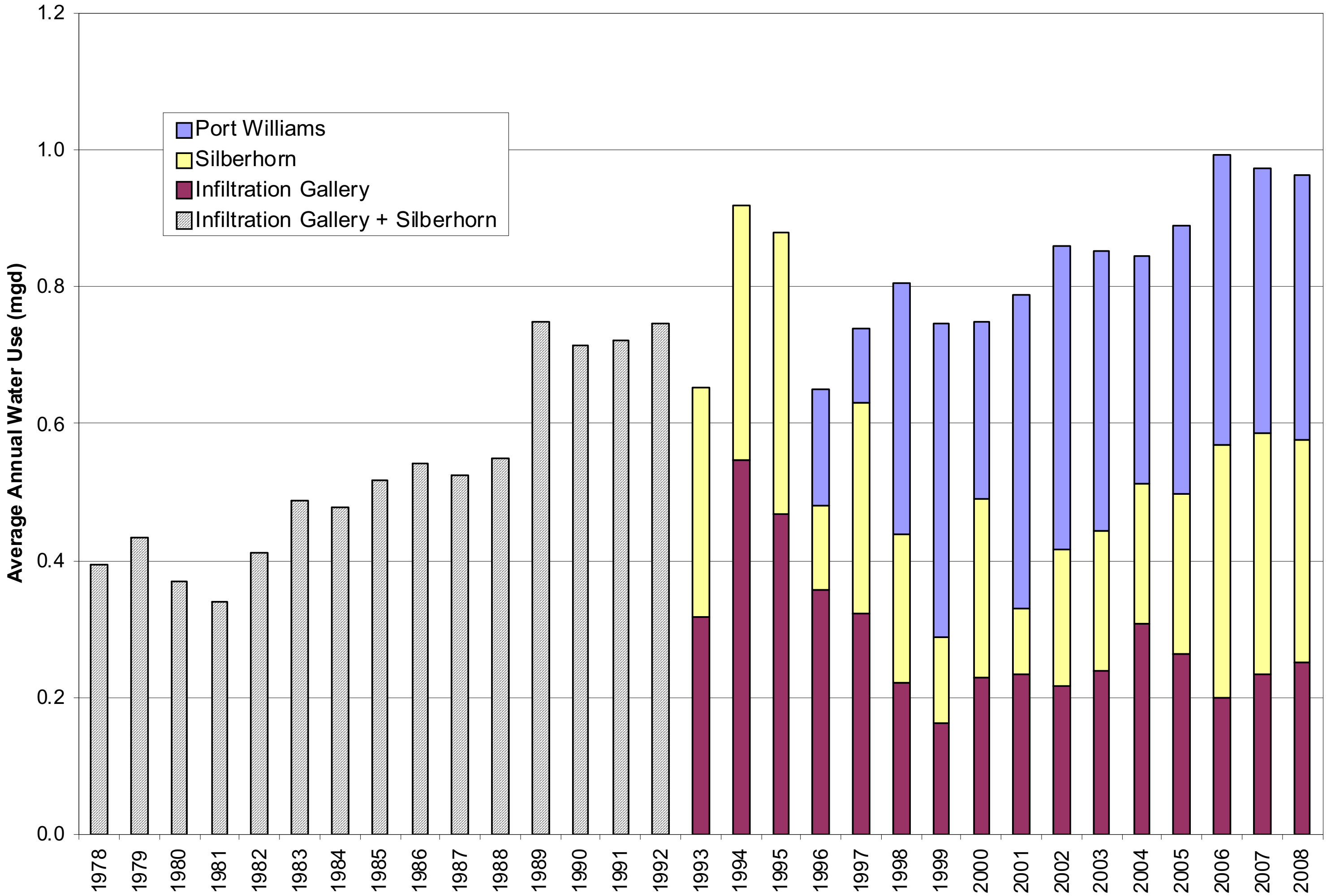

Figure 6-1
City of Sequim Average Annual Pumping

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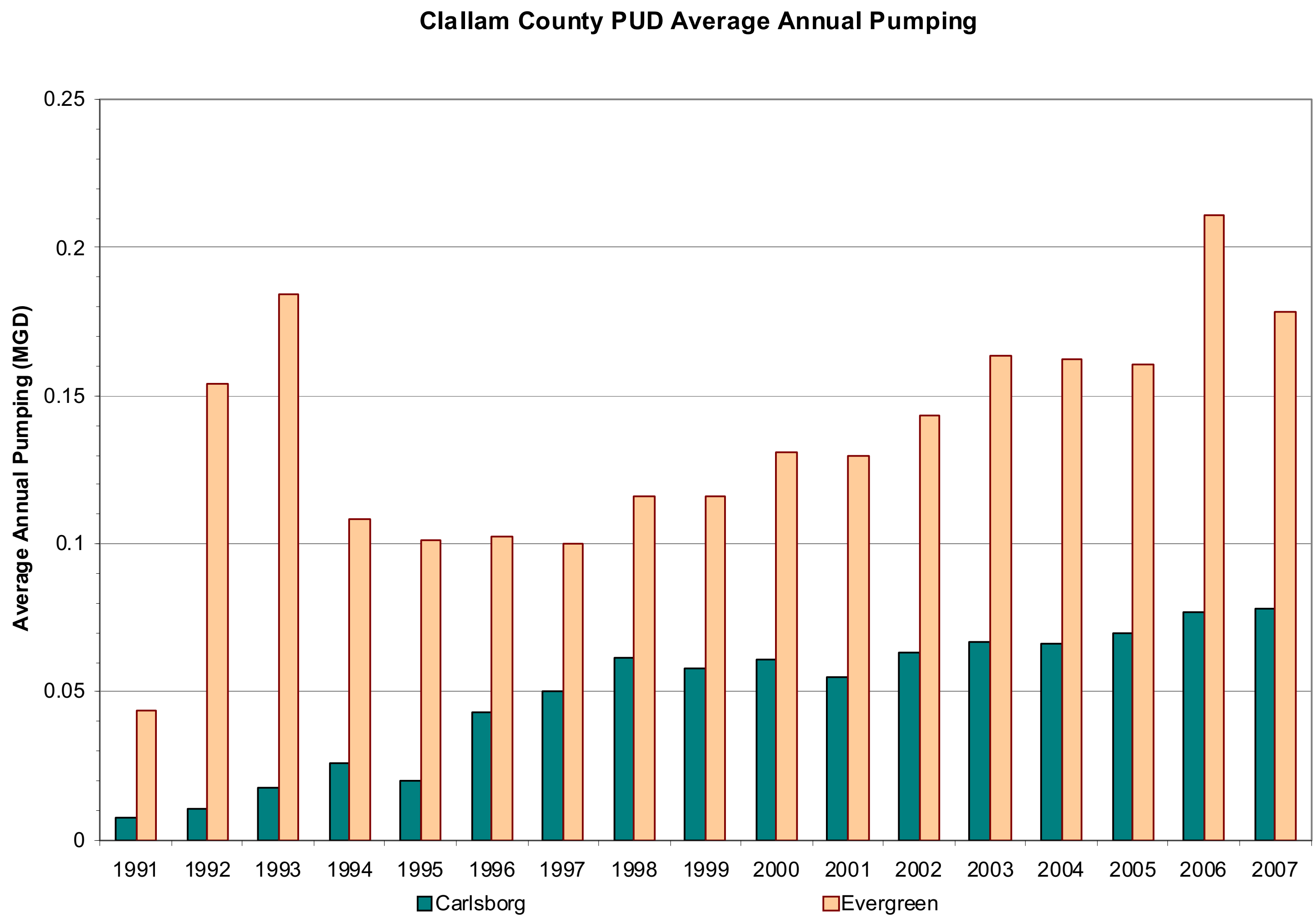

