City of Bainbridge Island
Level II Assessment

An Element of the Water Resources Study

Prepared by

Kato & Warren, Inc.
Robinson & Noble, Inc.

December 2000

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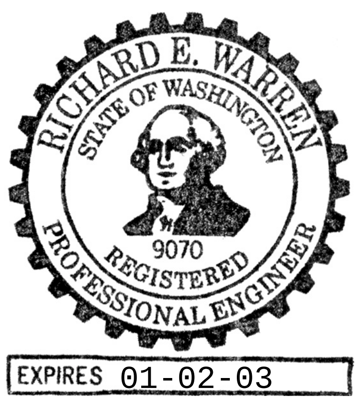
CERTIFICATE OF ENGINEER

CITY OF BAINBRIDGE ISLAND
Level II Assessment
2000

The technical material and data contained in this report were prepared under the supervision and direction of the undersigned professional engineers licensed to practice in the State of Washington.



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LEVEL II ASSESSMENT
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LEVEL II ASSESSMENT
EXECUTIVE SUMMARY

All public water systems on Bainbridge Island are dependent on groundwater as a source of domestic potable water. The vast majority of the recharge of the groundwater resource originates as precipitation that falls on the Island.

The Level II Assessment indicates that the natural groundwater recharge on the Island is sufficient to meet the Island's needs at full development under current zoning. This is true after allowing for the runoff needed to maintain the habitat values of the streams on the Island.

While overall there is sufficient groundwater resource for Bainbridge Island, its availability varies considerably throughout the Island. For example, the southern portion of the Island, which is generally underlain by Tertiary Bedrock, has limited groundwater availability, while several prolific aquifers underlay the north and central portions of the Island.

The aquifer that currently produces the most for the City of Bainbridge Island is the Fletcher Bay Aquifer System, which is encountered several hundred feet below seal level. Although the Fletcher Bay Aquifer System has considerable potential, it is not an unlimited source. Although the Fletcher Bay Aquifer System is a regional source, having been correlated with deep aquifers on Kitsap Peninsula, its recharge area and recharge rates are unknown.

Another source of great importance to the groundwater resources of the Island is the Sea Level Aquifer System. The use of the Sea Level Aquifer should be continued and must be protected from contamination. Increases in production should be generally from the Sea Level Aquifer. Also, future exploration for additional groundwater supply should be directed toward the Sea Level Aquifer System in the north and central portions of the Island.

There are a large number of surface and ground water rights on the Island. The total water right allocations for the Island exceed the estimated amount of water actually used. Based on the recharge rate for Bainbridge Island, estimated using three separate methods, the total ground water resource is 19,000 afy. The estimated current total water used on the Island, based on population data and a per capita use, is only 12% of the total groundwater resource and only 31% of the water rights allocations.

Ground and surface water right applications on Bainbridge Island total 3,080 gpm. This represents an estimated amount of 1,533 afy, or 8% of the total available resource.

It is recommended that the City begin a process of data collection to develop an historical record of water use and aquifer water levels. This would include a careful monitoring of the Fletcher Bay Aquifer System wells to preserve the resource.

The City should request that the Department of Ecology advise the City of all water right applications. The City should also discourage development on small exempt wells (under 5,000 gpd) by requiring connection to a larger system or transfer of the water system and water right to the City at the time of acceptance.

SECTION 2
LEVEL II ASSESSMENT
INTRODUCTION

2.1 Purpose And Scope

The recently completed Kitsap County Level I Basin Assessment (KPUD and others, 1997) identified Bainbridge Island as one of eighteen subareas within the County **(Figure 2.1)**. That study provided a substantial compilation of existing data available for the island, summarized the present level of understanding of the hydrologic system, and provided recommendations of topics needed to be addressed in a Level II assessment. The recommendations for the Bainbridge Island subarea (KPUD and others, 1997) were to:

- Complete a comprehensive hydrogeologic analysis of below sea level aquifers to complement the USGS study (Dion & others, 1988);
- Continue and expand hydrogeologic data collection network;
- Install stream gauges in the subarea if favorable conditions existed;
- Collect and document stream flow, temperature, and dissolved oxygen for appropriate large streams during the low flow period from mid-June to the end of September (or until the fall rains begin); and
- Catalogue the fisheries resource of the subarea.

Based on these Level I recommendations, the overall goal of the Level II Assessment is to build upon the preliminary analysis previously provided and to address and improve upon the understanding of the hydrology of the island. This improved understanding should allow for the proper management of the island's water resources into the future.

2.2 Previous Studies

Several geologic and hydrogeologic studies of Bainbridge Island have been conducted as part of regional studies of Kitsap County or the entire Kitsap Peninsula. The first regional study of Kitsap hydrogeology and groundwater resources was completed by Sceva (1957). Sceva mapped the geology, collected and compiled basic data, and described the occurrence, quantity, and quality of groundwater supply of Kitsap County. Garling and others (1965) also conducted a study of the groundwater and surface water resources of Kitsap County. This study was a comprehensive compilation of groundwater and surface water resource information available at the time, including the existing geologic and hydrogeologic mapping, streamflow data, water quality and quantity information, and water use. Later regional studies included work by Deeter (1979), which described and mapped the geology and stratigraphy of Kitsap County, and Hansen and Bolke (1980), which focused on broad-based estimates of groundwater availability. A hydrogeology study of the SUBBASE Bangor area recently completed by the USGS (Kahle, 1998) and a summary of the hydrogeology and a three-dimensional groundwater flow model of the SUBBASE (Becker, 1995a; and 1995b), while not directly involving Bainbridge Island, provided the basis for this study's nomenclature of the hydrogeologic units on Bainbridge Island.

The first study that specifically evaluated the groundwater resources of Bainbridge Island was done by Dion and others (1988). This study was a qualitative assessment which focused on the shallow groundwater system. The study established a monitoring network and measured coincidental water levels. Site-specific investigations of nearly 50 water-supply wells located on Bainbridge Island have been conducted by Robinson & Noble, Inc. Included in these studies are the majority of the wells operated by the large water purveyors on the island (for example, City of Bainbridge Island, Kitsap PUD, North Bainbridge Water Company, Island Utilities, Bill Point Water, and Gable Bay Water). Robinson & Noble also conducted an aquifer protection study of the Meadowmeer Aquifer near the center of the island. Other consultants (for example, Geraghty & Miller, 1992) have also conducted site-specific studies. Additionally, the Puget Sound Cooperative River Basin Team (1995) characterized the Bainbridge Island watersheds, providing information regarding land use, stream and wetland habitats, and watershed management.

As part of the Kitsap County Ground Water Management Plan (GWMP), a comprehensive update of the water resources of Kitsap County (EES, 1991) was prepared. This study included development of hydrostratigraphic cross-sections, a water well database, identification of areas of groundwater production (principal aquifers), a preliminary assessment of water quality, and the establishment of precipitation, ground water, and surface water monitoring networks. In 1997, an Initial Watershed Assessment (IWA), commonly referred to as a Level I Basin Assessment, was conducted for Kitsap County (KPUD and others, 1997) to help expedite water right decisions and characterize the state of available groundwater information. The assessment focused on assembling and reviewing existing groundwater resource information. The IWA established 18 subareas in the county (of which Bainbridge Island is one) based on local geology, hydrology, and topography. One of the recommendations for the Bainbridge Island subarea was to complete a comprehensive hydrogeologic analysis (Level II Basin Assessment) of the subarea to complement previous studies.

This report documents the results of the Level II Basin Assessment for Bainbridge Island.

Bainbridge Island is located in Washington State, in the eastern portion of Kitsap County along the western shore of central Puget Sound. The island is separated from the mainland Kitsap Peninsula by Port Madison Bay, Port Orchard Bay, and Rich Passage to the north, west, and south, respectively **(Figure 2.1)**. The study area, which includes the entire island, covers a total area of approximately 27.5 square miles.

3.1 Topography

Standard USGS 7.5-minute topographic quadrangles were used as a base throughout this project. A 1996/1997 laser-generated aerial image of the island **(Figure 3.1)**, supplied by the Kitsap Public Utility District (KPUD), was also utilized in part during this project for analysis and interpretation. Airborne Laser Mapping Inc., which produced the image, attained a high degree of image accuracy in this photo through the utilization of laser scanner and GPS technology.

The topography within the study area is dominated by gently rolling hills, which, as a result of recent glacial scouring, have a conspicuous north-south orientation and pronounced drumlin-like profiles. The major hills and uplands tend to have relatively flat to gently sloping summits with an average elevation of approximately 320 feet. Erosion by meltwater streams has produced a number of shallow to moderately incised valleys on the island. These stream valleys generally radiate outward from the island's upland areas or trend parallel between the hills before proceeding down-slope to the island's coastal areas. Erosion has also produced steep, intermittent sea cliffs around the coastal portions of the island, ranging in height from 100 to 200 feet. The elevation over the entire island ranges from sea level to just over 380 feet.

Across the inland portion of Bainbridge Island, the topography typically slopes less than 10° (equivalent to a grade of 17 percent or less) with the steeper slopes generally occurring within the stream valleys. The cliffs along the coastal areas are usually much steeper with slopes ranging from 40° to 45° (equivalent to 60 to 100 percent grades). In the adjacent offshore areas north, west, and south of the island, the seabed descends outward from the beach at slopes ranging from 3° to 6° (equivalent to 6 to 12 percent grades) and then tends to flatten approximately 0.5 miles from shore. Toward the east, the slope of the seabed extends much further and descends to a significantly greater depth below Puget Sound.

3.2 Climate

Bainbridge Island, as with most of Kitsap County, has a characteristic maritime climate, which is typified by short, dry summers and prolonged wet winters. Precipitation in the region is strongly influenced by the Olympic Mountains to the west and the Cascades to the east, which impede the flow of humid air masses that develop over the Pacific Ocean.

During a typical year the majority of the precipitation over the island occurs as rain between the months of October and April. An isohyetal map was presented in the Initial Basin Assessment

(**Figure 3.2**, KPUD and others, 1997). The isohyetal map was based on 21 gages on, and surrounding the Kitsap peninsula. Long-term precipitation records at Bremerton and McKenna Falls were used to normalize annual precipitation values for the remainder of the stations with shorter (less than ten years) periods of record. A normalized, long-term precipitation estimate of 34.3 in/yr was calculated for the Bloedel gage and is shown on **Figure 3.2**. The isohyetal map for Bainbridge Island shows mean annual precipitation ranges from approximately 38 inches per year (in/yr) in the southeast to just over 34 in/yr in the north. It should be noted that the short-term rainfall average for each precipitation station is greater than the long-term adjusted (normalized) average. The short-term averages are as follows: 41.01 in/yr at Bloedel (1991-98), 49.75 in/yr at Meadowmeer (1995-98), and 41.08 in/yr at Woodward Middle School (1991-98).

Occasionally, temperatures during the winter months are sufficiently low for snow to develop, but snow accumulation within the study area is typically not significant. Mean monthly temperatures for the region range from approximately 39°F in January to 64°F in August (at Bremerton NOAA weather station).

3.3 Geologic History and Stratigraphy

The present-day landscape and underlying hydrostratigraphy within the study area are in large part, the result of repeated advances and retreats of Pleistocene continental glaciers, which inundated the Puget Lowland during recent geologic time. Over approximately the past 300,000-year period, at least six glacial and intervening interglacial episodes have potentially affected the region (Easterbrook, 1994). During this time, a large volume of glacial and interglacial material was deposited over the basin, resulting in a complex accumulation of unconsolidated sediments which is up to 3,000 feet thick in some places. Several other geologic units are present within the study area, but are of less importance hydrologically. These include Quaternary alluvial deposits, which occur surficially in localized areas, and Tertiary sedimentary rocks, which are exposed at the southern end of the island on the up-thrown side of a major east-west trending fault that transects the study area.

A surficial geologic map of Bainbridge Island was developed by Deeter (1979) and is presented here as **Figure 3.3**. Below are the descriptions of the geologic units given from youngest to oldest.

The youngest deposit within the study area is Quaternary alluvium, which includes recent stream, lake, floodplain, beach, and peat deposits. These deposits, which occur surficially, are generally thin and discontinuous, and have minor to no regional hydrogeologic importance on Bainbridge Island. Combined, these units cover less than one percent of the study area.

The youngest glacial deposits present on Bainbridge Island are the Vashon deposits. These strata, which are well represented within the study area, were delivered to the Puget Lowland during a late stage of the Fraser glaciation (18,000 to 13,000 years before present (Easterbrook, 1968; and Easterbrook, 1991). The Vashon recessional outwash (Qvr), the youngest of the Vashon deposits, was laid down by meltwater streams emanating from the receding Vashon glacier. Within the study area, this unit has a limited distribution, but typically consists of poorly sorted sand and gravel. The Vashon till (Qvt), which lies stratigraphically below the recessional outwash, has a much greater distribution, comprising the majority of the island's surficial exposures. This unit was deposited in situ by the Vashon glacier and is typically composed of a mixture of unstratified clay through boulder size detritus. The Vashon till is a relatively dense unit and forms a moderately impermeable cap over much of the island. The Vashon advance outwash (Qva), which lies stratigraphically below the till, was deposited over the basin by meltwater streams flowing from the advancing Vashon glacier. It is composed largely of sand and silty sand with lesser amounts of gravel and occasional lenses of silt. The advance unit is relatively widespread on the island and hosts the shallowest (uppermost) hydrostratigraphic unit within the study area. The base of the Vashon is occasionally marked by the Lawton Clay (Qvl), which consists of glaciolacustrine clay and silt deposited in proglacial lakes that formed ahead of the advancing Vashon glacier.

Below the sequence of Vashon deposits are alternating groups of nonglacial and glacial sediments, many of which have been named by numerous earlier workers. Sceva (1957) was the first to apply a "modern" nomenclature. He was followed by Molenaar in Garling & others (1965), who was followed in turn by Easterbrook's numerous studies on Whidbey Island to the north. Deeter followed both Easterbrook and Molenaar while doing independent mapping in Kitsap County. The nomenclature did not remain consistent and the basic stratigraphic concepts were called to question by yet later studies (Blunt and others, 1987; Noble, 1990; Kahle, 1998). Because of the major inconsistencies and lack of agreements in stratigraphic nomenclature, we have deleted these terms from further use in this paper, and instead have assigned a more generalized sequence of "hydrostratigraphic units" which do not have formal names. There is general agreement on usage of the term Vashon for the youngest glaciation to cover the area. It began about 18,000 years ago. Prior to this, there was an interglacial time preceded by another major glaciation thought to be approximately 80,000 years ago. Deposits of that glaciation are not as evident as the Vashon, but can be observed above sea level. A third yet older glacial deposit and intervening nonglacial sediments have been recognized in outcrops above sea level. Well logs provide the only evidence of still deeper and older glacial/nonglacial deposits.

At the south end of Bainbridge Island, just south of Eagle Harbor, a major fault transects the island in an east to west direction and juxtaposes unconsolidated Pleistocene sediments (to the north) with Tertiary sedimentary bedrock (in the south). The sedimentary bedrock terrain is also unconformably overlain by Vashon drift. This terrain, which consists of mostly Miocene rocks of the Blakely Harbor Formation (Fulmer, 1975) and Oligocene rocks of the Blakely Formation (Fulmer, 1975), comprises the oldest material occurring in the study area. The rocks consist primarily of volcanoclastic shale, sandstone, and conglomerate deposited in a marine environment (Fulmer, 1975). Neither the upper surface nor the base of the formation are exposed, but the formation thickness has been estimated to be approximately 8,500 feet. The formation was folded during late Tertiary time and is presently inclined between 45 to 90 degrees from horizontal. Penetrative surface weathering and the formation of fairly thick soils on the bedrock often make it difficult to distinguish the Tertiary sedimentary terrain from Pleistocene glacial deposits.

SECTION 4
LEVEL II ASSESSMENT
SURFACE WATER

This section of the report describes the surface water quantity and quality assessment and groundwater quality assessment of Bainbridge Island and includes general information, testing/study efforts, observed problems, and regulatory efforts.

4.1 General Information

Bainbridge Island is comprised of 12 watersheds **(Figure 4.1)** with 43 miles of mapped streams **(Figure 4.2)** that generally lack reliable hydrologic data. It is estimated that roughly 50 percent are perennial and the other 50 percent intermittent. Where the Perched Aquifer System and Semi-Perched Aquifer System intercept the ground surface, a portion of the ground water flowing through the system is discharged as evapotranspiration or to surface water bodies. Fish do utilize seven of the island creeks. The island's subsurface flows, both aquifer and interflow components, have been largely unmapped. Wetlands and floodplains can also be found on the island.

