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IN-DEPTH PERSPECTIVE

GROUNDWATER MONITORING PROGRAM

City of Bainbridge Island
Bainbridge Island, Washington

Prepared for: City of Bainbridge Island

Project No. 060016-001-06 • December 12, 2006

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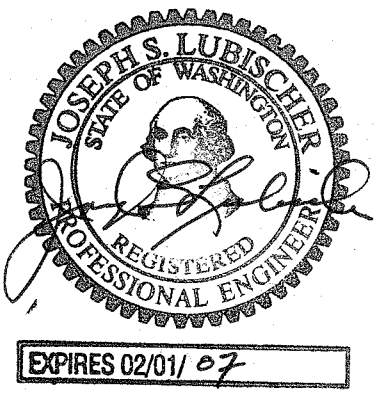

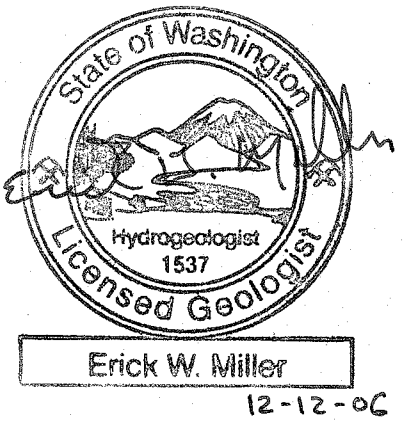

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Contents

Executive Summary **1**

1 Introduction **3**

2 Monitoring Network and Database Descriptions **4**

2.1 Existing Groundwater Monitoring 4

2.2 Bainbridge Island Aquifers 4

2.3 Criteria for Selection of Additional Wells 5

2.4 Description of Current Monitoring Well Network 6

2.5 Description of Database 7

3 Summary of Annual Monitoring Data **8**

3.1 Aquifer Water Levels 8

3.1.1 Collected Water Level Data 8

3.1.2 Precipitation 8

3.1.3 Tidally Influenced Groundwater Heads 9

3.2 Seawater Intrusion Indicators 10

3.2.1 Historic Chloride Concentration Data 10

3.2.2 Collected Chloride Concentration Data 10

3.3 Groundwater Production 10

4 Early Warning Levels **12**

4.1 Specification of EWLs 12

4.2 Seawater Intrusion 12

4.3 Safe Yield 13

4.4 Monitoring Responses to Exceedances of EWLs 13

4.4.1 Chloride Concentration 13

4.4.2 Water Level 15

5 Discussion of Aquifer Conditions **17**

5.1 Perched Aquifer 17

5.2 Semi-Perched Aquifer 17

5.3 Semi-Perched Aquifer / Sea Level Aquifer 17

5.4 Sea Level Aquifer 17

5.5 Glaciomarine Aquifer 18

5.6 Fletcher Bay Aquifer 18

6 Recommendations.....19

References.....21

Limitations.....22

List of Tables

1 Summary of Current Groundwater Monitoring Wells 6

2 Monitoring Responses for Chloride Conditions.....13

List of Figures

1 Groundwater Monitoring Well Network

2 Perched Aquifer Hydrographs

3 Semi-Perched Aquifer Hydrographs

4 Semi-Perched Aquifer/Sea Level Aquifer Hydrographs

5 Sea Level Aquifer Hydrographs

6 Glaciomarine Aquifer Hydrographs

7 Fletcher Bay Aquifer Hydrographs

8 Fletcher Bay Aquifer Hydrographs – Central Wells

9 Fletcher Bay Aquifer Hydrographs – Peripheral Wells

10 Cumulative Rainfall Departure

11 Historic Chloride Concentrations in Groundwater

12 Estimated 2005 Groundwater Withdrawals

List of Appendices

A Monitoring Well List and Well Logs

B Sampling and Analysis Plan

C Monitoring Well Hydrographs with Production and Chloride Data

Executive Summary

A Groundwater Monitoring Program (GMP) for the City of Bainbridge Island (COBI) has been established that expands previous monitoring efforts and centralizes data acquisition. The network of monitoring wells has been expanded to include areas and aquifers that were inadequately sampled or of special concern. Primary concerns on Bainbridge are the risk of seawater intrusion, especially in coastal areas, and pumping in excess of an aquifer's safe yield. To centralize data, a database has been constructed that allows Island-wide analysis of collected data.