Figure 6-2
Clallam County PUD Annual Pumping

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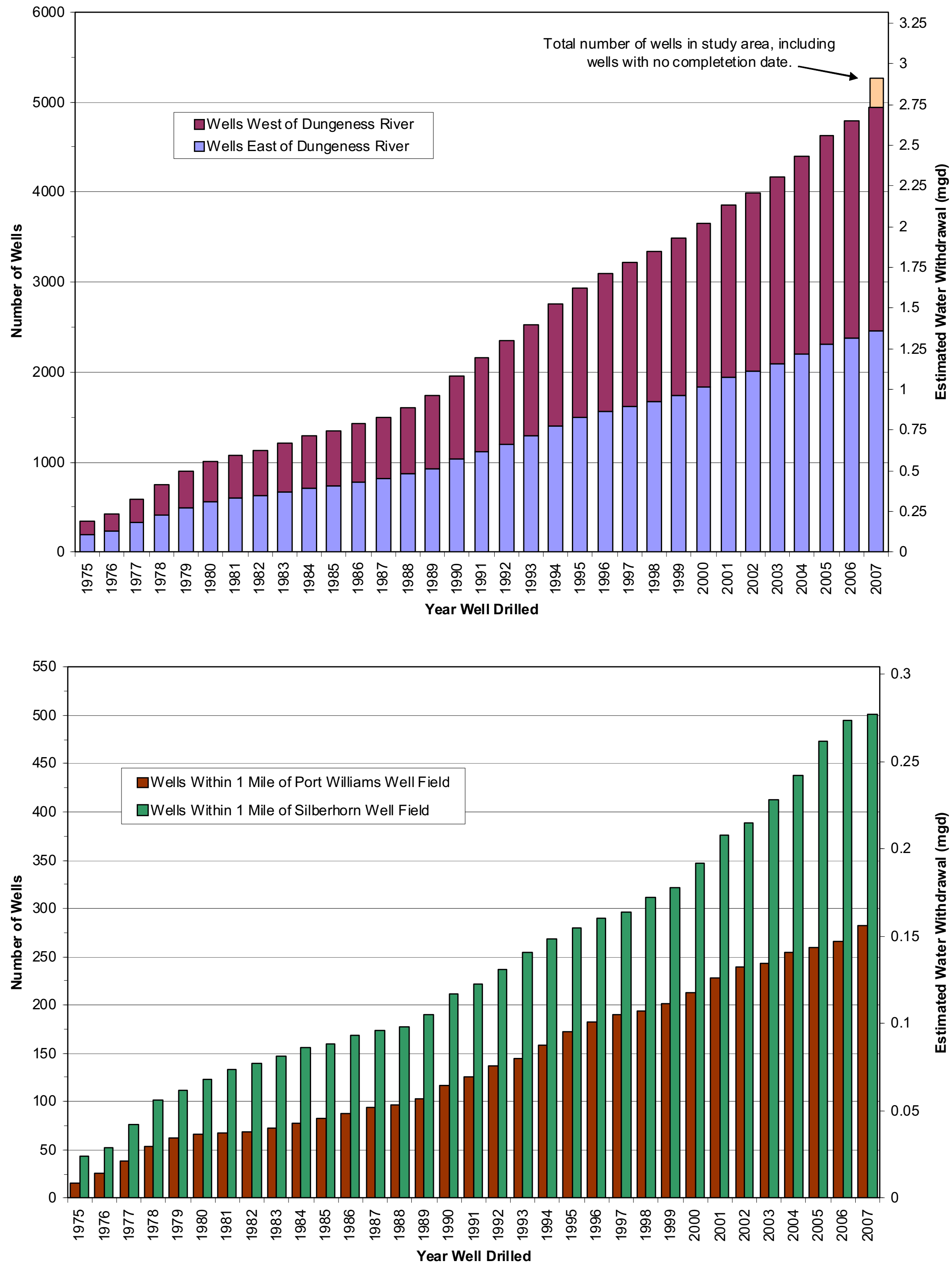

Figure 6-3
Counts of Study-Area Wells Over Time

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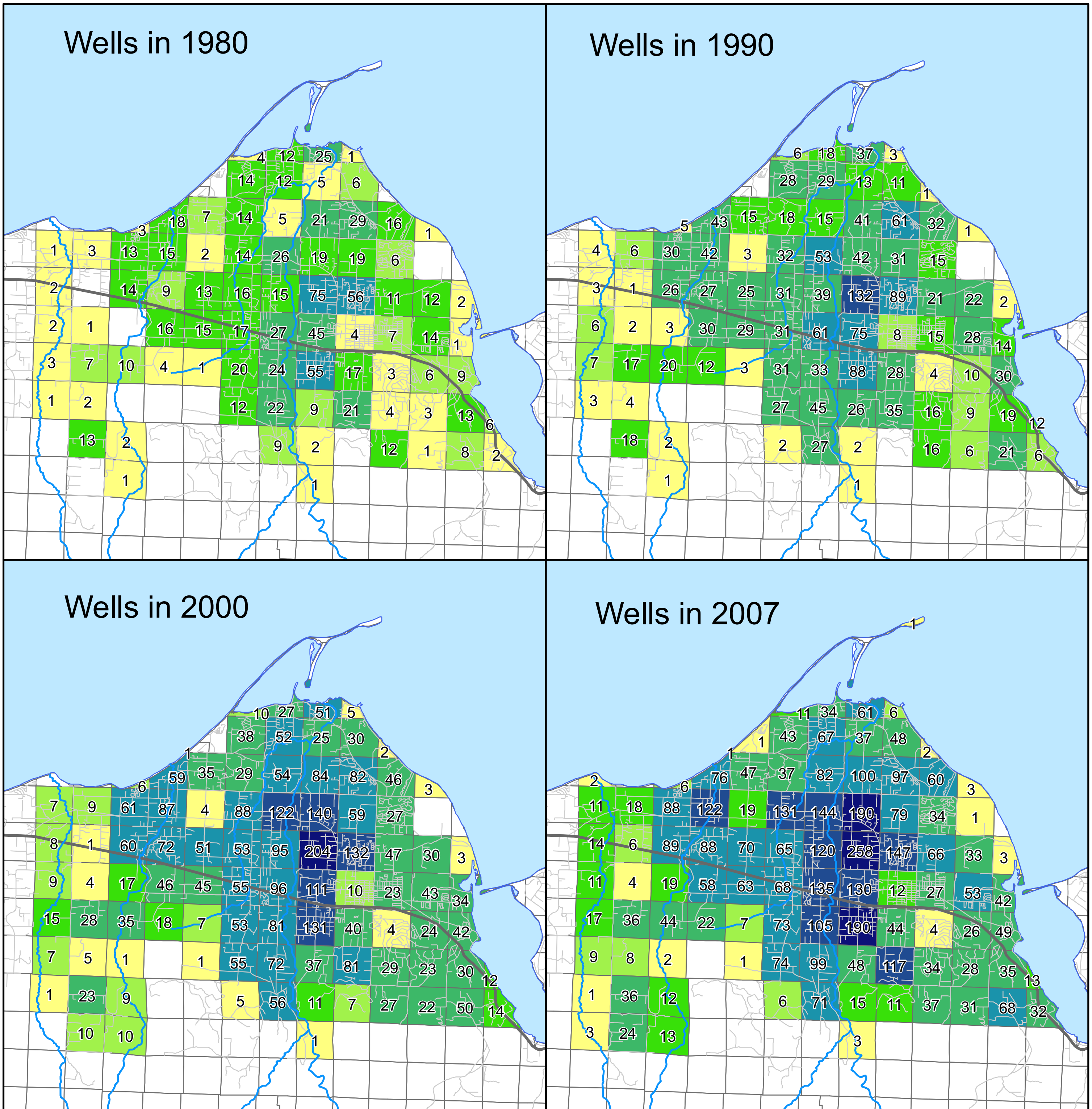

Well Logs in Section

- 1 - 5
- 6 - 10
- 11 - 20
- 21 - 50
- 51 - 100
- 101 - 150
- 151 - 267

Number in Section is actual number of wells.

Data from Washington Department of Eclogy's well log database.
Well log records in database without date drilled are not included.
Only "W" (Water) wells included, no Resource Protection,
or abandoned wells.