Sanitary sewer conveyance and treatment are used in historic Winslow and the Fort Ward areas only. Septic drainfields are used elsewhere. The majority of the island residents utilize on-site septic systems for wastewater.

Some island residents are on shallow wells. The remainder of the island residents buy water from private water purveyors who get water from deeper wells. An off-island water supply is unavailable at this time.

4.2 Testing/Study Efforts

Surface water quantity and quality and groundwater quality testing efforts have been conducted by a variety of individuals, organizations and agencies with varying degrees of success, coverage and detail. A description of each of the testing/study efforts follows and is sorted in chronological order with the most recent work described first.

Washington State Department of Ecology has an ambient water quality monitoring station between Brownsville and Bainbridge Island that is used for the Puget Sound Ambient Monitoring Program under the direction of the Puget Sound Water Quality Action Team.

A spokesperson from Bainbridge Island Public Works Department reports that the City of Bainbridge Island ran a volunteer-based water quality program throughout 1998. Water quality characteristics sampled under the program include: DO, pH, temperature, flowrate (reported to be unreliable) and fecal coliform.

Public Works staff indicated that the City of Bainbridge Island plans on having the Bremerton-Kitsap County Health District monitor water quality (specifically, fecal coliform and other parameters) for a period of one year starting March 1999.

A 7th grade middle school class, in cooperation with an environmental coordinator, has collected what they believe to be reliable DO, pH, turbidity and temperature data every other week since September 1998. They have been testing the stream near Woodward Middle School.

The Island School, a private institution, has provided intermittent surface water quantity and quality data gathered over a period of years.

For the 1995 Bainbridge Island Watersheds characterization study, the health department sampled streams for instantaneous water quality physical parameters and flowrates, and marine waters were sampled for water quality physical parameters. The efforts were documented in the following report: Grellner, K.J., Stewart Bauman, B., Ultican, S., and McNickle, M., 1997, **Bainbridge Island Watershed Nonpoint Source Pollution Water Quality Assessment Project**, Bremerton-Kitsap County Health District Environmental Health Division Water Quality Program, Final Report.

Kitsap County Public Utility District (KPUD) staff indicated that stream-flow gages have not been successfully installed on Bainbridge Island. KPUD tried to install a few stream gages in the early 1990's, but did not collect any data due to property access or acquisition problems.

As part of the Kitsap County Ground Water Management Plan (GWMP), a comprehensive update of the water resources of Kitsap County (EES, 1991) was prepared. This study included development of hydrostratigraphic cross-sections, a water well database, identification of areas of groundwater production (principal aquifers), a preliminary assessment of water quality, and the establishment of precipitation, ground water, and surface water monitoring networks and was documented in the following report: Kitsap County Ground Water Advisory Committee, and others, 1991, **Background Data Collection and Management Issues**: **Kitsap County Ground Water Management Plan**, Volumes I and II.

Garling and others (1965) conducted a study of the groundwater and surface water resources of Kitsap County. This study was a comprehensive compilation of groundwater and surface water resource information available at the time, including the existing geologic and hydrogeologic mapping, stream flow data, water quality and quantity information, and water use. This work was documented in the following report: Garling, M. E., Molenaar, D. E. and others, 1965, **Water Resources and Geology of the Kitsap Peninsula and Certain Adjacent Islands**, Washington State Division of Water Resources Water Supply Bulletin No. 18, 309p., 5 plates.

FEMA has mapped and published reports on 100-year floodplains on Bainbridge Island. **(Figure 4.2)**

The 1995 Bainbridge Island Watershed Study indicated that a Recreational/Shellfish Monitoring Program has been underway since 1993. Several other water quality studies are summarized in the report.

Water quality studies have been performed in conjunction with local development projects including, but not limited to, the following:

1985 Arco project at 305 and High School Road within the Eagle Harbor Basin.

Hidden Cove subdivision project (68 lots) off Phelps Road within the Port Madison Bay Watershed and adjacent to wetlands and streams. Twice in three years fecal coliform levels exceeded baseline measurements.

South Bainbridge Island Water Company runoff reservoirs.

The Port Blakely Mill Company has some local studies of their property.

The following additional resources were acquired and/or reviewed for pertinent surface water quantity and quality and groundwater quality data:

Puget Sound Water Quality Action Team, **1999-2001 Puget Sound Water Quality Work Plan**, 1999.

Puget Sound Water Quality Action Team, **1998 Puget Sound Update: Sixth Report of the Puget Sound Ambient Monitoring Program**. Puget Sound Water Quality Action Team, 1998.

Barker, C., **Sanitary Survey of Port Orchard Passage**, Washington State Department of Health Office of Shellfish Programs, 1998.

Unified Watershed Assessment for Washington State, Phase I: Categorization and Prioritization of Watersheds, 1998.

Kitsap County Public Utility District, and others, **Kitsap County Initial Basin Assessment**, Open File Technical Report No. 97-04, 1997.

Elfendahl, Gerald, **Streams of Bainbridge Island: Names, History, Folklore & Culture** Salmonberry Press, Fourth Edition, 1997.

The Bainbridge Island Watershed Management Committee, **Bainbridge Island Watershed Action Plan**, 1997.

Grellner, K.J., Stewart Bauman, B., Ultican, S., and McNickle, M., **Bainbridge Island Watershed Nonpoint Source Pollution Water Quality Assessment Project**, Bremerton-Kitsap County Health District Environmental Health Division Water Quality Program, Final Report, 1997.

Puget Sound Water Quality Action Team, **1997-99 Puget Sound Water Quality Work Plan**, 1997.

Puget Sound Water Quality Action Team, **1994 Puget Sound Water Quality Management Plan,** Amended May 1996.

R.W. Beck, **City of Bainbridge Island Water System Plan Summary**, Pursuant to the City of Bainbridge Island Comprehensive Plan Remand by Central Puget Sound Hearings Board, 1995.

R.W. Beck, **Draft City of Bainbridge Island Water System Plan**, 1994.

City of Bainbridge Island, **Non-Project Environmental Impact Statement**, Draft Comprehensive Plan, Department of Planning and Community Development, 1994.

City of Bainbridge Island, **Resolution No. 93-03 Water systems outside historic Winslow and other water resources on Bainbridge Island,** 1993.

Molenaar, D., **Geohydrology of Kitsap County, Washington, relative to land-use development and long-range planning**, 1993.

Geraghty & Miller. Inc., **The hydraulic and water quality effects of pumping the deep aquifer at the Old Mill Road Well Field and at the proposed deep well west of the Wyckoff site, Bainbridge Island, Washington**, prepared for Port Blakely Tree Farm, 1992.

Economic and Engineering Services, Inc., **Kitsap County Coordinated Water System Plan Regional Supplement**, 1992.

Kitsap County Ground Water Advisory Committee, and others, **Background data collection and management issues:** Kitsap County Ground Water Management Plan, Volumes I and II.

Dion, N. P., Olsen, T. D., and, Payne, K. L., **Preliminary Evaluation of the Groundwater Resources of Bainbridge Island, Kitsap County, Washington**, U.S. Geological Survey Water-Resources Investigations Report 87-4237, prepared in cooperation with Kitsap County, P.U.D. District No. 1 of Kitsap County, State of Washington D.O.E., and the City of Winslow, 1988.

Yake W. & Norton D., **Chemical Contamination of Groundwater, Inter-Tidal Seepage and Sediments On and Near Wyckoff Company Property, Eagle Harbor, Bainbridge Island**, Publication Number 86-E40, 1986.

City of Winslow, 1985, **Ordinance No. 85-13**: Drainage Control, 8p.

Gardner Engineers, Inc. and Warren Consultants, Inc., 1985, **City of Winslow Stormwater Drainage Plan**: Final Report.

Cummans, J. E., 1977, **Low-flow Characteristics of Streams on Kitsap Peninsula and Selected Islands, Washington**: U.S. Geological Survey Open-File Report 76-704, Tacoma, WA, Washington Geologic Survey, 19p.

Garling, M. E., Molenaar, D. E. and others, **Water resources and geology of the Kitsap Peninsula and certain adjacent Islands**, Washington State Division of Water Resources Water Supply Bulletin No. 18, 1965

4.3 Observed Problems

In general the 1994 Bainbridge Island Comprehensive Plan describes observed problems as the erosion of private property and drainage corridors; landslides and eroding steep banks; excessive wetness due to springs or lack of drainage; incomplete, inadequate, damaged or unmaintained culverts and drainage corridors, especially along beach roads; and siltation on the beach, wetlands and streams. Public Works Engineering staff have noted that many runoff quantity control ponds overflow during moderate storm events and therefore may not be functioning appropriately.

Kitsap County Conservation District deals primarily with water and soil impacts due to commercial and recreational livestock. They have had little activity on the Island.

The 1995 Bainbridge Island Watershed Study more specifically identifies observed problems. The specific problems have been categorized as shown below. The page reference is given for convenience. **(Figure 4.3)**

Existing surface water quality problem areas:
- Eagle Harbor (parts are a federally recognized Superfund site), pg3
- Lynwood Center, pg3
- Fort Ward area, pg3
- Boats have been tied to fecal coliform in Eagle Harbor, pg10
- Livestock contribute to WQ problem, pg10
- 160ac of shellfish habitat is classified as PROHIBITED near Winslow by USDA due to the sanitary outfall, pg43
- Paralytic Shellfish Poisoning (PSP) occurs occasionally, pg44

Existing groundwater quality problem areas:
- Day road industrial park area (source unknown), pg3
- Eagle Harbor – federally recognized Superfund site, pg3
- Marinas, pg3

Existing sanitary problems:
- Lynwood Center untreated outfall, pg3
- Sewer Dist. #7 Fort Ward minimal treatment outfall, pg3
- Septic systems may be contributing significant nutrients to streams but number of failed systems is undocumented, pg10

Existing stream problems:
- Streams are small, <1cfs, perennial and intermittent, none named, pg13
- Small stream size, pg9
- Lack of suitable spawning gravel, pg9
- Impassable barriers, pg9

Existing wetland problems:
- Both fresh and salt-water wetlands, pg13
- Most wetlands are degraded; mostly by filling, pg9

Existing solid waste problems:
- Hazardous materials are not regulated, pg10

Existing land-use problems:
- Forestry does not appear to be a major problem but Forest Practice Rules and Regulations are not adequate to protect streams. Perhaps a City tree ordinance and memo of understanding with DNR would place adequate restriction on forestland conversions, pg10
- No clearing or grading ordinance, pg10
- The City has a vegetation management ordinance but lacks staff to enforce it.
- Need to finalize the SAO, pg11
- Need a stormwater ordinance on quantity and quality, pg11
- Need a public education effort, pg11

Existing erosion problems:
- Erosion potential map, pg31

4.4 Regulatory Efforts

The following surface water and/or groundwater regulations are adopted or underway on Bainbridge Island:

The Instream Resources Protection Program (WAC 173-515) affects two streams on Bainbridge Island. The affected streams are Unnamed Stream #434, the tributary to Murden Cove and Unnamed Stream #461, the tributary to Fletcher Bay. Both of these streams are closed year-round to further consumptive appropriation. The Instream Resource Protection Program purpose is to retain perennial streams with flows and levels necessary to provide for preservation and protection of wildlife, fish, scenic, aesthetic and other environmental values, and to preserve water quality (WAC 173-515-020).

The 1994 **Comprehensive Plan** indicated that WSDFW has developed guidelines that apply to projects with more than 5,000sf of impervious area. Water quantity requirements may or may not be required depending on proximity to fish and shellfish resources. Water quality requirements are required for every project regardless of proximity to resources. Quantity control requirements involve using an HSPF or event hydrology model to keep the developed two-year peak flowrate below one-half of the pre-developed two-year peak flowrate and to keep the developed 25-year peak flowrate below the pre-developed 25-year peak flowrate. Quality control requirements involve the use biofiltration and TESC BMPs along with regular maintenance. The February 1992 WSDOE **Stormwater Management Manual** for the Puget Sound Basin has similar quantity and quality control measures.

Watershed planning, public education, recommendations for action, implementation, evaluation and accomplishments to date are presented in the **1997 Bainbridge Island Watershed Action Plan** produced by The Bainbridge Island Watershed Management

Committee. This plan identified the Island's wetlands and proposed an ordinance protecting the wetlands. **(Figure 4.4)**

Local Planning and Management of Nonpoint Source Pollution, Chapter 400-12 WAC .

Resolution No. 93-03 regulates water systems outside Winslow and water resources on Bainbridge Island.

The 1994 **Comprehensive Plan** indicated that Ordinance 85-13 regulates storm runoff from new development. The ordinance requires four inches per square foot impervious area storage. The allowable release rate is 0.05 cfs/gross acre. Runoff quality is controlled for oil, grease and sediment. Reductions in required storage and increases in allowable release peak rates are allowed where proponents contribute funds to planned regional downstream improvements.

Public Works staff indicated that new development on the east and west sides of Madison Street from Winslow Way to Wyatt do not require detention facilities as a result of conveyance improvements installed under a LID.

SECTION 5
LEVEL II ASSESSMENT
HYDROGEOLOGIC CHARACTERIZATION

As part of the Kitsap County GWMP **(EES, 1991)**, a well database was developed. This database was constructed using a transfer of USGS WATSTORE data and additional information from typically reliable sources. This database forms the core of the KPUD well database. Since then GWMP, well log information has been routinely added to the KPUD database and upgraded. For the Level II Basin Assessment, the Bainbridge Island portion of the KPUD database was separated and examined in detail. The study database was formed by comparing the Bainbridge Island portion of the KPUD database to Sceva's (1957) database and the field-located well database in Dion and others (1988) for corrections and confirmations. Additionally, locations and common names of the wells were confirmed using numerous site-specific consultant reports and KPUD's well tagging forms. The tagging forms provided excellent location information since they are based on site visits, and give GPS readings, elevation measurements, and map locations.

In all, there are 983 wells in the study database **(Appendix A)** with various amounts of information for each. Of these 983 wells, 938 wells are shown on **Figure 5.1**. (Due to the unreliability of locations for 45 wells, they were not included). In addition to the wells in the database, well logs from approximately 475 wells that are not included in the database were collected. Where information was believed to be reliable, well completion zones were assigned to hydrostratigraphic units based on correlation with cross sections created for the project. These cross sections, five in all **(Plates 1, 2, 3 and 4)**, were drawn from the surface geologic map of Deeter (1979), shown on **Figure 3.3,** and information gathered from subsurface lithologic descriptions on well logs. Cross section locations were selected **(Figure 5.1)** to cover the areas with the most available subsurface information. To assist in cross section formation and other aspects of this study, a hydrogeologic nomenclature was developed for the study which is generally similar to the recent hydrostratigraphic study by the USGS on the Bangor SUBBASE (Kahle, 1998). **Table 5.1** summarizes and compares nomenclature used in selected studies in the Bainbridge Island area with the nomenclature used in this study. The table is a modification of a similar table within the USGS's Bangor study (Kahle, 1998).

Table 5.1. Hydrostratigraphic Unit Terminology Used in Groundwater Studies in the Bainbridge Island Area

Sceva, 1957 (Kitsap County)	Garling and others, 1965 (Kitsap Peninsula)	Dion and others, 1988 (Bainbridge Island)	Kitsap County Groundwater Advisory Committee and others, 1991 (Kitsap County)	This Study
Alluvium	Alluvium	1	Qn1, alluvium and recessional deposits	---
A, recessional outwash	Qvr, recessional outwash			Qvr
B. till	Qvt, till	2	Qg1, till	Qvt
C, advance outwash	Qva, advance outwash	3	Qg1a, advance outwash/shallow aquifer	PA, perched aquifer system
D, Puyallup Sand	Qc, Colvos Sand			
---	---	4	Qn2, 1^{st} nonglacial deposits	C1, upper confining unit
			Qg2, 2^{nd} glacial deposits[1]	
ORTING GRAVEL: E, Kitsap Clay member	Qg/Qk, unnamed gravel/Kitsap Formation			SPA, semi-perched aquifer system
			Qn3, 2^{nd} nonglacial deposits	C2, lower confining unit
ORTING GRAVEL: F, Orting gravel member	Qss, SalmonSprings (?) Drift	5	Qg3, 3^{rd} glacial deposits/sea-level aquifer[2]	SLA, sea level aquifer
---	Qpu, pre-Salmon Springs (?) deposits	6	Qn4, 3^{rd} nonglacial deposits	C3, confining unit
		Pleistocene deposits (undifferentiated)	Qg4, 4^{th} glacial deposits/deep aquifer[3]; Qg4m marine/glaciomarine deposits	GMA glaciomarine aquifer system
G, Admiralty Drift			Qn5, 4^{th} nonglacial deposits	C4, confining unit
Pre-Orting deposits, undifferentiated			Qg5, 5^{th} glacial deposits[4]	FBA, Fletcher Bay Aquifer
			Qn6, ancient nonglacial deposits	C5, confining unit
Tertiary Blakeley Formation of Weaver, 1916	Tertiary Blakeley Formation of Weaver, 1916	Tertiary Blakeley Formation of Weaver, 1916	Tertiary Blakeley Formation of Weaver, 1916	Blakeley Harbor Formation of Fulmer, 1975
				Blakeley Formation of Fulmer, 1975

Correlation with Principal Aquifers of the GWMP, 1991:

1 The Meadowmeer Aquifer.

2 The shallow zone of the Wardwell Aquifer System, the Lynwood Center Aquifer, and the Bayhead Aquifer.

3 The shallow zone of the Gilberton-Fletcher Bay Aquifer System, and the Eagle Harbor Aquifer.

4 The deep zones of the Wardwell Aquifer System and the Gilberton-Fletcher Bay Aquifer System.

5.1 Hydrostratigraphic Unit Descriptions

The subsurface below Bainbridge Island has been divided into 13 major hydrostratigraphic units based principally on their hydrologic characteristics. These units are described below. The thickness of each unit was determined through a cross-sectional analysis of the study area. Each hydrostratigraphic unit is described below in order of youngest to oldest unit. For the major aquifer units on Bainbridge Island, maps were developed showing aquifer boundaries, potentiometric surface elevation, and hydraulic conductivity.