The following tasks have been accomplished for the GMP:

- Preparation of a Groundwater Baseline memorandum;
- Evaluation of existing monitoring and identification of new wells for the groundwater monitoring network;
- Arrangement for data sharing with PUD #1 of Kitsap County (KPUD) and private water purveyors;
- Preparation of a Sampling and Analysis Plan;
- Training of staff;
- Construction and population of a database with graphical spreadsheet output;
- Specification of Early Warning Levels and Monitoring Responses for seawater intrusion and for safe yield;
- Preparation of a reporting template;
- Preliminary analysis of aquifer conditions; and
- Recommendations for future work.

Early Warning Levels were suggested for seawater intrusion and safe yield. Seawater intrusion is monitored by chloride concentration and three Chloride Conditions were established with three levels of Monitoring Responses. These responses include confirmation of results, definition of affected areas, addition of monitoring wells, increased frequency of monitoring, consultation with other agencies, and recommendations for future actions.

The Early Warning Level for safe yield was set as an observable drop in water levels, greater than ½ foot per year for 10 years that cannot be explained by variations in precipitation. Suggested Monitoring Responses include aquifer analyses, acquisition of production data, groundwater modeling, and consideration of remedial measures.

Comments on the condition of Island aquifers are necessarily preliminary. Based on review of available data, there are no concerns at this time in monitored wells for the Perched Aquifer, Semi-Perched Aquifer or Glacio-Marine Aquifer. In the Sea Level

Aquifer, probable high chlorides were observed in the Seabold area. Dropping water levels are of concern in the Fletcher Bay Aquifer in the Eagledale area.

In order to strengthen and improve the Groundwater Monitoring Program, the following recommendations are made:

- Continuation of monitoring and provision for database maintenance;
- Survey of well locations and water level measurement points;
- Addition of the parameter “distance to coastline” to the database;
- Addition of any historical data that becomes available for monitoring wells;
- Evaluation of tidal influence on water levels;
- Addition of monitoring wells in strategic locations;
- Acceptance of Early Warning Levels and Monitoring Responses;
- Implementation of responses for seawater intrusion in the Sea Level Aquifer near Seabold and for safe yield in the Fletcher Bay Aquifer near Eagledale;
- Determination of background chloride levels in each aquifer; and
- Construction of a groundwater model to answer critical management questions.

This GMP was made possible by the cooperation of many owners of Island wells and water systems and by inter-agency assistance from Kitsap PUD staff and the Operations and Maintenance staff at COBI Public Works. Their contributions are gratefully acknowledged.

1 Introduction

This report presents development and initial findings of a groundwater monitoring program developed to support the City of Bainbridge Island (COBI) Groundwater Monitoring Program (GMP). This work expands and consolidates the groundwater monitoring performed by water purveyors on Bainbridge Island and creates an accompanying database for groundwater management purposes. Currently, several entities–the City, Public Utility District #1 of Kitsap County (KPUD), and some private water systems–monitor water level and water quality parameters at a number of wells.

Some areas or aquifers lack monitoring or are of particular importance due to high groundwater withdrawals or susceptibility to seawater intrusion. The existing set of monitored wells is supplemented with additional wells and the data from different sources is compiled into a single database. The database contains historic and future water level data, chloride concentrations, specific conductivity, production volumes, where available, and precipitation records.

The information derived from the monitoring network will be used to inform and advise water managers, both public and private, regarding issues of saltwater intrusion and safe yield and will also be used to support development of a groundwater model. The data will be shared via the City's website as well as through a yearly report that will be mailed to all participants. Participation in the program is voluntary.

Work completed under this project includes the following items:

- Expanded the monitoring network,
- Trained City staff to perform monitoring and transitioning of monitoring to City staff,
- Arranged for data-sharing with KPUD and some private water systems, and
- Created and populated a database.

This report:

- Describes the monitoring well network and the database (Section 2),
- Summarizes data collected to date (Section 3),
- Proposes "Early Warning Levels" based on groundwater level change and chloride criteria (Section 4),
- Presents preliminary interpretations of aquifer conditions (Section 5),
- Serves as a template for future reports, and
- Makes recommendations necessary to ensure future success of the Groundwater Monitoring Program (Section 6).

2 Monitoring Network and Database Descriptions

2.1 Existing Groundwater Monitoring

Existing groundwater monitoring by KPUD, COBI, and private purveyors provided the initial starting point for development of the groundwater monitoring network. Approximately 29 wells at 20 locations are currently monitored by PUD #1 of Kitsap County and by the Operations and Maintenance group in the City's Department of Public Works. KPUD collects manual water levels and has a number of continuously recording pressure transducers. KPUD also analyzes samples for chloride concentration, currently on a semi-annual basis. COBI Operations and Maintenance monitors water levels quarterly and has installed pressure transducers in a number of wells. Several private purveyors also monitor their wells.