N

0 Miles 5

Figure 6-4

Total Study Area Wells Per Section By Decade

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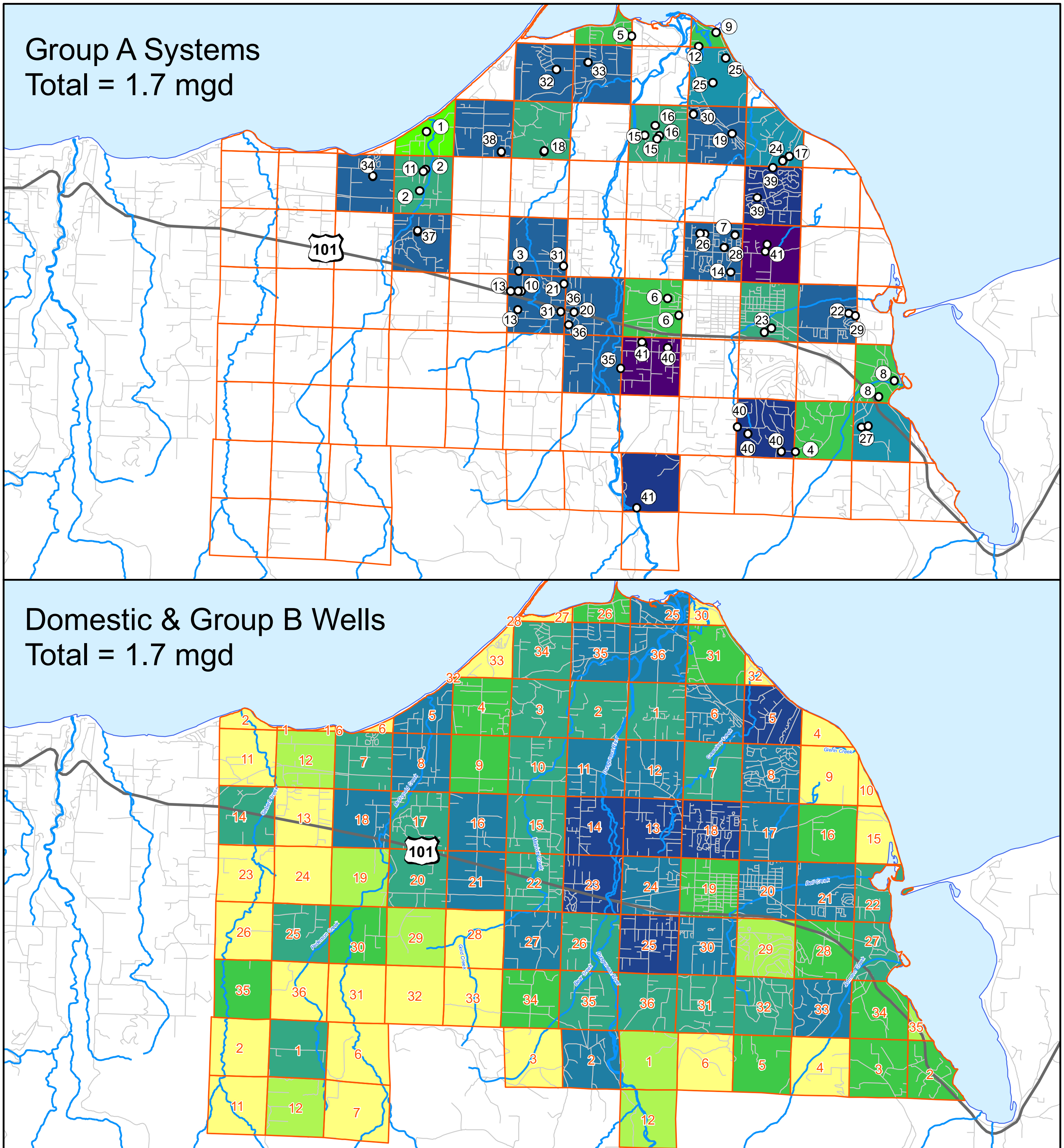

Total Consumption per Section (gpd)
- 0 - 500
- 501 - 1,000
- 1,001 - 1,132
- 1,133 - 2,500
- 2,501 - 5,000
- 5,001 - 10,000
- 10,001 - 20,000
- 20,001 - 100,000
- 100,001 - 250,000
- 250,001 - 500,000

Sections in PGG Study Area

(43) Group A Groundwater Sources

See Table 6-2 for Group A System Map IDs

0 Feet 10,000

N

Figure 6-5
Consumptive Water Use by Section

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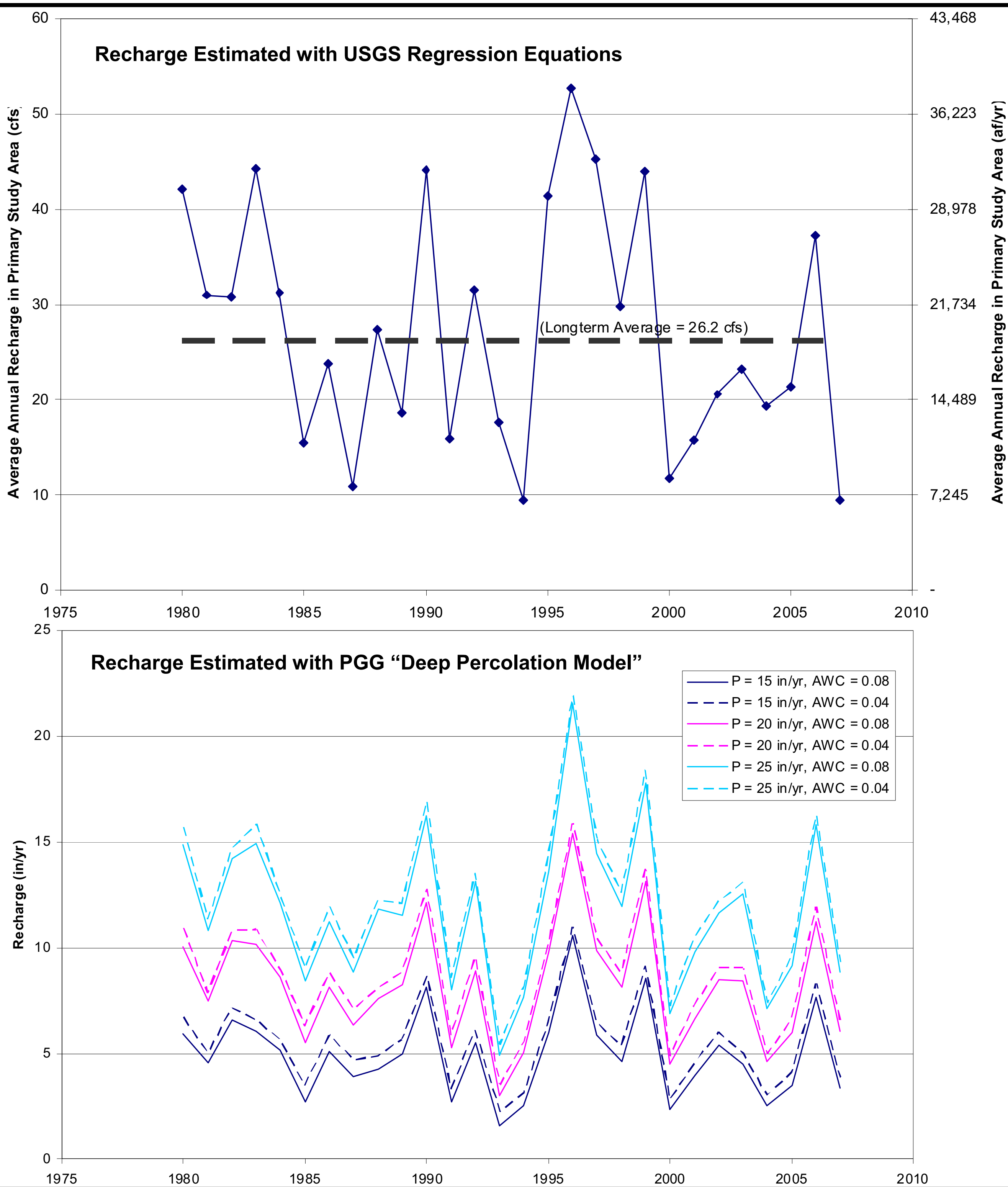