Hydraulic conductivity is a measure of a material's ability to transmit water. To develop the hydraulic conductivity maps, conductivity was calculated for each well with pump test data using one of two methods (depending on how the wells were completed). For wells completed with screened or perforated intervals, the transmissivity of the aquifer was iteratively calculated using the modified Theis equation:

$$s = \frac{Q}{4\pi T} \ln \frac{2.25Tt}{r^2 S}$$

Where:

s = drawdown in the well, in feet;
Q = discharge of the well, in ft^3/d;
T = transmissivity of the hydrogeologic unit, in ft^2/d;
t = length of time the well was pumped in days;
r = radius of the well, in feet; and,
S = storage coefficient, assumed to range from 0.001 to 0.0001.

Then the horizontal hydraulic conductivity was calculated by using the equation:

$$K_h = \frac{T}{b}$$

Where

K_h = horizontal conductivity of the material near the well opening, in feet per day; and,

b = thickness, in feet, given as the length of the well opening interval.

If the well is completed as an open bottom with no screen or perforated zone, the hydraulic conductivity at the well was calculated using an equation provided by Bear (1979). This equation is based on the assumption that horizontal and vertical conductivity are equal. In the Bainbridge Island study area this assumption is not likely to be true, resulting in a probable underestimate of the hydraulic conductivity (Kahle, 1998). This equation is as follows:

The calculated hydraulic conductivity values for the wells were then plotted for each aquifer. Boundaries were drawn around four gradations of average values: less than 10 ft/d, between 10 and 100 ft/d, between 100 and 500 ft/d, and greater than 500 ft/d. Due to the lack of the areal coverage of pump test data in the Glaciomarine, Fletcher Bay, and Bedrock Aquifer Systems, maps of hydraulic conductivity for these units could not be reliably drawn. The overall pattern of the hydraulic conductivity groupings for the Perched, Semi-Perched, and Sea Level Aquifer Systems are discussed below within their respective unit descriptions.

5.1.1 Vashon Recessional Outwash

The Vashon recessional outwash, which represents deposition during the final retreat of the Frasier ice sheet, is the youngest unit present on Bainbridge Island. This unit is comprised of fine to medium-grained silty sand with minor amounts of gravel. Typically, this unit is well drained but, if the topography is configured appropriately, it may contain minor, localized perched zones. Within the study area, however, no wells were designated as being completed in this unit. However, there are likely several shallow dug wells in this unit.

This aquifer has a limited distribution within the study area and occurs only in isolated areas, predominately in the south-central portion of the island. This unit covers less than one square mile, or two percent of the island's land surface. The unit's thickness in the study area ranges from approximately 10 to 40 feet with an average thickness of approximately 30 feet. This highly permeable unit readily accepts recharge directly from precipitation and is a source for leakage to underlying units and baseflow for the island's streams. Based on the deposit's characteristics, the recession outwash was estimated to have hydraulic conductivity that ranges from 10 to 1,000 ft/day.

5.1.2 Vashon Till Confining Unit

The Vashon till is the predominant surficial deposit on the island and forms an aquitard below the Vashon recessional outwash. Typically, it is a gray, dense stratum, composed of clay through boulder sized detritus. It is usually unsaturated but may contain small perched zones within isolated pockets of more permeable material. A few wells are known to have been completed in this unit within the study area; most are hand-dug wells with limited capacity.

In terms of area, this unit covers approximately 21 square miles, or 75 percent of the island's land surface **(Figure 3.3)**. Unit thickness varies from approximately 10 to 150 feet across the island in no discernable pattern. The average thickness in the study area is approximately 50 feet. Despite its relatively low permeability, leakage through it to the lower aquifer systems does occur. Within the study area, principle recharge to lower aquifer systems is likely accommodated in areas where the till is thin or absent. Based on the characteristics of the till, the hydraulic conductivity is highly variable and likely ranges from 10^{-6} to 10 ft/day.

5.1.3 Perched Aquifer System

Perched aquifers occur where the movement of water, flowing downward through a relatively permeable, unconfined unit, is impeded as it encounters a less permeable layer, causing localized areas of saturation with non-saturated sediments beneath them. On Bainbridge Island, these perched zones may occur, to a limited degree, within the Vashon recessional outwash and in permeable zones within the till. However, the majority of perched water on the island occurs in the Vashon advance deposits which are, consequently, the predominant host to the Perched Aquifer System (PA) within the study area. These deposits consist of fine to medium-grained silty sand with interspersed gravelly units. As a result of erratic deposition and subsequent erosion, this unit is laterally discontinuous, as can be seen on the cross-sections **(Plates 1, 2, 3 and 4)**. Within the study area, the Perched Aquifer System is generally constrained to the upland areas of the island at elevations above 200 feet MSL. The thickness of the aquifer ranges from 20 to 140 feet with an average thickness of approximately 90 feet. The boundaries of the Perched Aquifer System, shown on **Figure 5.2**, are primarily constrained by ground surface elevation of the confining unit below it. Consequently, the Perched Aquifer System is comprised of numerous small, discontinuous perched zones.

In terms of area, the system covers approximately nine square miles, or 33 percent of the island's land surface in eight major upland areas **(Figure 5.2)**. Generally, from north to south, these are located in the following areas of the island: at the far north end of island between Seabold and Agate Point, due west of Rolling Bay, in the center of the island between Fletcher Bay and Murden Cove, in the vicinity of Bainbridge Island High School, on the upland southeast of Fletcher Bay, due south of Eagle Harbor, due southwest of Eagle Harbor, and due south of Blakely Harbor.

The system receives direct recharge by leakage from overlying units, mostly the Vashon till. Where the aquifer intercepts the land surface, it is naturally drained by springs, particularly within upland valleys that have been cut by streams. The total discharge contribution from the Perched Aquifer System to the streams has not been quantified. However, as has been demonstrated in other areas of Kitsap County (Becker, 1995a; and Purdy, 1995b), the Perched Aquifer System likely contributes the majority of the baseflow for the island's streams.

A large number of the domestic wells in the higher elevation areas of the island are completed in permeable zones within these localized aquifers. The KPUD database shows that 44 of the database's 983 wells (approximately 4 percent) have been completed in this aquifer. It should be noted that it is likely that more wells are completed in this aquifer than are included in the database. These would mainly be pre-1960, shallow, dug wells or unreported wells. Yields from the database wells range from 5 to 110 gpm, with an average of 16 gpm and a median of 12 gpm. Pumping test data from these wells show specific capacity values (which reflect the combined efficiency from both the well and aquifer) range from 0.2 to 16 gpm per foot of drawdown (gpm/ft-dd), with an average value of 2 gpm/ft-dd and a median of 0.5 gpm/ft-dd. Calculated transmissivity values indicate that wells within this aquifer system individually produce at moderate to high production rates. Transmissivity values ranging from 332 to 20,540 gpd/ft across the aquifer with an average value of 2,785 gpd/ft and median of 598 gpd/ft.

Calculated hydraulic conductivity values also indicate a moderate to high production potential in the areas of the aquifer where data is available **(Figure 5.3)**. The highest conductivity values occur in the uplands east of Fletcher Bay, where conductivity exceeds 100 ft/day. Values ranged between 10 and 100 ft/day throughout most of the rest of the aquifer where data is available. Overall, available information shows that conductivity values range from 9 to 144 ft/day across the aquifer with an average value of 32 ft/day and a median of 16 ft/day.

5.1.4 Upper Confining Unit

Underlying the Perched Aquifer System is a sequence of less permeable strata that are collectively defined as the Upper Confining Unit (C1). This unit is usually found as a discontinuous silt and clay layer directly below the Vashon advance outwash or as a till or silt-rich sand deposits. Isolated peat zones are also occasionally present within this unit. The Upper Confining Unit is continuous across most of the study area, ranging in thickness from 10 to 150 feet, with an average thickness of approximately 50 feet. The materials present within this unit typically have a low permeability, with estimated hydraulic conductivity values ranging from 10^{-1} to 10^{-7} ft/day.

5.1.5 Semi-Perched Aquifer System

The Semi-Perched Aquifer System (SPA), like the Perched Aquifer System, generally occurs above sea level **(Figure 5.4)**. It is usually encountered between 20 feet below and 100 feet above MSL and is laterally more continuous than the overlying perched zone. The thickness of the aquifer ranges from 10 to 65 feet with an average thickness of approximately 30 feet.

This aquifer system is generally pervasive below most of the island and numerous domestic wells have been completed in this zone. The boundaries of the aquifer are, in large part, constrained by the elevation of the confining unit below it, and consequently, end at the cliff slopes along the western, northern, and eastern shorelines of the island. The Semi-Perched Aquifer System is absent in some of the deep stream valleys, such as the ones extending north from the head of Eagle Harbor **(Figure 5.4)**. To the south, the aquifer is also absent when it is truncated at the bedrock contact created by an east-west trending fault that transects the island just south of Eagle Harbor. The SPA unit occurs over approximately 20 square miles, or 73 percent of the island.

The well database shows that 247 of the database's wells (approximately 25 percent) have been completed in this aquifer system. Yields from wells completed in this zone range from 1 to 349 gpm with an average of 19 gpm and a median of 14 gpm. Specific capacity values for these wells range from less than 0.1 to 99 gpm/ft-dd with an average value of 4 gpm/ft-dd and a median of 1 gpm/ft-dd. Individual wells completed in this aquifer system have moderate to high production rates. Transmissivity values range from 119 to 207,844 gpd/ft with an average value of 6,718 gpd/ft and median of 1,301 gpd/ft. Anomalously high transmissivity values are found at several of the wells in the Meadowmeer area, near the center of the island (Purdy, 1990).

Calculated hydraulic conductivity values are also moderate to high throughout most of the aquifer **(Figure 5.5).** In the area northeast of Fletcher Bay and to the south of Port Madison, conductivity exceeds 500 ft/day. Values ranges between 10 and 500 ft/day throughout most of the rest of the aquifer. Areas in the south and northeast do not have sufficient data available to determine conductivity values. Overall, conductivity values across the aquifer range from 2 to 3,481 ft/day with an average value of 146 ft/day and a median of 36 ft/day.

5.1.6 Lower Confining Unit

Below the Semi-Perched Aquifer System is a sequence of material with relatively low-permeabilities that is designated here as the Lower Confining Unit (C2). This unit is comprised of alternating layers of silts, clays, and clay-rich sands. This unit also contains discontinuous sections of till, which usually occur in the upper portion of the unit, and interspersed layers containing wood and pumice. In areas where the Semi-Perched Aquifer does not occur, the Upper Confining Unit and the Lower Confining Unit are unconformably in contact with one another. The Lower Confining Unit is laterally continuous across the study area with thicknesses ranging from 30 to 300 feet. Typically, the thickness of this unit is approximately 100 feet. The materials present within this unit typically have a low permeability, with estimated hydraulic conductivity values ranging from 10^{-1} to 10^{-7} ft/day.

5.1.7 Sea Level Aquifer System

The Sea Level Aquifer System (SLA), with boundaries shown on **Figure 5.6**, is the most widely utilized aquifer system on the island. Because the aquifer is relatively shallow and laterally continuous, a large proportion of the island's domestic and purveyor wells have been completed in this zone. Several of the island's larger purveyors have completed moderately high-yield production wells in this aquifer. Lithologically, this unit is composed largely of sands and gravels, with lesser amounts of silt, clay, and clay-rich sands.

The thickness of the aquifer reaches 210 feet below the south central portion of the island; it has an average thickness of approximately 110 feet. The top of the aquifer appears to be conformable with C2 and is interpreted to be the point where saturated materials are permeable enough to yield water to wells. This elevation ranges from approximately 40 feet above MSL below the south-central portion of the island to 230 feet below MSL at the northern end of the island. The top surface of the aquifer, although not planar, generally slopes downward from south to north below the eastern portion of the island **(See Plates 1, 2, 3 and 4)**. Below the remainder of the island, the thickness of the aquifer and the elevation of occurrence is highly variable. Although many domestic and smaller purveyor wells have been completed in this aquifer, most have not penetrated its base. Several deep wells have penetrated the base of the aquifer, at elevations ranging from 30 to 260 feet below MSL.

Because a prolific number of wells have penetrated into this aquifer system, its occurrence below the island is fairly well defined **(Figure 5.6)**. The aquifer appears to be pervasive below the majority of the island, with the exception of a localized silt occurrence in the vicinity of Port Madison at the north tip of island and most of the southern end of the island south of the major east-west trending fault that defines the bedrock high south of Eagle Harbor. Local occurrences of the aquifer are found south of the fault, but are restricted to narrow shoreline areas in an approximately 0.5-mile swath extending from Lynwood Center through the center portion of the bedrock high. These occurrences south of the fault are local in nature and not continuous with the main aquifer system north of the bedrock high. Within the upland areas extending from the southwest portion of the island across the central portion of the island to the northeast near Port Madison, the preponderance of wells are shallow and are completed in the Perched or Semi-Perched Aquifers. Because the wells in these areas do not reach the elevation of the Sea Level Aquifer, the occurrence of the SLA is not definitive here, but it is likely continuous below these uplands. North and west of the island, the seafloor below Port Madison and Port Orchard is relatively shallow and the aquifer probably extends beyond the shoreline, possibly extending out below much of Kitsap County. The occurrence of this aquifer system below other portions of the county is well documented (Becker, 1995a; and Purdy, 1995b; AGI, 1997, Kahle, 1998). To the east, the seafloor of Puget Sound is considerably deeper and limits the distance the aquifer extends offshore. This aquifer underlies approximately 23.5 square miles, or 85 percent of island's total area.

The database shows that 524 of the database's wells (approximately 53 percent) have been completed in the Sea Level Aquifer. Yields from these wells range from 1 to 260 gpm with an average of 20 gpm and a median of 14 gpm. Specific capacity values range from less than 0.1 to 234 gpm/ft-dd with an average value of 3 gpm/ft-dd and a median of 0.6 gpm/ft-dd. Individual wells completed in this aquifer system have low to high production rates. Transmissivity values range from 20 to 43,901 gpd/ft. The average transmissivity value from the current data set is 3,387 gpd/ft and the median is 1,150 gpd/ft.

Hydraulic conductivity values also range from poor to high. The highest production potential for the aquifer appears to concentrate around the margins of the system **(Figure 5.7)**. Values are between 10 and 100 ft/day in the area west and southwest of Eagle Harbor, west of Murden Cove, southeast of Battle Point, in the uplands east of Manzanita Bay, and east and northwest of Port Madison. Values exceed 500 ft/day southwest of Murden Cove and southeast of Battle Point. Overall, conductivity values range from less than 0.1 to 998 ft/day across the aquifer, with an average value of 70 ft/day and a median of 19 ft/day.

5.1.8 Confining Unit C3

The first sequence of low permeability material occurring below the Sea Level Aquifer has been designated as Confining Unit C3. This unit is largely composed of silt and clay, with lesser amounts of sandy silt and clay. Thin, discontinuous layers of water-bearing sand and gravel also occur. Geophysical logging of wells drilled through the unit show occasional resistivity signatures indicating some zones of moderate permeability. The lithologic sequence, together with the occasional presence of organic material, suggests that this unit is primarily of non-glacial origin. The thickness of this unit ranges from approximately 150 to 600 feet, with an average thickness of approximately 350 feet. In cross section, this unit appears to thicken from the east side of the island to the west, proportionally as the underlying Glaciomarine Aquifer thins in the same direction. The materials present within this unit typically have low permeabilities, with estimated hydraulic conductivity values ranging from 10^{-2} to 10^{-7} ft/day.