Prior to the GMP, the data acquired for Bainbridge Island was not compiled in a single location. Rather, records have been kept separately by the City, KPUD, and private water system operators.

2.2 Bainbridge Island Aquifers

The Level II Basin assessment (Kato & Warren and Robinson & Noble, 2000) identified six principal aquifers on Bainbridge Island:

- **Perched Aquifer System (PA) –** This aquifer is comprised predominantly of Vashon Advance glacial outwash at higher elevations (> 200 feet above mean sea level [ft MSL]) and is utilized predominantly by domestic wells. About 4 percent of wells are reported to be completed in this unit.
- **Semi-Perched Aquifer System (SPA) –** The semi-perched aquifer consists of wells typically completed between 100 and -20 ft MSL. About 25 percent of wells are reported to be completed in this unit.
- **Sea Level Aquifer (SLA) –** This aquifer is present from 40 to -230 ft MSL and is the most widely utilized aquifer system on the Island. Fifty-three percent (53%) of wells are completed in the SLA. Wells that could not be clearly assigned to either the SPA or SLA were designated as Semi-Perched/Sea Level Aquifer (**SPA/SLA**).
- **Glaciomarine Aquifer System (GMA) –** This aquifer reportedly consists of water bearing units within a thick sequence of fine-grained glaciomarine drift. Wells in this aquifer are typically completed between -400 and -760 ft MSL. Several of Island's deep production wells and at least 4 domestic wells are completed in this aquifer, representing about 2 percent of wells.
- **Fletcher Bay Aquifer System (FBA) –** The FBA is the deepest identified aquifer on Bainbridge Island. Several large production wells are completed in this aquifer including the Fletcher Bay well. Wells in this aquifer are typically

completed between about -690 to -1,010 ft MSL. While representing only about 1 percent of wells on Bainbridge Island, the metered KPUD and COBI FBA wells provide approximately 30 percent of the estimated total Island groundwater production.

- **Bedrock Aquifer System** – Seven wells, or less than 1 percent, are completed in the sedimentary Blakely Harbor and Blakeley Formations on the south end of Bainbridge Island.

The determination of the aquifer tapped by a given well was made by comparing screen elevation with aquifer elevation and by comparing well location with lateral extent of an aquifer (Kato & Warren and Robinson & Noble, 2000). The GMP does not include the bedrock aquifer, due to the relatively small number and low production of wells in that unit.

2.3 Criteria for Selection of Additional Wells

The criteria for selection of additional wells for the monitoring network were to:

- Improve geographic coverage for each aquifer,
- Monitor in areas of large groundwater withdrawals,
- Monitor near elevated chloride concentrations and near shorelines,
- Include wells for which a historic record exists, and
- Acquire permission for access from owners on a voluntary basis.

At the beginning of this study, a review of the set of existing monitored wells indicated that certain aquifers were under-sampled. In general, the three upper aquifers–PA, SPA, and SLA–had a relatively low number of monitored wells. The SLA, containing over half of the Island's wells, was particularly under-sampled, especially in some coastal areas. On the other hand, a very high percentage of the larger and more expensive wells in the two deep aquifers–GMA and FBA–were already being monitored.

Improvement of geographic coverage was necessary for the PA, SPA, and SLA. Large groundwater withdrawals were generally well monitored, especially in the FBA, but significant effort was made in encouraging the participation of the larger private water systems. Areas of focus with respect to high chlorides included wells in the SLA within ¼ mile of the coastline and the north island (Seabold, Agate Point, and Port Madison) and Eagle Harbor areas identified in the Groundwater Baseline memorandum (Aspect Consulting, 2006a). Wells with historic records were mostly included in the set of previously monitored wells. A number of potential monitoring sites were eliminated from consideration by either refusal of access or lack of response.

The selection process for additional wells focused on privately owned Group A[1] and Group B[2] water systems, and only limited contacts were made with owners of one- or two-party wells. Public water systems were preferred over private wells as access would be less likely interrupted by the sale of individual homes. It is expected that any further additions to the monitoring network will be single- or two-party wells.

2.4 Description of Current Monitoring Well Network

Figure 1 presents the expanded monitoring well network, which currently consists of 43 wells at 36 locations in the five aquifers, plus the indeterminate SPA/SLA category. The distribution of wells by aquifer is summarized in Table 1. Monitoring of adjacent wells, typically where two or more production wells were drilled in close proximity creates the situation where the number of wells exceed the number of monitoring locations.