Figure 7-1
Estimated Annual Precipitation Recharge Over Time

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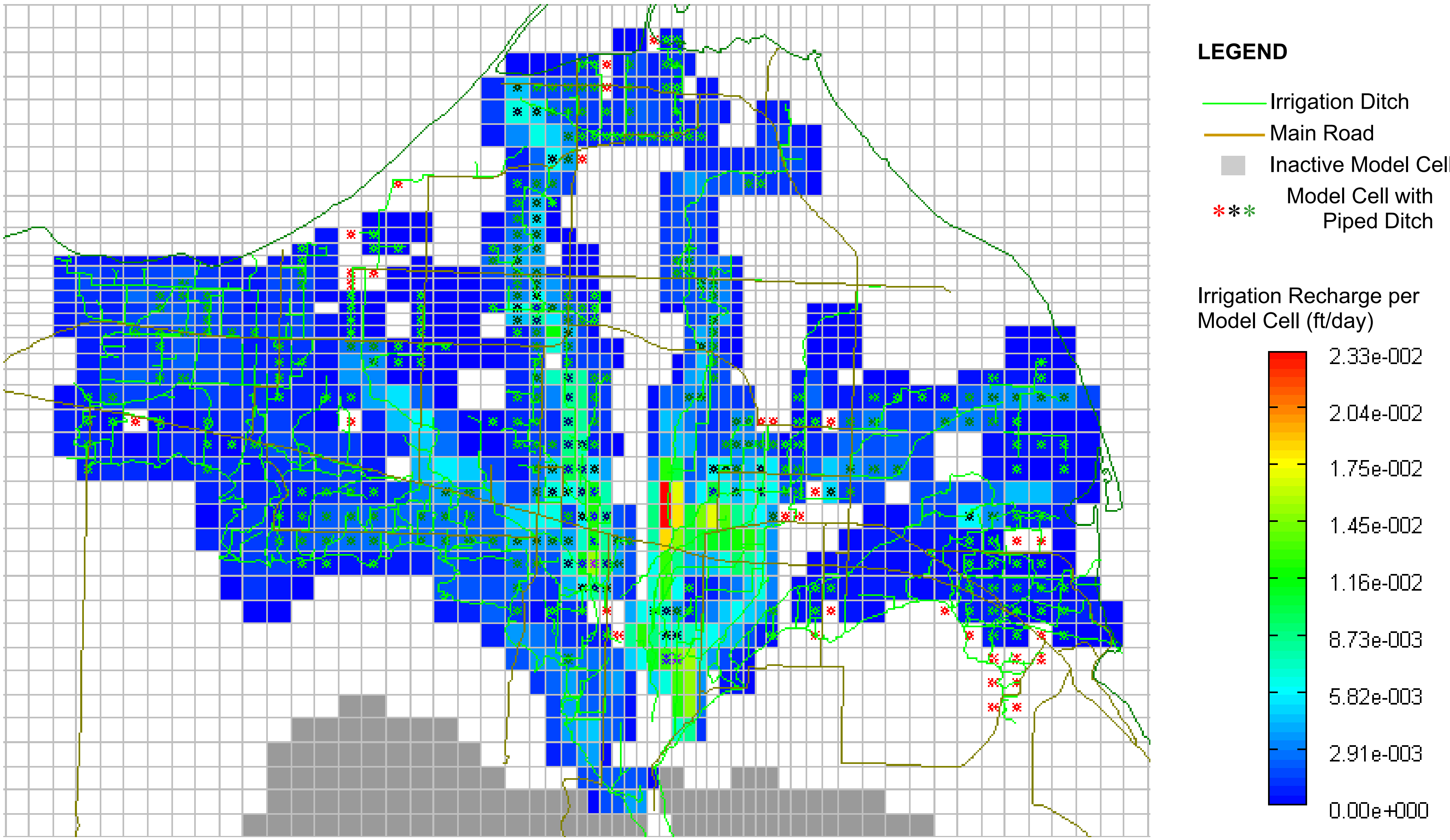

Figure 7-2
Irrigation Recharge and Model Cells Containing Piped Ditches

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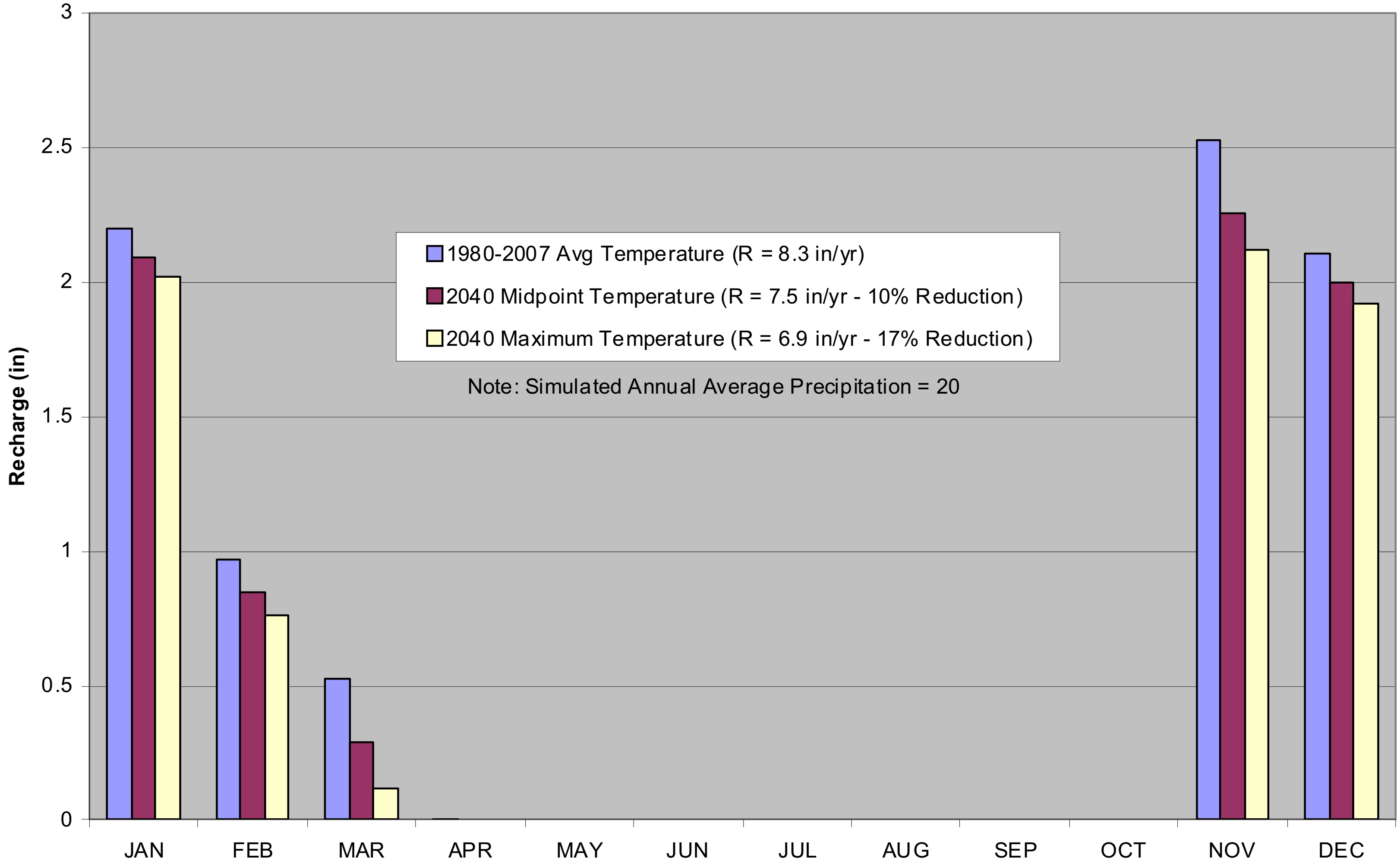

Figure 7-3
Estimated Monthly Recharge with Increased Temperature from Climate Change