5.1.9 Glaciomarine Aquifer System

The Glaciomarine Aquifer System (GMA) is the shallower of the two deep aquifer systems present below Bainbridge Island. The occurrence of this aquifer system **(Figure 5.8)** is based mainly on geophysical information from deep (greater than 1,000 feet) wells. The aquifer takes its name from the occurrence of shell fragments noted in several wells drilled in the central portion of Bainbridge Island. Well logs indicate that this unit ranges in composition from clay, silt, and silt-rich sand, to sand and gravel. It also contains interspersed organic material, indicating, for at least portions of the unit, a probable non-glacial origin.

The top of the aquifer system has been encountered in several of the island's deep production wells, in various test wells, and in at least 4 domestic wells, at elevations ranging from 400 to 760 feet below MSL. Eight of these wells, including two of the domestic wells, penetrate the base of the aquifer at elevations ranging from 510 to 760 feet below MSL. The thickness of the aquifer ranges from 30 to 230 feet, with an average thickness of approximately 120 feet. It appears to generally thicken to the east. Wells completed within the Glaciomarine Aquifer System generally have low production rates. Resistivity signatures from geophysical logging are generally low, and the material comprising the unit typically has a low permeability. Few wells withdraw water from this aquifer and those that do have limited production capacities.

Because a limited number of wells have been drilled to the depth of this aquifer, the boundaries of the system are not well defined. The aquifer, as shown on **(Figure 5.8)**, is apparently restricted to three general areas. Under the northern portion of the island, the aquifer occurs near Port Madison and may extend beyond the shoreline to the north and northwest. In the central portion of the island, the aquifer is encountered across most of the island's width. In the south, the aquifer is found only in a small area south of Eagle Harbor near Creosote. South of Creosote, the aquifer system likely terminates at or near the major east-west trending fault. The aquifer likely also terminates to the east of the island in the deep trough (greater than 750 feet) of Puget Sound. This aquifer is believed to occupy approximately 9.5 square miles, or 35 percent of the island's total area.

The well database shows that 22 of the database's wells (approximately 2 percent) have been completed in the Glaciomarine Aquifer. Yields from these wells range from 2 to 80 gpm, with an average of 18 gpm and a median of 14 gpm. Pumping test data indicate specific capacity values for these wells range from 0.1 to 1.7 gpm/ft-dd, with an average value of 0.4 gpm/ft-dd and a median of 0.1 gpm/ft-dd. Transmissivity values for this aquifer are very low to moderate, ranging from 13 to 3,000 gpd/ft, with an average value of 582 gpd/ft and median of 175 gpd/ft.

In areas where data is available, calculated hydraulic conductivity values indicate mostly low production potential throughout the aquifer **(Figure 5.9)**, although moderate production may be possible in the areas west of Port Madison and south of Eagle Harbor where conductivity values range between 10 to 100 ft/day. Overall, the database shows that conductivity values range from 0.2 to 80 ft/day across the aquifer, with an average value of 14 ft/day and a median of 2 ft/day.

5.1.10 Confining Unit C4

The sequence of impermeable material underlying the Glaciomarine Aquifer System is defined as Confining Unit C4. As with Confining Unit C3, this unit is composed largely of silt and clay, with lesser amounts of sandy silt and clay. This unit also contains thin, discontinuous layers of sand which do not appear to contain any appreciable amount of water. All of the geophysical data obtained for this unit indicate it has a low permeability. Thin wood-bearing zones, together with the general lithology of this unit, suggest it has a non-glacial origin. The thickness of this unit ranges from approximately 130 to 300 feet, with an average thickness of approximately 200 feet. Where the Glaciomarine Aquifer is not present, this unit is indistinguishable from Confining Unit C3, resulting in an 800-foot plus sequence of silt and clay. As with Confining Unit C3, this unit also appears to thicken westward across the island, correspondingly as the Glaciomarine Aquifer thins to west. The materials present within this unit typically have low permeabilities with estimated hydraulic conductivity values ranging from 10^{-2} to 10^{-7} ft/day.

5.1.11 Fletcher Bay Aquifer System

The Fletcher Bay Aquifer System (FBA) is named for a pair of deep wells drilled on the island near Fletcher Bay. It is the deepest of the six main aquifers encountered on Bainbridge Island. Well logs indicate that this unit is composed largely of sand and gravel with a lesser amount of silt and silt-rich sands. Geophysical data from this zone indicate that the materials here have relatively high permeability. Several of the island's most productive wells are completed in this aquifer, including the Fletcher Bay and Sand Road production wells that supply the majority of the water for the City of Bainbridge Island system.

The top of the aquifer has been encountered in six deep wells at elevations ranging from 690 to 1,010 feet below MSL. Five of the wells penetrate the base of the aquifer at elevations ranging from 880 to 1280 feet below MSL. The thickness of the aquifer at these five wells ranges from 85 to 270 feet, with an average thickness of approximately 180 feet.

As with the Glaciomarine Aquifer, the boundaries of the Fletcher Bay Aquifer **(Figure 5.10)** are not well defined due to the limited number of wells drilled to the depth of this zone. Based on the limited data, the aquifer appears to be relatively pervasive under the northern half of the island and likely extends out beyond the shoreline some distance. To the south of Manzanita Bay and Murden Cove, the aquifer appears to generally occur only beneath the central portion of the island and in a small area between Fletcher Bay and Gazzam Lake. To the south, the Fletcher Bay Aquifer, as with the other aquifers, likely terminates just south of Eagle Harbor at or near the major east-west trending fault. This aquifer is believed to occupy approximately 15 square miles, or 55 percent of the island's total area.

The well database shows that only 14 of the database's wells (less than one percent) have been completed in this aquifer. Yields from these wells range from 53 to 668 gpm, with an average of 329 gpm and a median of 250 gpm. Pumping test data indicate specific capacity values ranging from 1 to 14 gpm/ft-dd, with an average value of 7 gpm/ft-dd and a median of 5 gpm/ft-dd. Transmissivity values are moderate throughout the aquifer, ranging from 1,750 to 22,000 gpd/ft, with an average value of 13,496 ft/day and median of 10,225 gpd/ft.

Hydraulic conductivity values also are moderate, with the exception of the area generally to the west of Eagle Harbor **(Figure 5.11)** where conductivity values are less than 10 ft/day. Conductivity values range from 4 to 74 ft/day with an average value of 44 ft/day and a median of 59 ft/day.

5.1.12 Confining Unit C5

The sequence of low permeability strata occurring below the Fletcher Bay Aquifer is defined as Confining Unit C5. Well logs indicate that this unit is composed of silt and clay and occasional thin layers of silt-rich sand. Lithologically, it appears to be very similar to Confining Units C3 and C4, and where the Fletcher Bay aquifer is absent, this unit is indistinguishable from the two overlying confining units. This unit is also likely of a non-glacial origin. The materials comprising this unit have low permeabilities with estimated conductivity values ranging from 10^{-2} to 10^{-7} ft/day. Because few wells have penetrated this unit, there is minimal information pertaining to this zone. However, it appears to be laterally extensive below most of the island with the exception of the south end where bedrock occurs.

5.1.13 Bedrock Aquifer System

The Bedrock Aquifer System **(Figure 5.12)** is a minor source of ground water for Bainbridge Island, serving only a few domestic users. Ground water in this system occurs in the interconnected fracture and joint zones within the Tertiary sedimentary rocks of the Blakely Harbor and Blakely Formations. This aquifer is only accessible south of the major east-west trending fault transecting the island south of Eagle Harbor (it likely occurs north of the fault, but at great depth).

Only seven wells in the database are completed in the Bedrock Aquifer System. The wells all have low specific capacities of less than 0.1 gpm/ft of dd. The entire aquifer has an estimated conductivity that is less than 10 ft/day.

5.2 Groundwater Flow Directions

Groundwater flow below Bainbridge Island was assessed by developing potentiometric surface maps for each of the previously defined aquifer systems. Groundwater data for the Glaciomarine and Bedrock Aquifer Systems are, at present, very limited and a potentiometric surface map could not be generated for these systems without employing excessive speculation. The groundwater flow direction within these zones could not, therefore, be accurately assessed for this project.

A potentiometric surface is an imaginary surface representing the total head occurring over an aquifer system. This surface is shown in map-view using contours to represent lines of equipotential head. For this project, a 25-foot contour interval was used for each potentiometric surface map. Head elevations across each of the aquifers were determined from the static water level information contained in well logs in the KPUD database. These static water levels, which were obtained over a wide span of time, have inherently fluctuated in response to changing pumping and environmental conditions (i.e., seasonal precipitation patterns, year-to-year variations in precipitation, fluctuating barometric pressure, tidal variations, etc). As a consequence, the potentiometric surface maps generated from these data depict a generalized orientation for each potentiometric surface along with average hydraulic gradients.

The Perched Aquifer System is largely unconfined and is constrained to the upland areas of the island by topography. As a consequence, the groundwater surface tends to mimic topography. Overall, groundwater flows in a radial pattern, moving from higher heads which generally occur in the central portion of each upland area, outward toward lower heads which occur around the margins of each zone **(Figure 5.13)**. Head elevations within this system range from a high of 334 feet MSL at the south end of the island to a low of 170 feet MSL in the northern portion of the island. The hydraulic gradient within the individual aquifers ranges from approximately 150 to 300 feet per mile. Where the Perched Aquifer System intercepts the ground surface, a portion of the ground water flowing through the system is discharged to surface water bodies or is lost through evapotranspiration. The remainder of the water, excluding that portion withdrawn through wells, infiltrates downward to the lower aquifer systems.

Groundwater flow through the Semi-Perched Aquifer System is somewhat similar to the flow in the Perched Aquifer System. Much of the Semi-Perched System is unconfined, and its occurrence is largely constrained by topography. Higher heads tend to correspond to areas of the aquifer that occur higher topographically. Heads generally taper off toward the margins of the system where the corresponding topography is lower. Groundwater flow tends to follow topography and generally flows in a radial pattern away from topographically/hydrologically high areas, outward toward the margins of the system **(Figure 5.14)**. Head elevations within this system range from a high of 190 feet MSL to a low of 49 feet MSL. The hydraulic gradient in the aquifer system ranges from approximately 75 to 450 feet per mile. Where the aquifer intercepts the land surface, a portion of the ground water discharges to surface waters or is lost through evapotranspiration. Again, the remainder that is not withdrawn through wells infiltrates downward to the lower aquifer systems.

The Sea Level Aquifer is a confined system occurring, for the most part, below sea level. Groundwater flow directions are not controlled by topography to the degree that flow within the Perched and Semi-Perched systems are. Generally, higher heads tend to occur below the inland portion of island and decrease toward the shoreline (**Figure 5.15**). Correspondingly, ground water tends to flow from the central portion of the island outward toward the shore. Head elevations within the Sea Level Aquifer range from a high of 114 feet MSL near Murden Cove to approximately sea level near the shoreline. The hydraulic gradient in the aquifer ranges from approximately 75 to 300 feet per mile. The Sea Level Aquifer discharges naturally through underwater springs through upward leakage to Puget Sound and the other surrounding waterways, or through leakage to the deeper aquifer systems.

The Glaciomarine Aquifer System is a confined system occurring at least 400 feet below sea level. Since water levels have been recorded in only 14 wells on Bainbridge Island **(Figure 5.16)**, a reliable potentiometric surface map could not be developed. However, ground water in the Glaciomarine Aquifer System likely flows eastward toward its presumed boundary in the deep trough of Puget Sound. Head elevations within the Glaciomarine Aquifer System range from a high of 37 feet MSL near Eagle Harbor to approximately sea level near Port Madison. The Glaciomarine Aquifer System likely discharges naturally through underwater springs below Puget Sound to the east of the island, or through leakage to the deeper aquifer systems.

The Fletcher Bay Aquifer System is a confined system occurring from approximately 700 to 1,300 feet below sea level. Since water levels have been recorded in only nine wells on Bainbridge Island **(Figure 5.17)**, a reliable potentiometric surface map could not be developed. However, ground water likely flows generally eastward and discharges as leakage to Puget Sound. Head elevations within the Fletcher Bay Aquifer System range from a high of approximately 40 feet MSL near Manzanita Bay to approximately sea level near Port Madison.

Limited information is available for the Bedrock Aquifer System. Most wells completed in the Tertiary bedrock of sandstone, siltstone and conglomerate are producing water in secondary fractures and joints within the consolidated formation above sea level. Water levels have been recorded in only six wells on Bainbridge Island **(Figure 5.18)**, and these range from 261 to 4 feet MSL. A reliable potentiometric surface map could not be developed using this amount of data. The groundwater flow in the Bedrock Aquifer is likely radially from high points toward the shoreline, discharging naturally through underwater springs or leakage to Puget Sound. The amount of horizontal flow into or out from other aquifer systems within the unconsolidated aquifers abutting the bedrock is unknown, but is likely a small amount.

5.3 Groundwater Level Trends

Changes in the potentiometric surface, or water table, of each aquifer are determined by temporal rates of recharge and discharge **(Dion, 1988)**. Recharge on Bainbridge Island, except for the deepest aquifers, is entirely from precipitation on the island. Discharge from the aquifers is from four mechanisms: natural discharge to springs and surface water bodies; vertical leakage to underlying hydrogeologic units; vertical leakage to Puget Sound; and water-supply well production.

Water levels from 23 monitor wells (**Figure 5.19**), completed in four of the six aquifers on Bainbridge Island were collected and plotted in hydrograph form. The water level trends were analyzed and compared to local recharge and discharge trends. The discussion of water levels includes comparisons of seasonal variation and year-to-year trends. For the seasonal variation trends, the winter "high" non-pumping levels are compared to summer "low" non-pumping levels. For year-to-year or long-term trends, the winter non-pumping levels are compared with other winter levels. The discussion of the monitor-well data analysis for each aquifer is given below in Sections 5.3.3 through 5.3.7.

5.3.1 Rainfall Trends

The spatial distribution of precipitation on Bainbridge Island is shown on **Figure 3.2**. This map was developed for the Kitsap County IWA (KPUD, 1997) and is based on the average rainfall at the Bloedel rain gage normalized to the longer period of record at the NOAA station at Bremerton. In general, the average long-term rainfall on the island ranges from approximately 34 to 36 inches per year and is greater to the southwest. There are three active precipitation gages on the island: Bloedel, Woodward School, and Meadowmeer. As noted earlier, the short-term averages are as follows: 41.01 in/yr at Bloedel from 1991 to 1998; 41.08 in/yr at Woodward School from 1991 to 1998; and 49.75 in/yr at Meadowmeer from 1995 to 1998.

The precipitation on Bainbridge Island occurs largely as rain in the late autumn and winter months. **Figure 5.20** shows the average monthly rainfall at the Bloedel and Bremerton gages. At the Bremerton gage, which has a longer period of record than the Bloedel gage, the driest month on average is July (0.82 in/mo) and the wettest month is December (8.96 in/mo). Because of the seasonal variation of precipitation in the region, most hydrologic investigations use a water-year period of analysis. This method eliminates the segregation of a winter season that a calendar-year period creates. For example, the water year of 1998 started October 1, 1997 and ended September 30, 1998. **Figure 5.21** shows the record of annual water year precipitation from 1977 to 1998 at Bremerton, and 1991 to 1998 at the Bloedel gage. The average water-year rainfall at Bloedel and Bremerton is 52.44 in/yr and 39.93 in/yr, respectively.

To make comparisons between annual precipitation and water level trends, the cumulative departure from average rainfall at Bremerton and Bainbridge Island was plotted **(Figure 5.22)**. Cumulative departure is representation of the variation in rainfall from year to year as compared to the average rainfall over a selected time frame. Positive departures from the average (e.g., more than 39.93 inches on Bainbridge) show a graphical rise and negative departures show a graphical decline. By definition, the plot ends at zero cumulative departure (the sum total of all departures from average equals zero). The total data set graphically illustrates long-term precipitation trends. Since recharge to the aquifers on Bainbridge Island come from precipitation, it can be expected that relative rainfall trends will be reflected in relative water level trends.