Aquifer	Number of Wells	Number of Locations
Perched Aquifer	3	3
Semi-Perched Aquifer	10	10
Semi-Perched Aquifer / Sea Level Aquifer	1	1
Sea Level Aquifer	16	12
Glaciomarine Aquifer	3	3
Fletcher Bay Aquifer	10	7
Total	**43**	**36**

Table 1 - Summary of Current Groundwater Monitoring Wells

As noted in Section 2.3, deep wells in the GMA and FBA aquifers are nearly all monitored. Review of the enlarged network in Figure 1 indicates a good distribution of monitoring wells in the PA and SPA, with the number in proportion to the relative quantity of drilled wells. The SLA is well represented on the north portion of the Island and along the central north-south axis. The SLA is under-represented on the east side between Fay Bainbridge State Park and Eagle Harbor and on the west side between Seabold and Point White. The south Island area–South Beach and Blakely Harbor–is predominately bedrock and is not monitored due to the low number of low producing wells.

[1] A Group A public water system means (1) a community system serving 15 or more connections or 25 or more people for more than 180 days per year (dpy), (2) a non-transient non-community (NTNC) system serving 25 or more same non-residential people more than 180 dpy, or (3) a transient non-community (TNC) system serving 25 or more different people more than 60 dpy, 25or more same people 60-180 dpy, or 1000 people for 2 or more consecutive dpy.

[2] A Group B public water system serves less than 15 residential connections, an average non-residential population of less than 25 per day for more than 60 dpy, or any number of people for less than 60 dpy.

Water level is monitored manually for wells in all aquifers. In addition, water levels in a number of wells are continuously recorded with electronic pressure transducers and dataloggers. Chloride concentration and conductivity is measured in wells completed at or below sea level, that is, for the SLA, GMA, and FBA aquifers. Detailed measurement procedures are fully explained in the Sampling and Analysis Plan (Appendix B).

Specific conductivity is a parameter measured in the field that typically correlates with chloride concentration. After the correlation relationship between conductivity and chloride concentration has been determined, the specific conductivity will then serve as a surrogate measurement for laboratory testing for chloride levels. We recommend that the correlation be made for each aquifer.

2.5 Description of Database

A database using Microsoft® Access 2002 has been created to combine:

- Well identification, drilling logs, and location information,
- Manual and electronic water level data,
- Water quality data (chloride concentration and specific conductivity),
- Production volumes, and
- Precipitation records.

The database includes three elements that have been transferred separately to the City: the monitoring network database (populated through October 5, 2006), a spreadsheet–linked to the database–for displaying water levels and other information, and a User Manual (Aspect Consulting, 2006b). The spreadsheet has been setup to query the database and automatically create updated graphs. The User Manual provides full instructions for use and maintenance of the database and for graphical output via a Microsoft® Excel spreadsheet.

3 Summary of Annual Monitoring Data

3.1 Aquifer Water Levels

Static water level is the basic measurement of the quantity of water in an aquifer. On Bainbridge Island, groundwater levels are largely affected by recharge from infiltrating precipitation, discharges to surface water (including saltwater bodies), and withdrawals, i.e., pumping. Water levels fluctuate naturally in response to seasonal variations in precipitation and to multi-year trends in precipitation. Exceeding the safe yield of an aquifer can cause seawater intrusion or lower groundwater heads with impact on wetlands, springs, or creeks. Examination of water level trends requires simultaneous comparison with multi-year precipitation trends, withdrawal histories, and land use changes. Prediction of future water level changes is most readily addressed through groundwater modeling, which incorporates assumptions about precipitation patterns, climate change, water usage patterns, population growth, and changes in land use.

3.1.1 Collected Water Level Data

Water level data from all entities participating in the monitoring program are entered into the database. All manual measurements are entered, but continuous electronic data is filtered to include only the highest reading during the course of a day. Measurements are adjusted in the database to give water elevation in feet above mean sea level (NGVD 29). The accuracy of the computed water level elevations is limited by the accuracy of the measuring point elevations on the wellheads. The sources and estimated accuracies of elevation data are noted in the database and indicate that many wells have not been surveyed. Because the relationship between sea level and static water level is critical in the evaluation of seawater intrusion potential, we recommend that all wells in the monitoring network be surveyed for elevation as well as geographical position.

Water level data (hydrographs) for the monitoring wells in each aquifer are presented in Figures 2 through 7. These data have been additionally filtered to select weekly highs, which removes most, but not all, low values taken during pumping of the well. The figures provide a comparison of wells within each aquifer. For ease of interpretation, Figures 8 and 9 show enlargements of subsets of the FBA hydrographs. See Section 5 for a discussion of current aquifer conditions.