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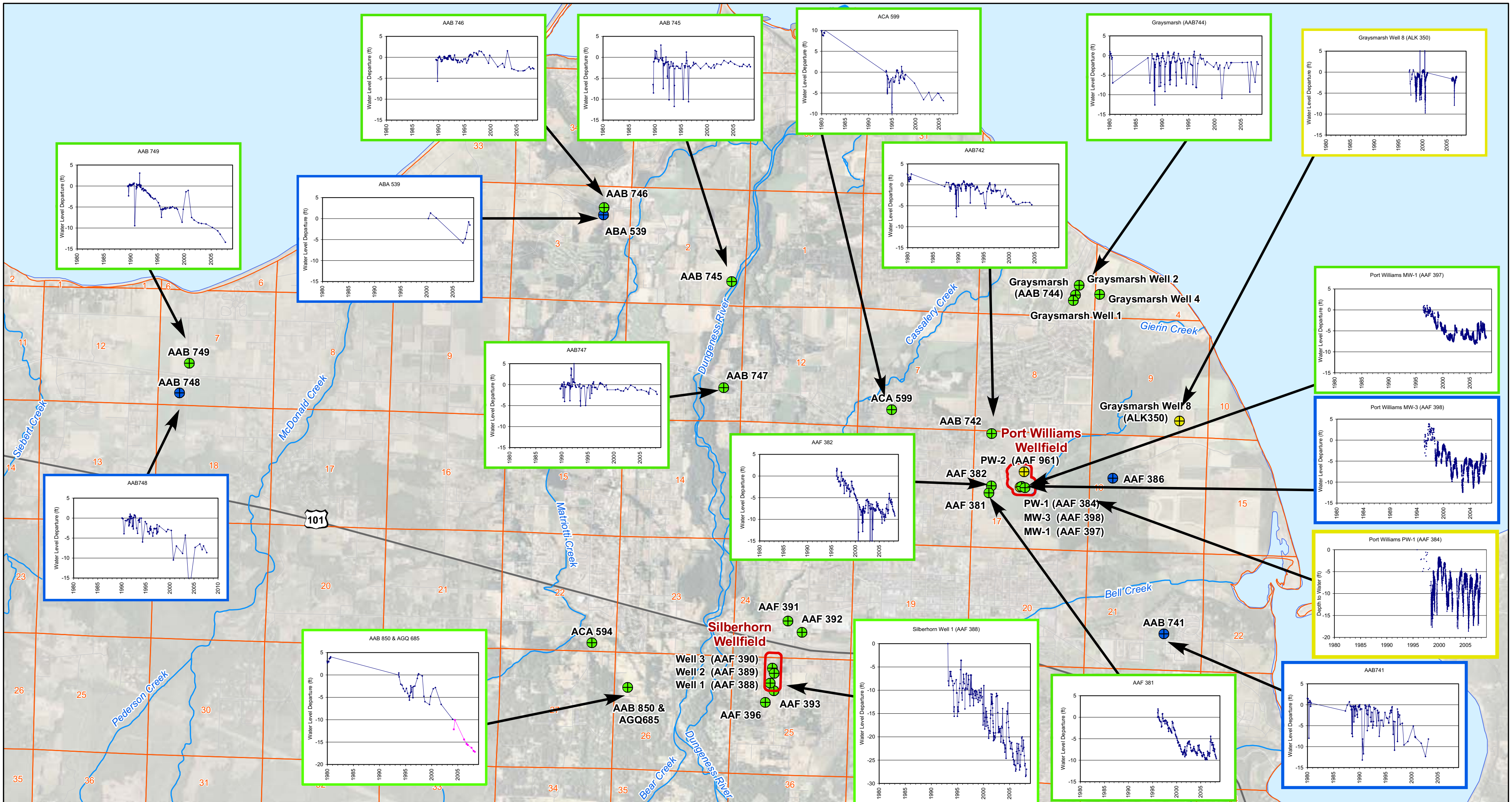

Shallow Aquifer Well

Middle Aquifer Well

Lower Aquifer Well

Sections in PGG Study Area

Please see Figure 8-2
for all Port Williams and Silberhorn Hydrographs

0 Feet 5,000

N

Figure 8-1

Representative Hydrographs

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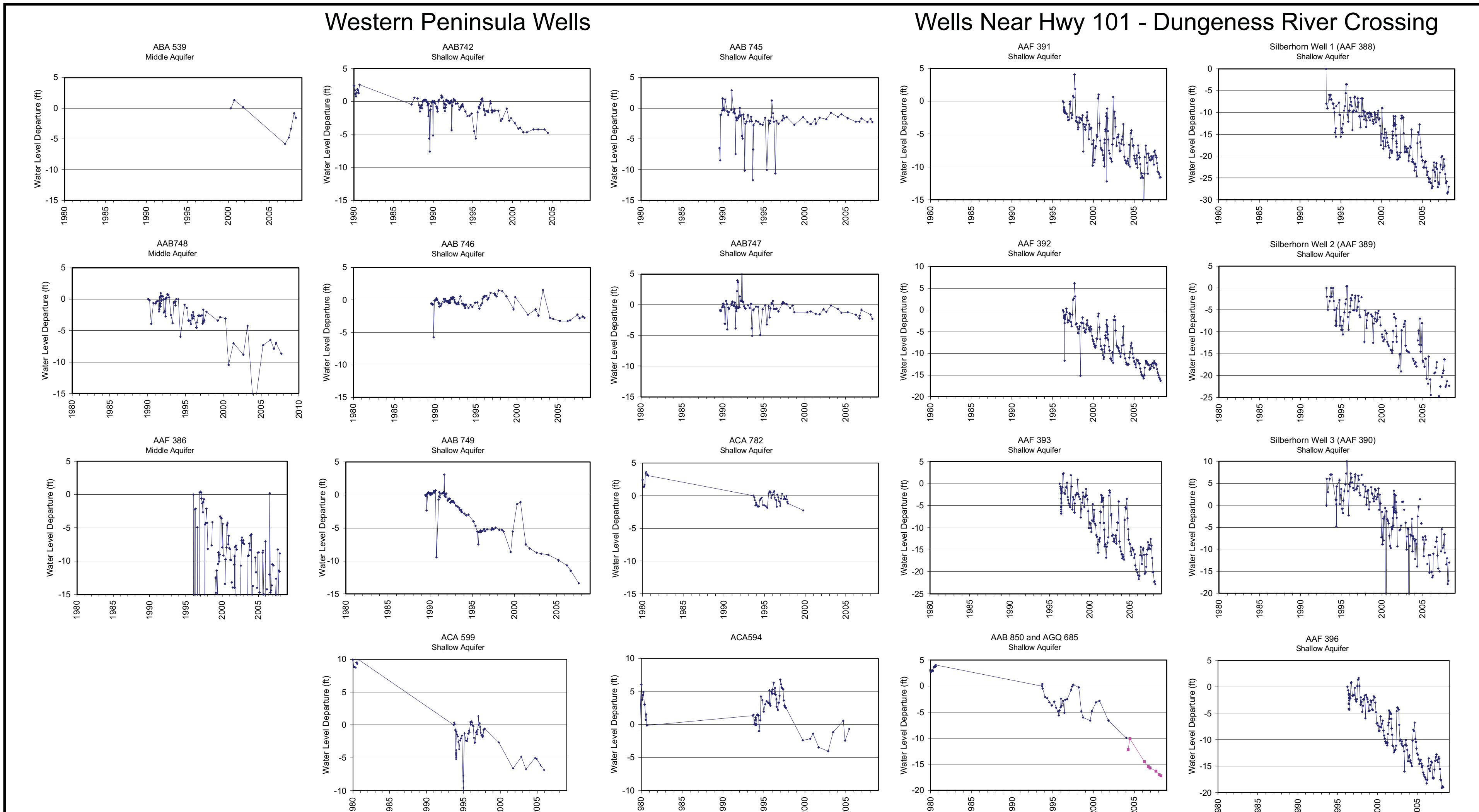