Figure 5.22, the plot of cumulative departure at the Bremerton, Bloedel, and Woodward School gages, indicates the overall trend of generally average rainfall between 1977 and 1984 (with two exceptions: one below-average year, and one above-average year), below average rainfall from 1984 through 1994 (with one exception), and above average rainfall from 1994 to 1998. For the overlapping periods of record for the Bainbridge Island and Bremerton stations (1991-1998), the general trends are similar. Thus, it can be assumed that the precipitation trend on Bainbridge Island before 1991 was likely similar to the trend at Bremerton. These trends will be compared with the water level trends of the monitored wells and discussed below. For the purpose of comparison, the plot of the cumulative departure at Bremerton is included on the hydrograph for each well. Note that for presentation purposes each water level hydrograph has the cumulative departure arbitrarily scaled for each aquifer and should not be misconstrued as a one-to-one relationship between water level change and precipitation change.

5.3.2 Production Trends

Since population has been steadily increasing on Bainbridge Island, and per capita water-use likely has remain relatively stable, it can be assumed that groundwater production has steadily increased. However, this cannot be confirmed because records of production from wells on Bainbridge Island are available from only a few sources. Where information is available, the production from specific wells was plotted on the hydrographs.

Production is greater in the summer months mainly because of increased demand for irrigation and other warm weather activities. Production is greater also in “dry” years and less in “wet” year. These seasonal- and yearly-production variations likely affect the magnitude of corresponding variations in water levels in the aquifers.

5.3.3 Perched Aquifer System Wells

Of the 22 monitored wells, two wells are believed to be completed within the Perched Aquifer System. The wells are North Bainbridge Water Company’s (NBWC) Well 8 (AAC832), located on the northeast portion of the island (T25/2E-11E01), and Bloedel Reserve “Farm” Well (AAC 759), located on the north end of the island (25N/2E-33B01) within the private park of Bloedel Reserve. NBWC Well 8 is located near one of the highest points on the island at an elevation of 351 feet MSL. It is completed at an elevation from 151 to 171 feet MSL (180 to 200 feet below ground). The static water level at the time of construction in 1985 was at 203 feet MSL. The water level data from December 8, 1986 to December 12, 1998 includes static and pumping water levels **(Figure 5.23)**. The static water level data show a trend of declining water levels from 1985 to 1994 (with the exception of 1991), then a rise in water levels from 1994 to 1998. This overall trend matches the pattern seen in the cumulative departure plot of precipitation **(Figure 5.22)**. This relationship indicates that water levels in this well, and presumably other wells in the Perched Aquifer, are affected by relative precipitation amounts. The magnitude of changes in water levels from year to year is larger in this well than any other of the monitored wells on Bainbridge Island. The change of approximately 20 feet from the end of 1994 to 1998 is dramatic, but is not unusual for shallow wells in the Puget Sound. Seasonal variation is difficult to quantify with the rapid year-to-year variation, but appeared to be approximately two feet in

1997. Production information for this well is not available. However it is assumed that the production has been steady or has increased with time. Since usage is presumed to be greater in "dry" years and less in "wet" years, the production from this well may have accentuated the magnitude of water level changes.

The Bloedel Reserve "Farm" Well (AAC759) is completed as an open-bottomed well at an elevation of 123 feet MSL (42 feet below ground). The earliest recorded water level for the well was 154 feet MSL (14 feet below ground) on May 27, 1964. The data set for this well **(Figure 5.24)**, which includes pumping and non-pumping water levels, is the most complete and longest running record of any well on the island, with a nearly continuous record since March 2, 1977. The non-pumping water levels have a trend that mimics the precipitation trend. This relationship indicates that water levels in this well are affected quickly by relative precipitation amounts. A change of approximately 11 feet from the annual high level in mid-1994 to the annual high level in mid-1998 occurred during a period of above-average precipitation. From 1977 to 1996, the well was used on demand at 10 gpm. The well has not been used for production since mid-1996.

The water level changes seen in North Bainbridge Water Company's Well 8 and Bloedel Farm Well are examples of what should be expected in the Perched Aquifer System: large magnitude, relatively rapid water level changes dependent on the relative amount of local rainfall. Because of the limited recharge area, and a corresponding limited storage capacity of the Perched Aquifer System, extended periods of below average rainfall will cause the water level to drop in the aquifer. If the water level drops to a critical level (below a pump intake or the top of a well screen), the capacity of certain wells would be affected. However, if the long-term trends are taken into account, the water levels have been maintained in the Perched Aquifer System in the Well 8 and Bloedel areas, allowing for sustained production with no long-term impairment of the wells or aquifer.

5.3.4 Semi-Perched Aquifer System Wells

Three monitored wells are completed within the Semi-Perched Aquifer System. These are located in the central and northern portions of Bainbridge Island. All three wells show patterns similar to the precipitation trends.

The water level trends in the three monitored wells in the Semi-Perched Aquifer System are similar. North Bainbridge Water Company's Well 1 (AAC826) is located in 25N/2E-09G. The well is screened from 62 to 67 feet MSL. The static water level at the time of construction in July 1977 was at 85 feet MSL (39 feet below ground). The data record **(Figure 5.25)**, containing predominantly non-pumping and some pumping water levels, shows seasonal variation from approximately 3 to 12 feet. The annual high water levels, occurring in late winter, show a general stable trend from 1987 to 1994. Between the winters of 1994 and 1995, the water levels rose approximately 3 feet and have been generally stable thereafter (with seasonal variations). The lowest water level recorded in the summer of 1998 was essentially equal to the original static water level in July 1977.

Meadowmeer Well 1 (AAC447) is located in 25N/2E-16A. The well is nearby to three other production wells near Meadowmeer Golf Course. Well 1 is screened from 88 to 98 feet MSL. The static water level at the time of construction in August 1969 was at 120.1 feet MSL (111.3

feet below ground). The data record **(Figure 5.26)**, containing predominantly non-pumping and some pumping water levels, shows seasonal variation from approximately 3 to 6 feet. The annual high water levels, occurring in late winter, show a general stable trend from 1989 to 1992, and a decline of approximately 3 feet between 1992 and 1993. From 1993 to 1998, the annual high water levels show a rise of approximately 7 feet. The 1998 water levels in the well are approximately five feet lower than the original water level in 1969. Monthly production from Meadowmeer Wells 1 and 2 (AAC448) between 1990 and 1997 has ranged from 2 to 14 million gallons per month and the annual production from 25.0 to 37.3 million gallons per year. Over this time period the production has generally increased while the winter water levels have risen approximately 5 feet.

The City of Bainbridge Island's Commodore School Well (AAA239), completed from 16 to 75 feet MSL, is located in 25N/2E-22R. The water level record for the Commodore Well **(Figure 5.27)** is spotty but does show an overall trend of decline from 1990 to 1994, followed by a rise until the end of the period of record in 1996.

Overall, these three wells completed in the Semi-Perched Aquifer System show a general stability or decline in water levels (with seasonal variations) from 1977 to 1994, and a general rise from 1994 to 1998. This trend also corresponds to the relative rainfall pattern. From the information gathered from the monitoring of these four wells, the Semi-Perched Aquifer System appears to have a sustainable production capacity and water level trends within the aquifer are highly dependent on precipitation trends and not, at this time, on production trends.

5.3.5 Sea Level Aquifer System Wells

Fifteen monitored wells are completed within the Sea Level Aquifer System. These are located in the central and southern portions of Bainbridge Island. Most have water level records that generally start in 1990 or 1991.

North Bainbridge Water Company's Well 6 (AAA113), located in north-central Bainbridge Island (25/2E-09K02), is a production well within a wellfield and thus is affected by drawdown interference and recent pumping by nearby wells. The record for Well 6 **(Figure 5.28)** shows erratic water levels with a general decline in annual high water levels between 1991 and 1994 of approximately 3 feet. Between 1994 and 1996, annual high water levels rose approximately 10 feet to a level above its construction water level (measured on August 15, 1979). The sporadic data record after 1996 suggests an apparent decline of approximately 5 feet. Well 6 has not been monitored since November 1997 due to an obstruction. North Bainbridge Water Company's Wells 3 and 7 also have water data available. However, calibration discrepancies make analysis of the data sets dubious at this time.

The Island Center Test Well (AAA110), located near the center of the island (25/2E-21G03), was originally drilled for KPUD as a deep test well to -1,000 feet MSL (1,300 feet below ground) but was finally completed in the Sea Level Aquifer System from –83 to –98 feet MSL. The water level record **(Figure 5.29)** shows seasonal variation of 2 to 4 feet. The highest water levels for each year, occurring in late winter, show an overall decline of approximately three feet between 1991 and 1994, and a rise of approximately three feet from 1994 to 1998. This trend corresponds to the overall precipitation trend for the same time period. The April 1998 water level is approximately one foot lower than the original static water level (in April 1975).

The Sea Level Aquifer System well (AAA108) with the most complete water level record is the Island Utilities Well 1 (25/2E-34F06), with water levels dating back to November 1987 **(Figure** 5.30). Well 1 is located on the south portion of the island near the bedrock high. It has never been, and is not currently, used for production. The water level record shows seasonal variations and a decline between 1987 and 1990, followed by a period of relative rise until 1994. After 1994, unlike any other well in the semi-perched aquifer, the general trend shows a decline, totaling approximately one foot. The annual high water level in 1998 is approximately 2 feet lower than the original SWL of 50.6 feet, measured at the time of construction in November 1987.

Bill Point Water Company's Well 3 (AAA238, 25/2E-35J03), located approximately 1¼ miles to the east of Island Utilities Well 1, has a water level record from 1990 to 1998 that includes pumping and non-pumping water levels **(Figure 5.31)**. The record shows that the non-pumping water levels generally declined approximately 3 feet between 1990 and 1994, then rose approximately 4 feet from 1994 to 1998. The highest non-pumping water levels in 1998 are apparently 9 feet below the original static water level measured in 1974.

The City of Bainbridge Island operates a wellfield of seven wells near the head of Eagle Harbor **(Figure 5.19)**. The production wells all are under flowing-artesian conditions. Therefore, the non-pumping water levels are measured using pressure gages at each wellhead. Pressure gage readings were converted to water levels and plotted. An example of a typical water level record is the hydrograph for Bayhead Well 1 (**Figure 5.32**). The hydrograph includes the total production from the Bayhead Wellfield. Because of the erratic nature of the data record, all that can be said is that annual high water levels are at or above the level seen at the time of construction of the first well in the wellfield (1967). Production from the wellfield has been as high as 34.7 mg/yr and averaged 27 mg/yr between 1992 and 1995. Data since 1996 is not currently available.

The South Bainbridge Water Company operates a wellfield located near Lynwood Center in 24N/2E-4 **(Figure 5.19).** The water level record for South Bainbridge Water System's Wells 1, 3, 6 and 7 only includes measurements taken either while the wells are pumping, while a nearby well is pumping, or after recent pumping. Therefore, the data for these wells reflects local pumping effects and levels below general aquifer water levels. Also, the number and frequency of the water level measurements are sporadic. Because of the quality of the data, the hydrographs **(Figures 5.33, 5.34, 5.35, and 5.36)** will not be discussed in detail herein except for the fact that they show an overall declining water level.

Ignoring the data from the Bayhead and South Bainbridge Water Company wellfields, which do not have adequate records, the wells completed in the Sea Level Aquifer System show a general stability or decline in water levels (with seasonal variations) from 1977 to 1994, and a general rise from 1994 to 1998. This trend also corresponds to the relative rainfall pattern. The exception to this trend is the Island Utilities Monitoring Well 1. The decline seen in the water level in this well between 1994 and 1998 is contrary to the trend of above average precipitation during the same time period. Even though the decline is on the order of just one foot, this trend may suggest that production within the aquifer has increased enough in nearby Sea Level Aquifer System wells to affect water levels in the aquifer. (Production at the Island Utilities Wellfield is from the Fletcher Bay Aquifer System 734 feet below MSL, not the Sea Level Aquifer). However, this also illustrates the need for more monitoring wells in the Sea Level Aquifer System in the southern portion of the island. Despite the prolonged, significant production from the City of Bainbridge Island's Bayhead wellfield, water levels there apparently show stable levels that are equivalent to historical levels dating back to 1967.

5.3.6 Glaciomarine Aquifer System Wells

According to the well database, there are 23 known wells completed in the Glaciomarine Aquifer System. However, there is no record available for monitored wells for the aquifer. Most of the wells completed in the GMA are single domestic wells. A prime candidate for monitoring of the GMA is the Battle Point Park Well (AAC558), located in 25N/2E-17C02.

5.3.7 Fletcher Bay Aquifer System Wells

Some of the largest producing wells on Bainbridge Island are completed in the Fletcher Bay Aquifer System. Water level data for six of these monitored wells, located from near Port Madison to Eagle Harbor, are available. The water level record for two of the wells is too sporadic, or in need of calibration, to provide an adequate data set to evaluate water level trends. The hydrographs for these two wells, North Bainbridge Water Company's Well 9 (AAB455, 25/2E-09G04) and Gail Cool's deep well (a.k.a. KPUD's Wardwell Road Test Well, AAA112, 25/2E-09J02), are presented as **Figures 5.37** and **5.38**, respectively.

The well in the aquifer system with the most complete record (nearly continuous dating back to 1980) is the City of Bainbridge Island's Fletcher Bay Observation Well **(Figure 5.39)**. The record shows a water level decline from its construction static water level in 1973 through 1989. A data gap occurs in the record, starting in 1989 and ending in 1994 when a dedicated transducer and data-logger was installed. At the end of the data gap, water levels appear to have been generally the same as they were in 1989. From 1994 to 1998, the data record includes non-pumping and pumping water levels. The non-pumping water levels rose from 1994 to 1998, presumably in response to above average precipitation. Overall the winter water levels in 1998 are approximately 10 feet higher than in 1994, but 10 feet lower than in 1973. These water level trends correspond with the timing of the overall trend of precipitation. Another influence on the water level trends is the production from the Fletcher Bay Production Well. Production steadily increased from 1980 to mid-1994, when the production was reduced significantly. Since 1994, production has been relatively steady, but lower than pre-1994 rates.

Another well with an excellent data record (dating back to 1988), is the Island Utilities' Well 1 (AAA109). Well 1, located south of Eagle Harbor (25N/2E-34F07), is completed from 734 to 789 feet below MSL. Production from the deep aquifer is currently approximately 10,000 gallons per day (equivalent to seven gpm continuously) (Scott Shelton, personal communication). The water level record includes pumping and non-pumping water levels. **Figure 5.40** shows erratic water levels with a general decline in non-pumping water levels since its construction in 1988 until 1995, followed by overall stability and perhaps a slight rise through 1998.

Bloedel Reserve "Orchard" Well (AAC606) is located on the northern end of the island (26/2E-33B03) and is equipped with a pressure transducer and data-logger. The monitoring equipment allows for a nearly continuous record of pumping and non-pumping water levels, collecting a water level every two hours. The water levels, plotted on **Figure 5.41**, show a general rise of approximately four feet from the time of construction (in June 1995) through June 1998. This rise has a similar trend to the precipitation trend over the same time period.

The City of Bainbridge Island has two major production wells in the aquifer system, Sands Road Wells 1 and 2 (AAC875 and AAC876, respectively). Pumping and non-pumping water levels are measured by transducer and stored in the City's utility information database. The hydrograph of Well 1 **(Figure 5.42)** shows relatively stable non-pumping water levels (with seasonal variations of approximately three feet) between 1990 and 1994. In the late summer of 1994, production from the two wells increased and a corresponding decline in the non-pumping water levels of approximately eight feet occurred. (This increase in production at Sands Road along with the production of North Bainbridge Water Company's Well 9 **(Figure 3.38)** may be the cause of the decline in water level seen during the same time in the Cool Well **(Figure 5.37)**, located approximately one mile northeast). Water levels in late 1995 apparently show a rise of approximately 15 feet, ending at a level above the original construction SWL recorded in 1989. It is likely, however, that a calibration error occurred between data sets. A discrepancy of approximately two feet was seen recently between the transducer readout and a manual measurement (City of Bainbridge Island, personal communication). The post-1995 data shows that the seasonal variation in Well 1 has increased with increased production but the annual high levels appear to be relatively stable. In 1998, the seasonal variation was approximately 17 feet, likely caused by the large difference between summer and winter production rates.

Wells completed in the Fletcher Bay Aquifer System show a greater sensitivity to production rates (indicating highest confinement) than any other aquifer system on Bainbridge Island. Aquifer levels decline with increases in production and rise when production decreases. For example, in the Fletcher Bay monitor well **(Figure 5.39),** aquifer water levels show a steady decline as production from the nearby production well gradually increased between 1980 and 1994. In late 1994, production was reduced at the Fletcher Bay site and aquifer levels responded by rising. Additionally, it appears that relatively stable annual production rates, as seen in the City of Bainbridge Island's Sands Avenue wellfield **(Figure 5.42)** since 1994 (after a shift from production at the Fletcher Bay wellfield), are manifested as relatively stable comparative water levels.

Fletcher Bay Aquifer System levels are less sensitive than other aquifer systems to precipitation rates, yet aquifer levels do show response to relative precipitation trends. Seasonal variations are seen in each Fletcher Bay Aquifer System well, but the magnitude of the variation is difficult to quantify because of the likely influence of seasonal production differences. Since production from the Fletcher Bay Aquifer System is the major portion of the City's supply, it is imperative to accurately monitor water levels and compile production data for the wells that are completed in this aquifer.

SECTION 6
LEVEL II ASSESSMENT
GROUNDWATER QUALITY ASSESSMENT

An assessment of the groundwater quality was conducted using the an updated version of the database developed by Kitsap Public Utilities District No. 1 for the Kitsap County Initial Basin Assessment (1997). This database was a combination of water quality databases acquired from five sources: Kitsap PUD (private testing program, 1990 to 1994), Bremerton-Kitsap County Health Department, U.S. Geologic Survey's Bainbridge Island Study (Dion and others, 1988), USGS WATSTORE database, and Kitsap County Ground Water Management Plan (KCGWAC, 1991). Most of the wells were sampled once, and thus no time-series analysis was performed as part of this study.

In general, groundwater on Bainbridge Island is of good quality. With the occasional exception for high iron and/or manganese concentrations, most of the wells meet State drinking water standards. A comparison of the State drinking water standards and the water quality results reported in the database is shown on **Table 6.1**. As in much of the Puget Sound area, drinking water standards on the Island are routinely exceeded for iron and manganese. The water is generally soft to moderately hard (less than 120 mg/l as $CaCO_3$, Dion and others, 1988). The geographic distribution of the wells with water quality data is shown on **Figure 6-1**.

Table 6.1. Water quality testing results on Bainbridge Island (source: KPUD well database, July 1999).

Parameter	MCL[1]	Total number of wells sampled	Wells exceeding MCL	Percent exceeding MCL
Chloride-Cl	250 mg/l	206	1	<1
Conductivity	700 μmhos/cm	275	1	<1
Iron- Fe	0.3 mg/l	276	63	23
Manganese- Mn	0.05 mg/l	277	103	37
Nitrate- NO_3-N	10 mg/l	289	0	0

[1] MCL- Maximum Contaminant Level for nitrate; Secondary Maximum Contaminant Level for chloride, iron and manganese and conductivity, set for aesthetic, cosmetic, and technical reasons and are not considered health-threatening at the MCL.

To assess the general groundwater quality of Bainbridge Island, several parameters were used. These parameters were chloride, specific conductivity, iron, manganese, and nitrate. Spatial distributions of wells with significant levels of each of these parameters were plotted. Chloride and specific conductivity are used as indicators of seawater intrusion. Iron and manganese occur naturally and are indicators of aesthetic qualities of waters. Nitrate is used as an indicator of contamination from on-site septic/sewage, animal wastes, and/or fertilizer applications. The geographic distributions of significant levels of these parameters were plotted on **Figures 6-2, 6-3, 6-4 and 6-5**. In the case of multiple analyses on a single well, the measured values on the plots represent the most recent measurement.

6.1 Chloride

The secondary Maximum Contaminant Level (MCL) for chloride has been set at 250 mg/l, the level at which most people can detect a salty taste. The background level for chloride on Bainbridge Island is generally below 25 mg/l. Concentrations above this level may, if near the shoreline, indicate incipient seawater intrusion. Wells with high chloride levels that are located in the interior portions of the island may indicate local geologic (connate) conditions or septic drainfield contamination, neither of which are indicative of seawater intrusion. Fourteen wells with levels of greater than or equal to 25 mg/l were plotted on **Figure 6-2**. The distribution of the fourteen wells indicates that no regional seawater intrusion is occurring on Bainbridge Island. The well with the highest level of chloride at 351 mg/l (the only well to exceed the MCL of 250 mg/l) is located along the shoreline Eagle Harbor. The high chloride result from this well may indicate a local occurrence of seawater intrusion.

6.2 Specific Conductivity

As with chloride, specific conductivity is often used to indicate seawater intrusion, but is a less accurate indicator due to the fact that a variety of constituents may be responsible for high values. One sampled well on Bainbridge Island exceeded the State drinking water standard for specific conductivity of 700 μmhos/cm.

Wells with conductivity values of equal to or greater than 500 μmhos/cm were also plotted on **Figure 6-2**. Only five wells meet this threshold. Most are located near the shoreline and may be associated with the zone of diffusion, which forms a transition between fresh ground water and seawater (see Section 6.5). Wells with high conductivity values that are located in the interior portions of the island may indicate local geologic (connate) conditions and are probably not indicative of seawater intrusion.

6.3 Iron and Manganese

Iron and manganese are common constituents of ground water in Puget Sound region aquifers. They are derived from the weathering of rocks and minerals within the groundwater flow system. Iron and manganese are frequently found in association with each other. Dissolved iron and manganese are limited to trace concentrations in oxygenated ground water, but occur at significant concentrations under reducing conditions. Elevated iron and manganese are frequently associated with each other. Iron and manganese are regulated as secondary contaminants with MCL's of 0.3 and 0.05 mg/l, respectively. Concentrations above these MCL's are generally not considered a health problem, but can encrust plumbing and stain laundry or dishes. It should be noted that the turbidity of water samples can greatly affect the concentrations of these two parameters causing false high readings. Many of the water quality data from the database are from new wells. Water from new wells can often have higher turbidity than water from wells that have been used for some time. This may increase the frequency of iron and manganese data that exceed the MCL and thus exaggerate the distribution of high iron and manganese from wells on Bainbridge Island.

Wells with iron concentrations above the MCL of 0.3 mg/l were plotted on **Figure 6-3**. The geographic distribution of these 63 wells is fairly uniform over the entire island. However, clusters of wells with iron concentrations above 1.0 mg/l occur near Battle Point Park in sections

25N/2E-17 and -20, and south of Eagle Harbor in sections 25N/2E-34 and -35. The relatively high concentrations seen in these areas are likely a result of the characteristics of naturally occurring deposits at these locations. Differentiation of the iron concentrations versus completion aquifer did not reveal any pattern of the vertical distribution of iron.

Wells with manganese concentrations above the MCL of 0.05 mg/l were plotted on **Figure 6-4**. The geographic distribution of these 110 wells is also fairly uniform over the entire island, although the northwest portion of the Island from Fletcher Bay to Port Madison has somewhat higher concentrations than elsewhere. Differentiation of the manganese concentrations versus completion aquifer did not reveal any pattern in the vertical distribution of iron.

6.4 Nitrate

Nitrate can indicate the occurrence of groundwater contamination from sewage, animal waste, industrial waste, and/or fertilizers. The State drinking water standard for nitrate as Nitrogen is 10 mg/l. Out of the 288 wells sampled, no wells were found to exceed the MCL. The geographic distribution of wells with nitrate concentrations greater than 2.5 mg/l, a concentration above the assumed background level, is shown on **Figure 6-5**. These 13 wells are fairly evenly distributed on the island.

Improperly constructed wells can contribute to groundwater contamination. Wells constructed before the mid-1970's were not required to have a surface seal. An improper seal, or no seal, can allow the vertical movement of contaminated water along the outside of the well casing into the well. This potential exists especially for shallow wells. The wells with elevated nitrate were shown to have a strong correlation with shallow wells. All but five wells that showed nitrate above 2.5 mg/l are completed at less than 100 feet below ground.

6.5 Seawater Intrusion

Seawater intrusion occurs when marine water displaces fresh water inland in coastal areas. In aquifers that are hydraulically connected to the sea, a transition zone referred to as the "zone of diffusion" marks the boundary between fresh ground water, which floats upon denser seawater, and seawater. The position of this boundary largely depends on the properties of the aquifer and the amount of fresh ground water being flushed through the system and is controlled by the dynamic balance between sea level and water levels in the aquifer. The fact that the zone of diffusion is not a sharp interface but, rather, is a mixing zone, is the result of shifts in the equilibrium between the fresh and salt waters which, in turn, result from diurnal variations in sea level (tides) and long-term variations in groundwater levels. In a natural, unaltered groundwater system, the zone of diffusion can migrate inland when groundwater levels reach a seasonal low, and recede seaward when groundwater levels recover.

The dynamic balance between fresh water and seawater can be altered by human activities, which influence groundwater levels. Groundwater levels are lowered by both pumping and land-use practices which reduce recharge to underlying aquifers. Both of these activities intercept water and can affect the position of the zone of diffusion. The lowering of groundwater levels will cause the zone of diffusion to migrate landward, causing "lateral intrusion." If pumping (and localized aquifer drawdown) occurs directly above the zone of diffusion, deep seawater can be drawn upward towards the pumped well, in a process called upconing. In this case, the zone of diffusion rises directly below a well, and areas between the well and the shoreline may appear to be unaffected.

Incipient seawater intrusion is indicated by an increasing salinity in ground water. Monitoring for seawater intrusion often involves regular measurement of the electrical conductivity and/or chloride concentration in wells. Although seawater intrusion is a reversible process, longer periods of time are typically required to flush saline water out of the system than for intrusion to occur in the first place. Reversal is especially slow where intrusion occurs on a regional scale. Prevention of seawater intrusion is by far the preferred option.

Based on the current water quality data for the parameters of chloride and specific conductivity, there is no evidence of extensive seawater intrusion on Bainbridge Island. Nor is there evidence of increasing salinity based on comparison of the USGS study of Dion and others (1988) and recently collected data in the KPUD's water quality database. This result should not be unexpected based on the amount of recharge the island receives versus the amount of water the island uses (see Section 9).

With little industry and limited farmland, Bainbridge Island's primary land use is residential. The area of densest residential zoning occurs in the vicinity of Winslow and around the periphery of the island where waterfront property is highly valued. According to a 1992 land use inventory, slightly over half of the Island had been developed to some degree (51 percent). Seven percent was devoted to rights-of-way, and the balance (42 percent) was undeveloped.

Goals and policies outlined in the Land Use Section of the **City of Bainbridge Island Comprehensive Plan** are intended to preserve the rural character of the island, protect the water resources, foster the diversity of residents, balance the costs/benefits to property owners in land use decision making, and base development on the understanding that the island's environmental resources are finite and must be maintained at a sustainable level.

7.1 Population Projections

An island-wide population of 24,280 residents has been projected by the Bainbridge Island Long Range Planning Department by the year 2012. In adopting its 1994 Comprehensive Plan, Bainbridge Island chose to direct 50 percent of its anticipated growth to the Winslow area where public facilities and service capacities already exist. Another five percent of growth is to be directed to three neighbor-hood centers: Rolling Bay, Lynwood Center, and Island Center. The remaining 45 percent is to be absorbed throughout the island.

7.2 Directing Growth to Urban Center at Winslow (GMA)

Approximately 7,000 residents are anticipated to live in Winslow by the year 2012. To ensure that Winslow receives 50 percent of the projected growth in Winslow, a Transfer of Development Rights program has been initiated (Ordinance 99-19). The mechanism of the Transfer of Development Rights (TDR) has been used elsewhere to preserve farmlands threatened by urban and suburban development. This allows a property owner in a designated "sending area" to sell the right to develop single family homes ordinarily permitted by the underlying zoning. These rights are then transferred to a "receiving" area for the purpose of increasing the density there.

Designated receiving areas are generally urban centers where public utilities already exist, in this case Winslow. A developer may purchase rights from a sending area and build additional units in the receiving area beyond the number otherwise allowed. For example, a developer could propose multi-family housing in an area that allows 14 units per acre and by applying purchased development rights from a sending area could increase the density up to 28 units per acre. Initially, sending areas will be farmlands only, although critical areas will also be designated as sending areas. The program is voluntary and development rights may also be donated from any area at any time. This is the primary mechanism to direct growth to the urban center at Winslow. There is also a special planning district at Lynwood Center where up to twelve units per acre with commercial use may be allowed if served by public water and sewer. Higher density may be achieved with affordable housing. (City of Bainbridge Island Ordinance 97-16)

7.3 Zoning

Roughly 95 percent of the Island is zoned for residential use. **(See Figure 7.1)** Low density (one unit per 2.5 acres or R-0.4) residential use is designated over the greater part of the Island. Along the shorelines and in the areas of concentrations at Fletcher Bay, Manzanita Bay, and Port Madison zoning varies between one and two units per acre (R-1 or R-2). One small area, north of Fay Bainbridge State Park, allows six units per acre. Additionally, the Fort Ward Area is the only residential area isolated from a commercial district with zoning that allows up to four units per acre. The remaining five percent of the Island is zoned Light Manufacturing (LM), Neighborhood Service Center (NSC), or is limited to the current use. In Winslow a Mixed Use Town Center (MUTC) is intended to have a residential component as well as commercial viability. Residential densities in Winslow range from two units per acre up to 28 units per acre through the use of TDR and other density bonus programs.

7.4 Critical Areas

As part of its planning process, the **Bainbridge Island Comprehensive Plan** studied and mapped aquatic resources (wetlands and streams), frequently flooded areas, geologically hazardous areas, and fish and wildlife habitat. (Geologically hazardous areas are those where slopes are 40 percent or greater). For areas with slopes between 15 and 40 percent, geotechnical analysis has to be completed before building permits will be issued). One of the goals of the Comprehensive Plan is to protect the island's natural systems. A Critical Area Overlay District (CAOD) has been designated for areas considered environmentally sensitive, including critical aquifer recharge areas, priority wetlands, streams and creeks. Along with farmlands, the CAOD will be reviewed for the TDR program in September 2001. Roughly 11 percent of the island is in wetlands (244 have been mapped) or hydric soils. Wetlands connected to streams or ditches make up 80 percent of the wetland acreage. Approximately 23 percent of wetland acreage is in areas already in residential use. The City of Bainbridge Island has adopted a **Critical Areas Ordinance** intended to prevent disturbances within the areas identified above. This includes definitions of sensitive areas, determines buffer widths by category, includes a mitigation process, and lists replacement ratios for wetlands. The City's **Municipal Code** Section 16.20 further discusses policies related to protection of Critical Areas.

7.5 Land Cover

The dominant land cover type is tree-covered (73 percent or 12,849 acres). This type includes home sites when the cleared area is less than one acre. Grass/shrub cover types are located on 20 percent of the island, concentrated in valley bottoms but also on small parcels in all watersheds. Developed areas with impervious surfaces cover about six percent of the island, mostly in Winslow. **(Bainbridge Island Watersheds, 1995)**

7.6 Percentages of Land Use

7.6.1 Residential uses occupy the largest percentage of land on the Island (75 percent). Single-family homes account for 84 percent of residential units and multi-family units account for 16 percent, mostly concentrated in Winslow where densities up to 14 units per acre are permitted. The main population center will continue to be Winslow, which in 1998 had a population of about 4200.

7.6.2 Commercial/Light Manufacturing developments occupy 325 acres (two percent) of land use. The major commercial uses are retail and service businesses in the Winslow area. Light Manufacturing and Water Dependant Industrial use occupies 150 acres, the largest concentration being along Day Road near SR-305 (75 acres). Also included in this category are the Washington State Department of Transportation (WSDOT) ferry repair facility, which includes a marine and boat yard near Winslow in Eagle Harbor. The Pacific Resources (formerly Wyckoff) area at the southeast entrance to Eagle Harbor is no longer being used for industrial purposes.

7.6.3 Agricultural uses occupy roughly six percent of the land uses. Approximately 1,005 acres are devoted to active commercial farming and pastureland. While there are no agricultural lands of long-term commercial significance, there are many small farms scattered throughout the Island. Berry, tree, and organic vegetable farms are the most common types of agricultural pursuits. Salmon production and aquaculture are also features of local agriculture.

7.6.4 Forest Land occupies approximately 385 acres (two percent) of the land use. These private forest lands are dedicated to long-term timber management as “open space timber” or “designated forestland” in Kitsap County’s Current Use Property Tax Exemptions Program. Landowners with more than five contiguous acres primarily devoted to growth and production of forest products can apply for enrollment as “open space timber” or “designated forestlands”. The Island has no public or private industrial forest land.

7.6.5 Recreation Land occupies approximately 1,300 acres (seven percent) of the Island. Of these acres, public recreation use occurs at two Washington State Parks, Fort Ward and Fay Bainbridge, and the remaining public recreation land (approximately 900 acres) is under the Bainbridge Island Parks and Recreation District and the City of Bainbridge Island. Private recreation holdings include three golf courses as well as the Bloedel Nature Reserve. Private marinas and associated small parcels are also included in this acreage. An environmental education center of 326 acres at the south end of the Island has recently been added to this land use category.