Figure 8-2a
Groundwater Level Trends

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Eastern Peninsula Wells

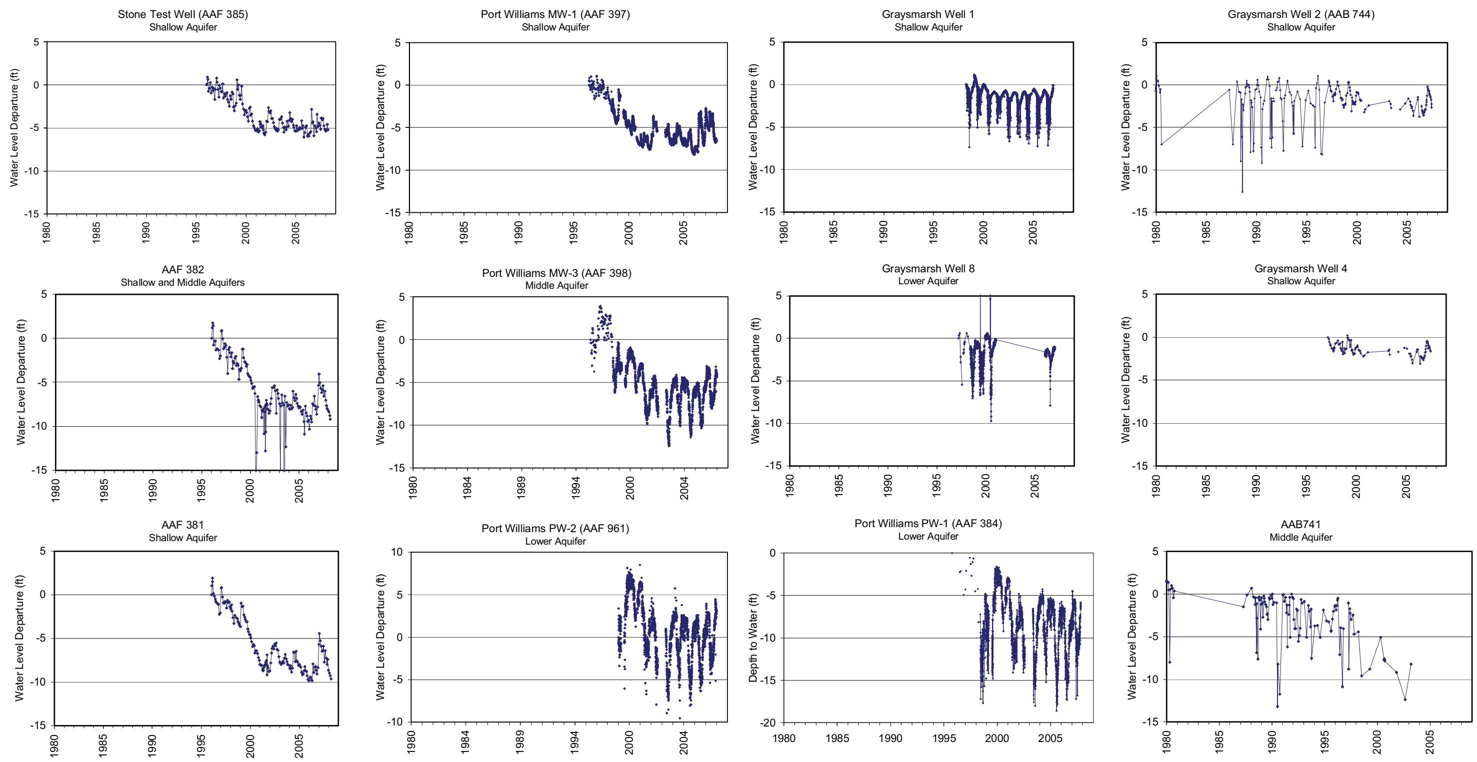

Figure 8-2b
Groundwater Level Trends

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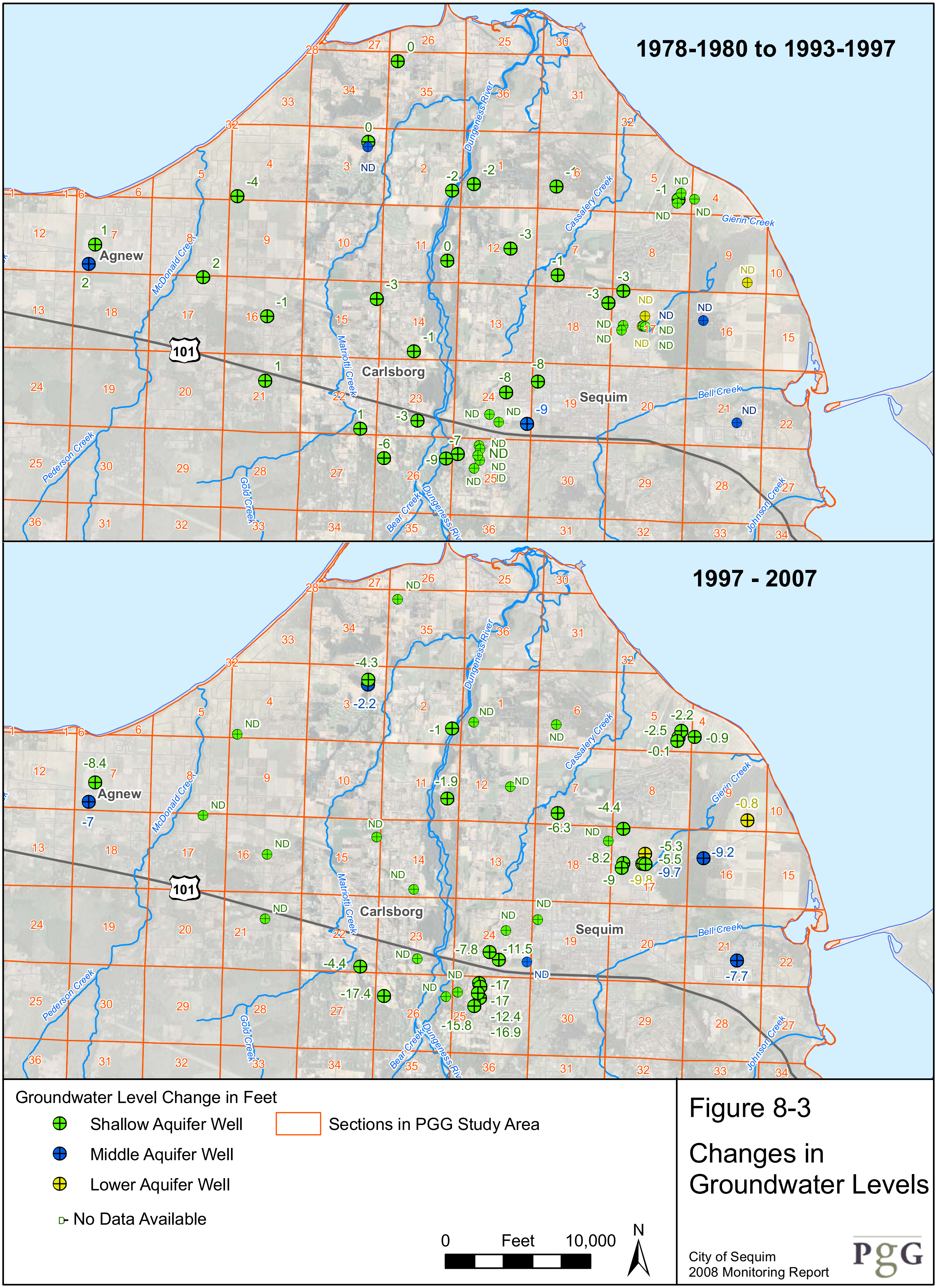

Figure 8-3

Changes in Groundwater Levels

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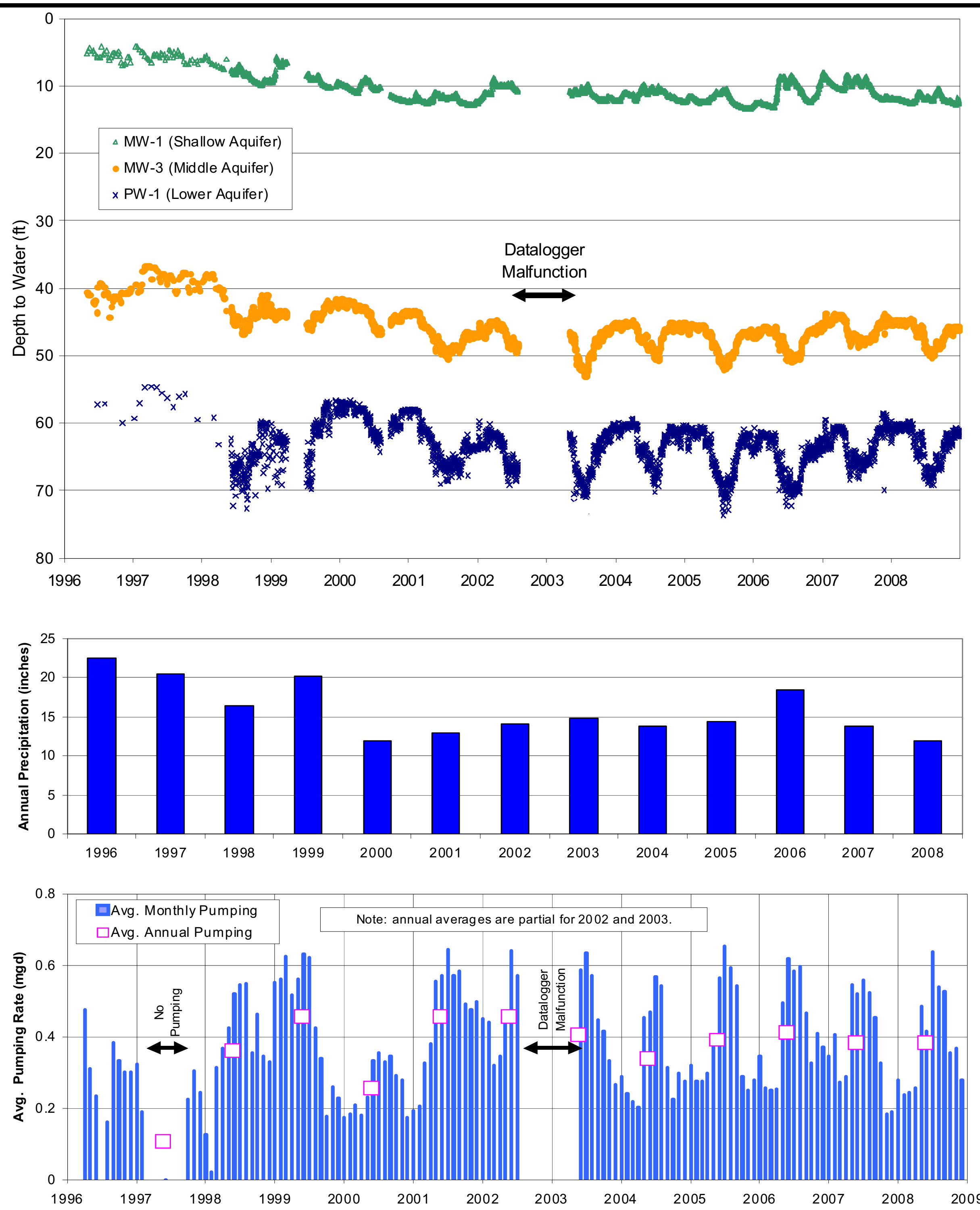