7.6.6 Transportation Corridors make up roughly 1,084 acres (six percent). SR-305 is the region’s main transportation corridor, linking Bainbridge Island to the Kitsap Peninsula. This six-mile highway contains 145 right-of-way acres and bisects the Island from northwest to southeast. The state has one park-n-ride lot along the route. The remaining acreage of roads is in the 137 miles of paved roads throughout the Island. The Washington State Department of Transportation ferry terminal at Winslow connects the island to the Seattle area.

7.6.7 Public Facilities occupy 350 acres (two percent) of the land use. Miscellaneous uses such as schools, cemeteries, library, fire stations, power substations, utilities, and government services occur at these sites.

7.7 Comprehensive Plan

The **Comprehensive Plan** in its *Natural Environment* section lists those areas considered important to preserving the natural environment while still allowing compatible uses to occur. These include geologically hazardous areas (landslide, erosion, and seismic hazard areas), watersheds (including wetlands, streams, and groundwater as well as aquifer recharge areas), and fish and wildlife habitat. Among the goals of the Comprehensive Plan are preserving open space and the character of the natural landscape, preserving environmentally sensitive areas, protecting the water resources, and preserving and encouraging agricultural activities.

7.8 Residential Densities and Recharge Areas

Because the island is entirely dependent on groundwater for its potable water supply, those areas where underlying pervious material allows recharge to aquifers are considered important in the context of land use. Retaining the recharge capabilities of the soil and substrate could be encouraged through restrictions on the amount of surface area property owners could pave or otherwise cover. The **Bainbridge Island Municipal Code** (16.08.050) states that "Development which may adversely affect aquifer recharge areas or drainage areas in the Bainbridge Island vicinity should be prohibited or restricted".

7.8.1 Perched Aquifer

This aquifer is generally located in the upland areas of the island and provides water for approximately four percent of the island's wells. Infiltration rates for the Perched Aquifer are high (greater than 20 inches a year) in the Winslow area as well as on the north end of the island (between the Agate Passage Drainage Basin and Port Madison Drainage Basin) where zoning is less dense (one unit to two and a half acres). **(See Figure 7.2)** Along the border between Port Madison Drainage Basin and the Sunrise Drainage Basin, where zoning varies between one unit per acre to one unit to two and a half acres, is a zone with moderate infiltration capabilities for the Perched Aquifer. The remainder of the infiltration areas for this aquifer generally occur where zoning allows one unit per two and a half acres. This aquifer provides base flow for most of the island's streams.

7.8.2 Semi-Perched Aquifer

This aquifer covers roughly 73 percent of the island and provides water for 25 percent of the island's wells. It also provides water for some of the Group A water service associations. The greater part of this aquifer underlies areas zoned one unit per two and a half acres. **(See Figure 7.3)** While one corner of it having high infiltration rates is found under the Winslow area, the remainder underlies most of the length of the island (with the exception of the very southern end). Areas with high infiltration rates generally correspond with those for the Perched Aquifer, but the greater part of infiltration (although low) occurs throughout the island where zoning is one unit per two and a half acres.

7.8.3 Sea-Level Aquifer

Figure 7.4 shows that this aquifer occurs under all zoning classifications. Much of Winslow covers areas with both low and high infiltration capabilities. Areas around the edge of the island where zoning is either one or two units per acre generally have low infiltration rates for this aquifer. The three neighborhood service centers also occur over this aquifer and are allowed somewhat greater densities. Areas of highest infiltration correspond with those for the Perched and Semi-Perched Aquifers. This aquifer underlies approximately 85 percent of the island and provides water for 53 percent of the wells as well as for the major purveyors.

7.9 Well-Head Protection Zones

To assure water quality withdrawn from specific wells, an area is commonly defined around them that denotes the amount of time it would take contaminants entering the surface or sub-surface surrounding the well or well field that supplies a public water system to reach underlying water resources. Kitsap County has defined well-head protection zones for three areas on the island **(See Figure 7.5)**. At the time of this writing the City of Bainbridge Island has no restrictions on development or land use within areas defined as Well-Head Protection zones.

SECTION 8
LEVEL II ASSESSMENT
WATER BUDGET ANALYSIS

A water budget is an accounting of the major components of a hydrologic system and includes an assessment of the interactions between surface water and groundwater systems. Typically, some quantities (e.g., surface water inflows and outflows) are relatively easily determined because they can be directly measured. However, other quantities, including groundwater recharge and evapotranspiration) are difficult to measure directly. One common means of determining groundwater recharge or evapotranspiration, then, is to obtain values or estimates for the other inputs to and outputs from the system and solve for difference. Water budgets often have the general form:

$$\text{Inputs} = \text{Outputs} + \text{Recharge}$$

Specific estimates of the inputs (e.g., precipitation) and outputs (e.g., evapotranspiration and surface runoff) are then substituted into the equation. The equation is then rearranged in order to solve for the parameter of interest, as in the following simplified equation:

$$\text{Recharge} = \text{Precipitation} – \text{Evapotranspiration} – \text{Runoff}$$

Various means for determining these inputs and outputs exist. The values placed in the equation may consist of general values determined for an entire basin, or a series of site-specific equations designed to account for each parameter. Once these variables have been determined, the results for a specific basin can often be exported to other, adjacent basins via regression equations.

In the Initial Basin Assessment (IBA) (KPUD and others, 1997) the water balance equation was used to estimate recharge in each subarea. Precipitation rate for each subarea was based on the long-term isoheytal map developed for the IBA. For the Bainbridge Island subarea, precipitation averages 35 inches/year. Evapotranspiration was calculated to be 15 inches/year using the Blaney-Criddle method (Dunne and Leopold, 1978), which uses crop, latitude, and temperature data. Runoff, based on studies in south King County (Woodward and others, 1995), is assumed to be approximately 20 percent of precipitation which equates to 7 inches/year. Thus, the water balance equation for the Bainbridge Island Subarea in the IBA is:

$$\text{Recharge} = 35 \text{ in/yr} - 15 \text{ in/yr} - 7 \text{ in/yr}$$
$$\text{Recharge} = 13 \text{ in/yr}$$

This amount represents the estimated total recharge to the ground water system. The recharge occurs when water infiltrated into the soil passes through the root zone and migrates downward to a local or regional water table. Physiography and subsurface conditions control whether the recharge continues downward to deeper aquifers or discharges to local surface water bodies.

8.1 Spreadsheet Estimations of Recharge

In an effort to obtain a more accurate estimate of groundwater recharge, two independent methods of estimating groundwater recharge were utilized. The first method utilized a series of regression equations developed by the USGS from the results of a computer model of the Big Soos Creek Basin, King County, WA. The second, more empirical method was originally developed for the Bangor area, Kitsap County, WA. It is based on general hydrogeologic principles and observations. Both methods were used to investigate groundwater recharge rates in an effort to develop a realistic estimate of recharge.

8.1.1 Regression Recharge Estimate

Woodward and others (1995) presents the results of a Deep Percolation Model (DPM) for the Big Soos Creek Basin, as well as a series of regression equations used to extrapolate the model results to unmodeled basins in southwestern King County. In their analysis, an equation was developed for each combination of land use and soil type/geology, using the independent variables of annual precipitation and the available water capacity of the dominant soil.

For this study, a model grid was superposed over maps of annual precipitation, geology, land use, and soil type and values for each parameter were assigned to each cell. A Microsoft Excel spreadsheet model was then constructed using Visual Basic programming code, that automatically looked up the soil type/geology and land use for each cell, and used a series of sorting criteria to look up the assigned values of precipitation and available water capacity (AWC). The spreadsheet then applied the appropriate regression equation developed by Woodward and others (1995). It should be noted that the AWC, as used in the Woodward and others (1995) regression equations and in this study, is weight-averaged by soil horizon. Specifically, the average AWC (in inches of water/inch of soil) for each soil horizon in a particular soil type, listed in the SCS Soil Survey (U.S. Dept. of Agr. S.C.S., 1980), was multiplied by the maximum horizon thickness (in inches). The resulting quantity of water (in inches) for all horizons was summed and then divided by the total profile thickness (in inches), yielding a weight-averaged AWC for the entire soil profile (in inches of water/inch of soil).

The average of the calculated regression recharge estimate for all active model cells was then determined as the average recharge rate across the area. The result of this spreadsheet model **(Figure 8-1)** is an estimate of 16.4 inches of recharge annually, which compares favorably with the 13 inches annually indicated in the Kitsap County Initial Basin Assessment (KPUD, 1997).

8.1.2 Empirical Recharge Estimate

Becker (1995) presented an empirical method of estimating annual recharge in the Bangor area of Kitsap County. This method incorporates estimates of average annual precipitation and evapotranspiration with assumptions regarding runoff, land use, and the infiltration potential of different materials.

However, many parameters in this method are dependent upon multiple factors. For instance, recharge to a model cell is a function of the quantity of precipitation falling on that cell and the infiltration potential of the surface material in that cell. However, not all precipitation is available for infiltration, as some portion of the water runs off and out of the cell and some portion of the water is lost to evapotranspiration. The portion of water that runs off is itself a function of the conductivity and slope of the surface materials. The conductivity of the material is a function of composition and the vegetation cover and land use. This empirical estimation process, therefore, involves a step-by-step accounting of the fate of precipitation on the study area that incorporates all of these factors. Although the majority of values for this recharge estimate can be obtained from geologic maps and soil surveys, this method does require some hydrogeological expertise to assign realistic hydraulic conductivity values to surface materials in both developed and undeveloped areas.

In similar fashion to the regression recharge estimate, the model grid was superimposed over maps of annual precipitation, topography, and soil type and a value for soil type was assigned for each cell. A Microsoft Excel spreadsheet model was then constructed that evaluated numerous expressions for each cell in order to determine the quantity of precipitation that ultimately recharges the groundwater system.

The average of the empirical recharge estimates for all active model cells, which is equal to the average recharge rate across the area, was then determined. The result of this spreadsheet model is an estimate of 12.9 inches of recharge annually, virtually identical to the 13 inches annually derived in the Kitsap County Initial Basin Assessment (KPUD, 1997).

8.2 Implications of Recharge Estimates

The groundwater recharge results found using the three methods discussed above are on the same order of magnitude. However, the recharge rate of 16.4 inches per year, found using the regression recharge approach, is 27 percent greater than the result found using the empirical recharge method (12.9 inches per year). For perspective, the difference of 3.5 inches per year represents 5,133 afy, or an amount greater than the estimated, future total demand of Bainbridge Island in 2014 (3,329 afy, or 2.27 inches of recharge per year; see Section 9.7.2). Using a recharge of 13 inches per year applied to the entire island, the total groundwater resource is estimated to be approximately 19,000 afy. It should be noted that groundwater recharge furnishes base stream flows and water discharged to the sound via marine springs in addition to water pumped from wells.

9.1 The Water Right Process

Since 1917 for surface water and 1945 for ground water, water rights filings consist of three basic stages. The first stage is an application, which establishes a request for a specific quantity of water and establishes a priority date. The application alone is not a water right, but it does establish the priority data for any subsequent allocation. The second stage is a permit, which follows an investigative procedure by Ecology. The permit is a water right and allows construction and beneficial use of the water. The permit documents Ecology's opinion that water is available for beneficial use, and such use will neither impair existing rights, nor be detrimental to the public welfare. The permit authorizes an instantaneous withdrawal rate (Qi) from the source, expressed as gallons per minute (gpm) from wells or cubic feet per second (cfs) from surface water. The permit also authorizes an annual allowance (Qa) expressed as acre-feet per year (afy). The third and final stage of a water right process is the certificate, which is granted following the determination by Ecology that all conditions have been met, and the water has been put to beneficial use. For a certificate, Qi and/or Qa allowances may be decreased from the permit amounts, subject to information developed by Ecology. However, under no circumstances is the applicant able to increase the amount beyond that advertised during the application period.

Another facet of the water right process is the water right claim. This process allows users of water developed before 1917 for surface water and 1945 for ground water to register withdrawals. To preserve active water withdrawals developed prior to these two dates, the state required individuals to register withdrawals during a "claims period" between 1969 and 1974, and again in 1998. A water right claim is not authorization to use water, but rather a statement of claim to water withdrawal generally developed prior to the establishment of the water right process. In most cases, the validity of existing claims has not been determined. Thus, a water right claim is not necessarily a water right, but just a claim for use of water. A water right claim on file with Ecology may or may not represent a valid water right. The validity of a claim cannot be determined until a court rules on it through an adjudication process. The amount of annual usage for each claim also is not established. Thus, claims on Bainbridge Island, numbering 1,200, could not be included in the analyses of water rights by purpose of use, spatial distribution, or usage amounts. However, the usage amounts for the claims is estimated in Section 9.7.2, which presents a discussion of actual usage based on population statistics.

Another category of water rights that cannot be quantified accurately as part of this assessment is groundwater withdrawals exempt from permit requirements. Use of 5,000 gallons or less a day of ground water without a permit is allowed for one or more of the following purposes: irrigation of less than one-half acre, watering stock, single domestic, multiple domestic, and industrial water supply. Exempt users have water rights with priority dates, but are not required to apply for a water right. Most exempt users withdraw far less than 5,000 gallons per day. The quantification of exempt uses is estimated in Section 9.7.2.

9.2 Water Rights Through Time

A total of 211 water rights have been certified, permitted, or applied for on Bainbridge Island, 59 surface/reservoir and 152 ground water. The water rights on Bainbridge Island, collected from the Department of Ecology's database, are listed in **Appendix B**. **Appendix B**, for purpose of completeness, also lists cancelled and relinquished rights. However, the Qi and Qa totals listed in the database for these cancelled and relinquished rights are not included in the totals discussed below.

A plot of the cumulative total of instantaneous quantities (Qi) for all rights on Bainbridge Island **(Figure 9.1)** shows an increase at a progressive rate over time, with two periods of larger than average growth in the early 1970's and the late 1980's. Currently, the cumulative total of permitted and certified groundwater and surface water allocations on Bainbridge Island is 8,878 gpm. Surface water right allocations show a "plateau" since the mid-1960's, gradually reaching its current total of 2,089 gpm. This is the result of the lack of surface water right applications. Ground water right allocations plateau in the early 1990's. This leveling-off is a direct result of the lack of water right processing by Ecology, with allocations having all but ceased since 1993. Currently, accumulative groundwater right applications (there is only one surface water right application for 100 gpm pending) since 1990 total 2,980 gpm. Note that the total shown for the water right applications are for the totals applied for which is likely to be less than the quantity eventually allocated. If a permit is issued for these applications, the Qi will likely be less than the applied-for quantity.

For the annual quantities (Qa) allocated on Bainbridge Island, the cumulative total of certified and permitted water rights through time is shown on **Figure 9.2**. This graph also shows the steady increase in allocations on Bainbridge Island, with a significant increase in groundwater rights in the early 1970's. No new annual quantities for groundwater rights have been allocated since 1993. For surface water rights, as stated above, allocations have not significantly increased since the early 1960's, and no new quantities have been allocated since 1987. Currently, the total certified and permitted ground and surface water rights on Bainbridge Island total 7,561 afy.

Figure 9.2 illustrates the large relative difference in amounts of annual allocations for surface/reservoir and ground water (ground water = 5,378 afy and surface/reservoir water = 2,183 afy). The difference will likely grow in time. No additional allocation of surface water is anticipated and cancellation of surface water rights or conversion to groundwater rights is expected to occur because of instream flow, fisheries, and other concerns.

9.3 Instream Resources Protection Program

The Instream Resources Protection Program (WAC 173-515) affects two streams on Bainbridge Island. The affected streams are unnamed stream #434, a tributary to Murden Cove and unnamed stream #461, a tributary to Fletcher Bay. Both of these streams are closed year-round to further consumptive appropriation. The Instream Resource Protection Program's purpose is to retain perennial streams with flows and levels necessary to provide for preservation and protection of wildlife, fish, scenic, aesthetic and other environmental values, and to preserve water quality (WAC 173-515-020).

On Bainbridge Island, salmonid species have been noted in several streams. The following discussion is taken from the **Kitsap County Initial Basin Assessment** (KPUD, 1997) and a more detailed description is found in the **Bainbridge Island Watersheds** (Puget Sound Cooperative River Basin Team, 1995). None of the streams on Bainbridge Island have official names, but they have been designated with numbers by Garling (1985). These numbers are used in WAC 173-515 and in this assessment. In the **Bainbridge Island Watersheds** a different numbering scheme is presented, with local names given where known. The comparison of the streams is shown on **Table 9.1**. **Figure 9.3** shows the location of the main streams on Bainbridge Island, with those with salmonid use highlighted. Fletcher Bay stream #461 ("Springbrook Creek") supports out-migrating steelhead, cutthroat trout, coho, and chum salmon. The largest stream on the island, stream #463 ("Little Mosquito Bay Creek" or "Big Manzanita Creek"), which outlets into Manzanita Bay, supports cutthroat trout, coho, and chum salmon. Cutthroat trout and coho utilize the largest stream (#429) in the Port Madison drainage. The primary stream that drains into Murden Cove (#434) and its tributaries contain some of the best fish habitat on the island and support cutthroat trout, coho, and chum salmon. All of the streams in Blakely Harbor drainage, except the one draining Mac's Dam, have insufficient flow to support salmonids. The Mac's Dam stream (#443) supports coho and cutthroat trout. Chum salmon and cutthroat trout have been identified in stream #437 ("Canyon Creek", "Winslow Creek", or "the Ravine") in the Eagle Harbor drainage.