Figure 8-4
Water Levels and Pumping at the Port Williams Wellfield

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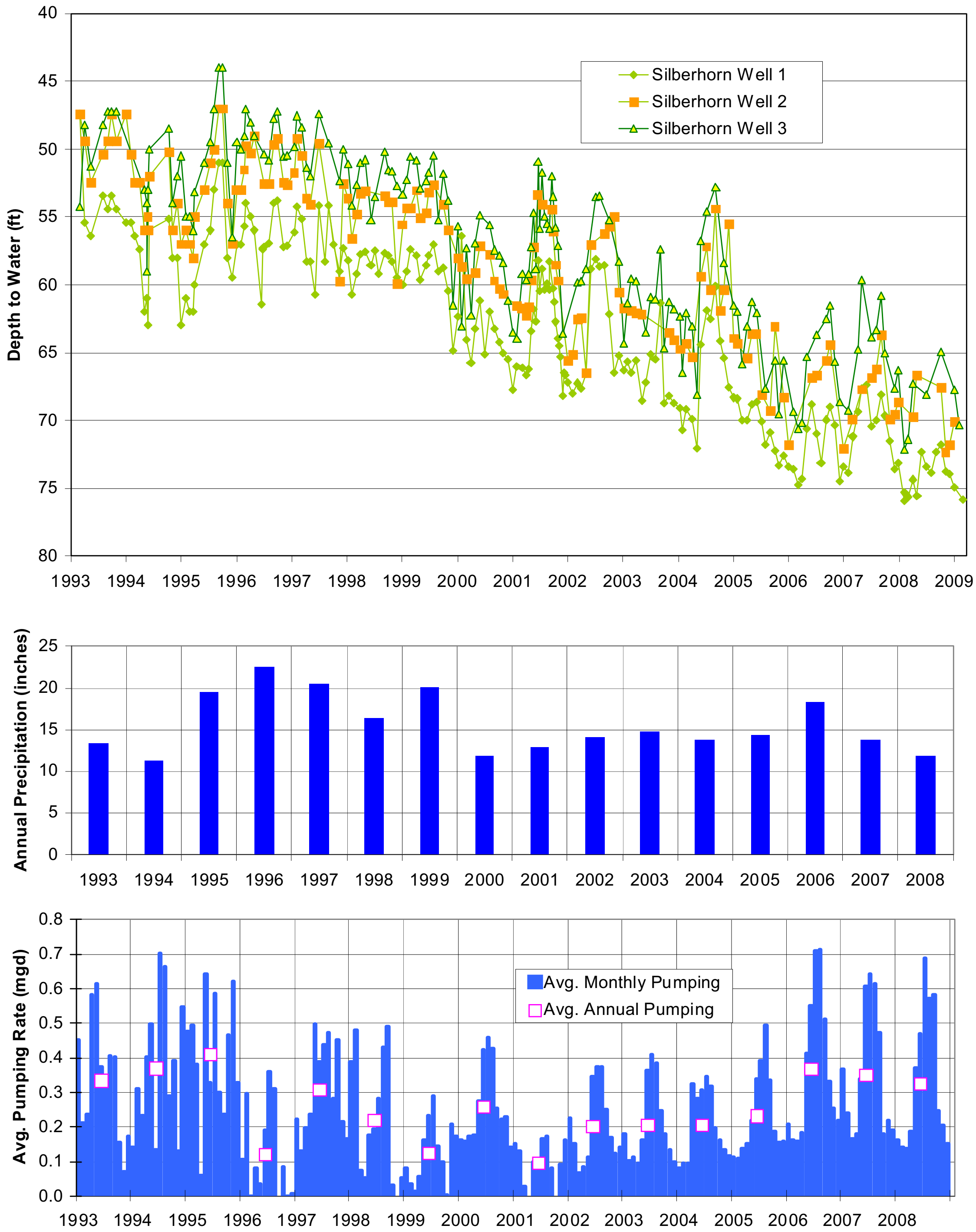

Figure 8-5
Water Levels and Pumping at the Silberhorn Wellfield

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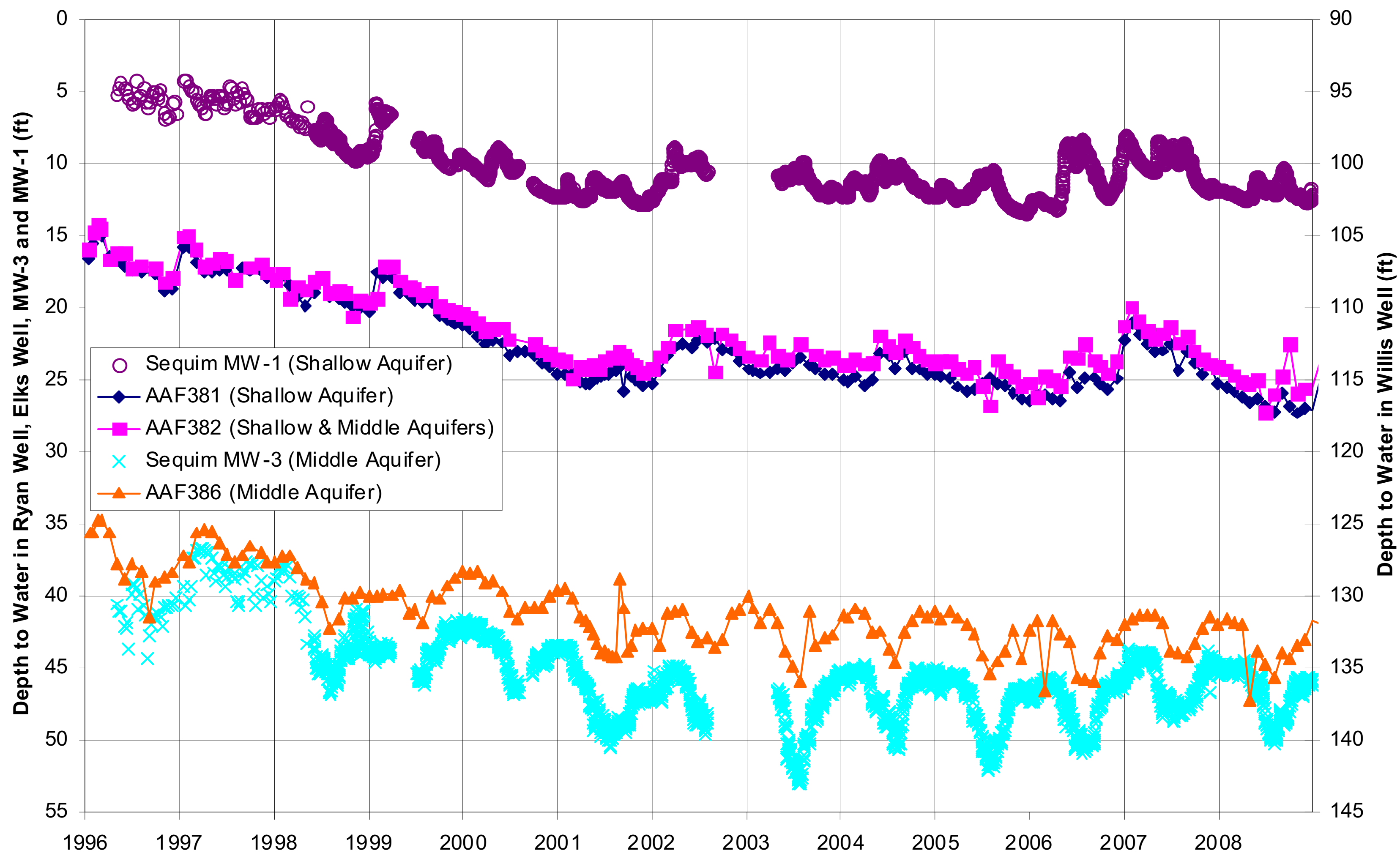