Table 9.1: Stream Name/Number Correlation Table

Local Name (PSCRBT, 1995)	Bainbridge Island Basin Assessment Map Reference No. (Garling, 1965; WAC 173-515)	PSCRBT, 1995 Reference No.
---	427	0319
---	429	---
---	431	0320
---	434	0321, 0322, 0323
Canyon Creek, Winslow Creek, The Ravine	437	0324
---	438	0325
---	439	0326
Mac's Dam	443	---
---	452	---
---	459	0329
Springbrook Creek	461	0340, 0341, 0342
---	462	0343
Little Mosquito Bay Crk, Big Manzanita Crk	463	0344, 0345

9.4 Surface Water Rights

The spatial distribution of the total allocation of instantaneous quantities (Qi) of surface water rights on Bainbridge Island is shown on **Figure 9.4**. The distribution appears to be fairly random over the entire island. Although nearly all of the "major" streams on the island have surface rights associated with them, most rights are on small streams of limited (possibly ephemeral) flows and drainage areas, or springs (e.g., Section 32 of Township 25 north, Range 2 east).

The 59 permitted and certified surface and reservoir water rights on Bainbridge Island, listed in **Appendix B**, total 4.65 cfs (Qi) and 2,183 af/yr (Qa) (**Table 9.2**). Not included in **Table 9.2** is one non-consumptive water right that totals 0.05 cfs (Qi). Also not listed in **Table 9.2** are the 138 surface water right claims of unknown amounts of usage. Many of these claims are redundant to the permitted and certified water rights.

Figure 9.5, shows surface and reservoir water rights categorized by use. The major use for allocated surface water is for irrigation, with 59.3 percent of the total allocation. The next largest use is domestic multiple, which represent multiple domestic connections utilizing one right, with 25.5 percent of the total allocation. One water right for the City of Bainbridge Island, totaling 253 afy, represents the total allocation (11.6 percent) for municipal use. Single domestic use accounts for 2.1 percent of the islands total allocation. Other use categories such as commercial/ industrial, fish rearing, fire safety, wildlife, stock watering and recreation and beautification together total 1.5 percent.

Table 9.2: Surface And Reservoir Water Filings

		Certificates and Permits			Applications	
	Number of Rights	Qi (cfs)	Qa (afy)	Number of Applications	Qi (cfs)	Qa (afy)
Bainbridge Island Total	58	4.65	2,183	1	0.22	N/A

Compared to the estimated runoff total of approximately 14,000 afy (based on figures in Garling, 1965), it appears from the water right totals that consumptive water rights on the streams and springs of Bainbridge Island are a significant percentage (16 percent) of the stream flows.

9.5 Groundwater Rights

The spatial distribution of the total allocation of instantaneous quantities (Qi) of groundwater rights on Bainbridge Island is shown on **Figure 9.6**. The distribution appears to be mainly concentrated, as would be expected, near the population centers on the island, such as the City Center (Winslow) and Lynwood Center. Another concentration of groundwater rights is near Manzanita Bay, the location of several major purveyors, such as North Bainbridge Water Company and Meadowmeer Golf Course.

The 130 permitted and certified groundwater rights on Bainbridge Island, listed in **Appendix B**, total 6,889 gpm (Qi) and 5,378 af/yr (Qa) (**Table 9.3**). **Figure 9.7**, shows groundwater rights categorized by use. The major use for allocated ground water is for multiple domestic use, with 50.7 percent of the total allocation. The next largest allocation is municipal purpose with 37.2 percent of the total. Irrigation use accounts for 5.9 percent, and commercial/ industrial use for 5.4 percent of the island’s total allocation. Other use categories such as domestic single, fish rearing, fire safety, wildlife, stock watering and recreation and beautification, together total one percent.

Table 9.3: Groundwater Filings

	Number of rights	Certificates and Permits		Number of applications	Applications	
		Qi (gpm)	Qa (af/yr)		Qi (gpm)	Qa (af/yr)
Bainbridge Island TOTAL	130	6,889	5,378	22	2,980	N/A

Table 9.3 lists the total of all the groundwater rights on Bainbridge Island. These totals do not include rights that have a status of: canceled, relinquished or rejected. The totals also do not include private domestic users in the area, who are served by exempt wells, and the 1,042 groundwater claims on the island. (As discussed earlier, claims are not water rights, but could become valid rights through an adjudication process). Usage by exempt wells and claims are estimated in **Section 9.7.2** using population figures**.**

9.6 Water Rights Applications

Of the 23 water right applications currently submitted for Bainbridge Island, 22 of those are for ground water. The single surface water right application accounts for only 100 gpm of the total 3,080 gpm currently applied for on the island.[1] The distributions of the surface water and groundwater right applications are shown on **Figures 9.4** and **9.6**. The large number of water rights pending results from the fact that few applications have been processed since 1990.

9.7 Distribution of Groundwater Resources

In the following section, estimates are made for the distribution of the groundwater resource for several categories: total groundwater resource, actual use, annual withdrawal for applications, and total stream baseflow. Based on these estimations, the availability of groundwater resources was derived.

9.7.1 Total Groundwater Resource

To estimate the groundwater resource on Bainbridge Island, the groundwater recharge has been analyzed using three different methods: a simplified water budget equation; a regression recharge estimate; and an empirical recharge estimate. Using a simplified water budget equation, a recharge rate of 13 inches per year was estimated (KPUD and others, 1997). The regression recharge (see preceding section) estimated the recharge to be 16.4 inches per year. And the empirical recharge estimate resulted in an estimate of 12.9 inches per year. For this discussion, the groundwater recharge rate is assumed to be 13 inches per year.

Using an area of 27.5 square miles (17,600 acres), a recharge rate of 13 inches per year translates to approximately 19,000 acre feet per year (afy). Therefore, the total implied available groundwater resource, including all aquifers, is 19,000 afy.

9.7.2 Actual Usage Estimates

Because of the existence of inactive water rights, invalid claims, withdrawal capacity constraints, overestimation of need on the part of applicants, and difficulty in estimating the amount of water

[1] As of October 22, 1998.

used by exempt wells, it is likely that actual water used on Bainbridge Island is less than the current allocations. The maximum permitted annual allocation for surface and ground water on the island is 7,561 afy, which does not include applications, claims, or exempt wells. To estimate actual usage, the population for Bainbridge Island was multiplied by an estimated per capita consumption rate. The total population was 15,736 in 1990 (KPUD and others, 1997). At a projected growth rate of 2.6 percent, population will be 22,556 by the year 2014 (KPUD and others, 1997). For Kitsap County, the average use per capita is 132 gallons per day (KPUD and others, 1997). This per capita rate includes municipal, domestic, commercial, irrigation, fish propagation, and stock watering uses. Therefore, the estimated current consumption (for 1990) is a continuous 1,442 gpm or 2,326 afy. The projected 2014 consumption will be 2,067 gpm or 3,329 afy.

Current allocations for surface and ground water total 7,561 afy. Thus, an estimated 31 percent of the allocations on Bainbridge Island is currently being put to beneficial use. The difference between the allocation of 7,561 afy and the estimated actual use of 2,326 afy is 5,235 afy and represents the portion of the allocation that is potentially unused.

The current estimated actual usage of 2,326 afy represents approximately 12 percent of the estimated total groundwater resource of 19,000 afy. The per capita estimation method includes water use from claims and users of wells that are exempt from water rights.

9.7.3 Instream Baseflow

Although some streams are closed to further appropriation, no minimum instream flow requirements have been established on Bainbridge Island. Due to a lack of information on streamflow on the island, the baseflow (minimum flow in streams maintained by discharge from ground water sources) could only be estimated from low flow measurements done in August 1961 (a year of above average precipitation) by Garling and others (1965). Based on these measurements, the baseflow of all 37 streams on Bainbridge Island was approximately 1.4 cfs, or 1,012 afy. This baseflow estimate represents approximately 5 percent of the total groundwater resource. Certified surface water right holders use an unknown, but likely small, portion of this baseflow.

9.7.4 Estimated Annual Withdrawal for Water Right Applications

The annual quantity (Qa) for applications cannot be directly compared to allocations. However, for most permitted and certified water rights, the Qa is generally less than the continuous withdrawal at the instantaneous quantity (Qi) rate. On Bainbridge Island, the Qa for allocations is on average 48 percent and 65 percent of the Qi for groundwater and surface water rights, respectively. Ground water applications on Bainbridge Island total 2,980 gpm (Qi), which, based on the aforementioned factors, equates to an estimated Qa for ground water applications of 1,430 afy. For surface water, the total applied for Qi is 0.22 cfs (159 afy), which equates to an estimate Qa for surface water of 103 afy. Thus the estimated annual withdrawal for surface water and ground water right applications, if approved, is 1,533 afy, or 8 percent of the total available resource.

9.7.5 Estimated Groundwater Resource not Appropriated or Required for Stream Baseflow

A summary of the distribution of the estimated ground water resource is illustrated on **Figure 9.8**. The total groundwater resource is 19,000 afy, based on 13 in/yr of recharge over an area of 17,600 acres. The categories of distribution discussed above total 10,106 afy. Thus, there are 8,894 afy, or 47 percent of the resource remaining. It must be noted that all of the groundwater resource available (less the supply to stream baseflow) is not available for allocation. To prevent seawater intrusion, a portion of the resource must be left in the aquifers to maintain the differential pressure between freshwater and seawater. Also, because of physical and economic limitations, not all of the ground water can be extracted by wells.

SECTION 10
LEVEL II ASSESSMENT
SUMMARY AND CONCLUSIONS

The overall goal of the Level II Assessment of Bainbridge Island was to build upon the preliminary analysis given in the Kitsap County Level I Basin (KPUD and others, 1997). The assessment provided improved understanding of the hydrology of the island, allowing for proper management of the island's water resources into the future.

A water well database containing information on 983 wells provided by KPUD was upgraded to improve on the accuracy of the information available. Where information was believed to be reliable, well completion zones were assigned to 13 hydrostratigraphic units based on correlation with five hydrostratigraphic cross sections that were created for the project. Based on the correlation of the subsurface information, the Bainbridge Island Assessment has delineated five aquifer systems on the island. The aquifer systems are, from shallowest to deepest: the Perched Aquifer System, the Semi-Perched Aquifer System, the Sea Level Aquifer System, the Glaciomarine Aquifer System, and the Fletcher Bay Aquifer System. Aquifer boundary, potentiometric surface, hydraulic conductivity maps were created for these aquifer systems. From these maps the head relationships between aquifers can be inferred.

A water level monitoring network established and maintained by KPUD provided data for detailed analysis of historical water level trends for some wells on the island. Better coordination between the major water purveyors in regards to water use and water level information should be a future goal. In all, 23 wells were categorized by aquifer system and comparisons were made between precipitation, production, and water level trends. It was found that all of the aquifer systems have a direct correlation between yearly precipitation (relative to long-term averages) and aquifer water level. Aquifer water levels generally rise during years of above average rainfall, and generally decline during years with below average rainfall. The Fletcher Bay Aquifer System appears to be responsive to production rates on a island-wide scale. The other aquifer systems appear to be responsive only to nearby pumping activity. Based on long-term records, none of the aquifers show evidence of over-pumping (mining).

Land use on the island is predominately residential. Single family homes account for 84 percent of residential units and multi-family for the remaining 16 percent. The greatest density is in Winslow and along the island's shoreline. The combination of open land (parcels larger than 10 acres), recreation land, and agricultural uses account for 26 percent of the land uses. Commercial/industrial uses account for less than two percent. Transportation corridors account for six percent of land uses, forest lands two percent and public facilities two percent.

The most important aquifer for supplying potable water, the Sea Level Aquifer, occurs under all zoning classifications. This aquifer underlies roughly 85 percent of the island and provides water for 53 percent of the wells as well as for the major purveyors.

Water budget analyses were done to estimate groundwater recharge on Bainbridge Island utilizing three separate methods: a simplified water balance equation; a regression recharge estimate; and an empirical recharge estimate. The water balance equation, as done in the Initial Basin Assessment, estimated the groundwater recharge on Bainbridge Island to be 13 inches annually (KPUD and others, 1997). The regression recharge estimate, based on work of Woodward and others (1995), resulted in an estimate recharge of 16.4 inches annually. The empirical method used by Becker (1995) to estimate recharge in the Bangor area, when applied to Bainbridge Island resulted in an estimate of 12.9 inches annually. The general agreement of the results between the separate methods, suggests that the groundwater recharge on the island is within this range.

Water rights on Bainbridge Island were compiled and sorted by type, use, and location. It was found that there are 58 certified and permitted surface and reservoir water rights totaling 4.65 cfs (Qi) and 2,183 afy (Qa). There are 130 certified and permitted groundwater rights totaling 6,889 gpm (Qi) and 5,378 afy (Qa). Thus the current water right allocations total 7,561 afy (Qa). There is one surface water and 22 groundwater applications for 0.22 cfs and 2,980 gpm (Qi), respectively.

A comparison of the total estimated groundwater resource of 19,000 afy based on the groundwater recharge rate of 13 in/yr and water usage derived from population estimates, implies that approximately 2,326 afy (12 percent) of the resource is actually being put to beneficial use. Stream baseflow requirements, based on low flow measurements of Garling and others (1965), account for approximately 1,012 afy (5 percent) of the resource. The estimated annual allocation for pending applications, if approved, is approximately 1,533 afy (8 percent). Based on the aforementioned estimations, the implied ground water resource available is 8,894 afy, or 47 percent of the estimate ground water resource.

SECTION 11
LEVEL II ASSESSMENT RECOMMENDATIONS

The Bainbridge Island Basin Assessment has added greatly to the understanding of the hydrogeologic characteristics of the Island. The report also has revealed several elements that need a greater amount of information to assess. The following recommendations are categorized in order of the assessment organization. Within each category, the recommendations are prioritized by order of perceived importance.

Surface Water

- A City of Bainbridge Island water resource coordinator position should be established to coordinate and deal with water resources issues including the implementation of recommendations made in this report.
- Establish one or more year-round, continuous streamflow gages.
- Establish an effort to annually measure the flow on all creeks under "low-flow" conditions during the late summer.
- Conduct a survey of surface water quality in coordination with local organizations, government agencies, tribes, and Bainbridge Island residents.

Hydrogeologic Characterization

- Continue and expand KPUD's well database on Bainbridge Island, with special attention to accurate well location and elevation.
- Standardize well monitoring procedures, continue and expand the well monitoring network through KPUD as established in the GWMP.
- Expand the well monitoring network to include more Sea Level Aquifer System wells in the Eagle Harbor area and one or more Glaciomarine Aquifer System wells.
- Continue and expand reporting by purveyors of monthly and yearly production amounts and coordinate the collection and reporting of water level, water quality, and production data.

Groundwater Quality

- Groundwater quality testing for selected parameters was conducted by the USGS in 1985 (Dion and others, 1988). This study found not seawater intrusion problems. Recent water quality results also indicate that currently there is no seawater intrusion problem. However, because of the susceptibility of the below sea level aquifers on Bainbridge Island to seawater intrusion, periodic rounds of water quality testing should be conducted to compare with the baseline established in the USGS study.
- This water quality survey should include the study of the nitrate levels of shallow ground water on the island.
- Older individual wells and septic systems are not regulated for maintenance or proper function after construction. An effort to regulate older well and septic systems should be attempted and would ferret-out failing systems, provide a baseline maintenance program to extend facility life, provide valuable water resources information, and protect public health.

Land Use

- Coordinate land use policies with regard to aquifer recharge areas.
- Coordinate water resource issues with land use planning.
- Assess impacts of different types of land use on stormwater runoff.

Water Budget

- Refine runoff and baseflow rates by establishing year-round, continuous monitoring sites in streams on the Island.
- Establish a precipitation gage on the southern portion of Bainbridge Island.

Water Rights and Water Use

- Collect additional water production records from water purveyors on the island.
- Determine which water rights are valid (being put to beneficial use) and which water rights, especially surface water rights, are inactive.

SECTION 12
LEVEL II ASSESSMENT
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