Figure 8-6
Water-Level Trends in Wells Surrounding the Port Williams Wellfield

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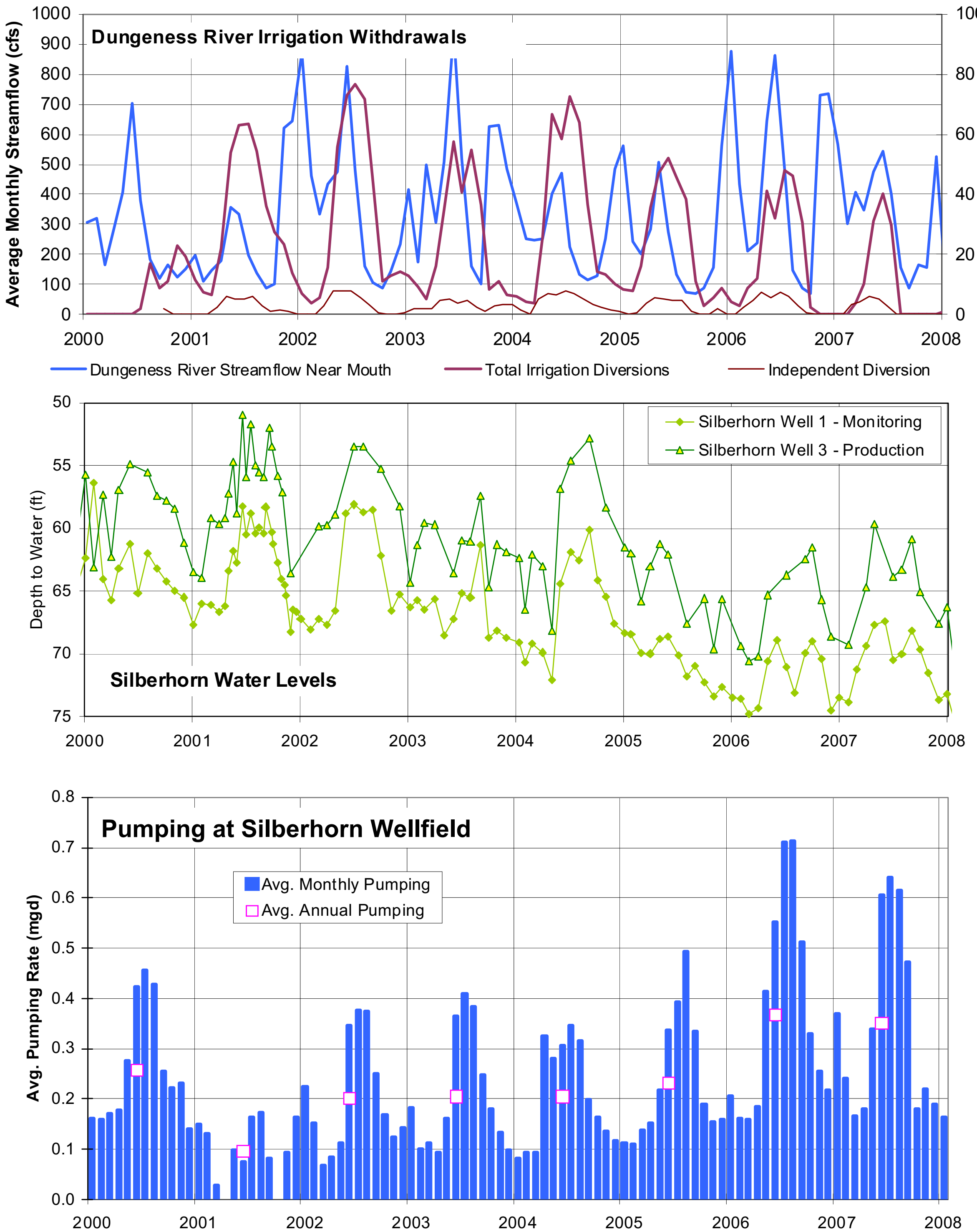

Figure 8-7
Hydrologic Trends Near the Highway 101 - Dungeness River Crossing

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K:\Peter\Dungeness_AR\GIS\mxds\SequimMonitoringStudy\Fig5_Nitrate_1980_1996_2007.mxd

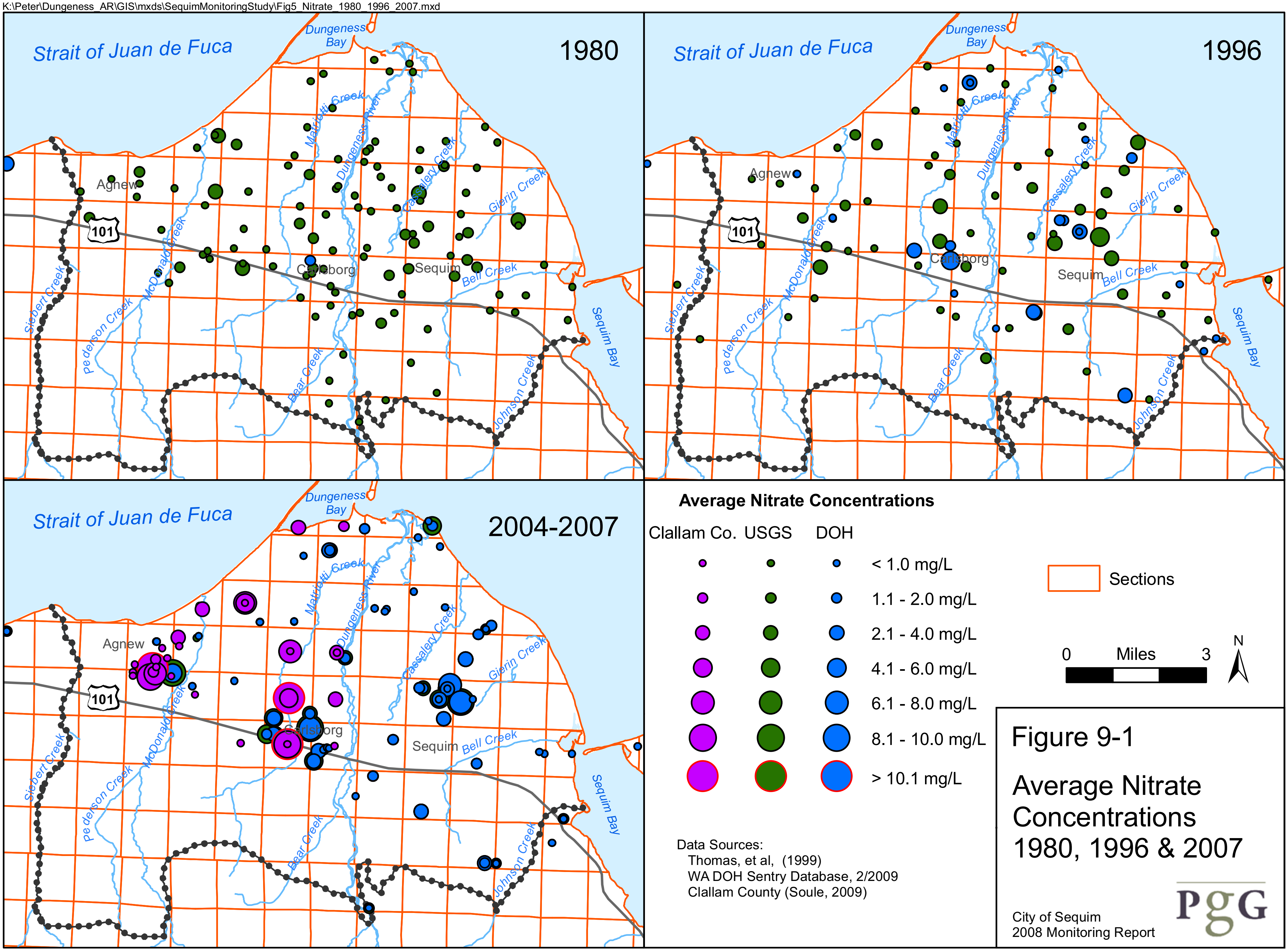

Figure 9-1

Average Nitrate Concentrations 1980, 1996 & 2007

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