The hydrographs and well production data for all wells are presented individually in Appendix C, where they are sorted by aquifer. These water data have not been filtered to remove pumping levels. The plots also show the “cumulative rainfall departure” curve that is discussed below.

3.1.2 Precipitation

Precipitation is used as a measure of potential recharge to groundwater aquifers. Viewing the graph of precipitation over time can indicate wetting or drying periods that could influence groundwater levels.

3.1.2.1 Selection of Measuring Station

The longest precipitation record available on Bainbridge is from the climate station at Commodore Middle School, which provided a baseline of local precipitation over the last 15 years. However, the period of record for water level data in some wells extends back more than 30 years and a similar length of precipitation record is necessary for evaluating these water level charges. Two off-island stations, Bremerton and Seattle-Tacoma International Airport (STIA), have historical records extending back to the 1950s.

The stations were compared using average annual precipitation, inter-station correlation, and continuity of record. Average annual precipitations, from 1991 to 2005, for Commodore, Bremerton, and STIA were 38.7, 49.0, and 37.4 inches per year, respectively. The STIA and Commodore stations receive similar amounts of rain, whereas the Bremerton station is significantly higher.

Correlation of monthly total precipitation between stations was evaluated using a least-squares regression method. Both the Bremerton and STIA stations provided acceptable correlations with the Commodore data. The squared correlation, i.e., R^2, values, were 0.85 and 0.91 for STIA and Bremerton, respectively. A value of 1.0 indicates perfect agreement.

The precipitation record at STIA has been continuous since the 1950s. Since 1975, the Bremerton station has 49 months of missing or partial precipitation data. Due to the continual precipitation record, along with a similar magnitude of rainfall and acceptable correlation, the STIA precipitation record was selected for comparison with Bainbridge Island groundwater levels.

3.1.2.2 Cumulative Rainfall Departure

The cumulative rainfall departure (CRD) from average precipitation for the period from 1975 to mid-2006 at STIA is presented in Figure 10 and also included with the hydrographs in Appendix C. The CRD graph is constructed by taking the mean for the period of record, computing the departure from the mean for each month, and plotting the cumulative total of the departures. Downward slopes indicate periods of below normal precipitation and upward slopes indicate periods of above average precipitation. Major peaks and troughs indicate a change from short-term wet-to-dry and dry-to-wet conditions, respectively. (The major peaks and troughs should not be confused with the annual cycles, which are due to seasonal variation in rainfall.) Analysis of long-term trends must also include the use of a detailed water budget and rainfall/recharge relationships (Weber and Stewart, 2004).

3.1.3 Tidally Influenced Groundwater Heads

Tidal influence has the potential to significantly affect water levels in coastal wells. Determination of mean water level requires measurement of water level over a period of time, typically for a one or three day period (Serfes, 1991). Use of a downhole transducer and datalogger is recommended to make a series of level measurements during a non-pumping period. The extent of tidal influence on Island wells should be investigated, initially by inspection of the detailed data available for wells with downhole dataloggers.

One well in the monitoring network, EPA/Wycoff in the GMA, has been identified as having a strong tidal influence. That well is a flowing artesian well with a sealed wellhead that prevents water from rising above about 3 feet above ground surface. The current wellhead configuration has an intake valve that allows air in during pumping, but compresses air in the casing during recovery. Obtaining a time-series of water levels will require temporary installation of an air-relief valve and transducer, during a period without pumping.

3.2 Seawater Intrusion Indicators

The primary indicator used for seawater intrusion is chloride concentration. Concern with possible intrusion is limited to aquifers below sea level, that is the SLA, GMA, and FBA systems.

Specific conductivity of the water usually correlates well with chloride concentration and can therefore be used as a surrogate measure for chloride level. Accurate measurement of chloride concentration requires laboratory analysis, whereas conductivity can be quickly and accurately measured in the field. The correlation between chloride and conductivity needs to be verified for each aquifer regime. The next annual report, which should include two additional chloride sampling events (April and September of 2007), should include plots of chloride concentration versus specific conductivity for each aquifer.

3.2.1 Historic Chloride Concentration Data

Historic data on chloride concentrations (Figure 11) was compiled and reported in the Groundwater Baseline memorandum (Aspect, 2006a). Nine wells within ¼ mile of the coastline and two inland wells exhibited elevated chloride levels. Most of the wells with elevated chloride had only single measurements. Additional sampling is necessary to determine if those measurements are repeatable. As a result of the elevated chloride levels, the north island area (Agate Point, Seabold, and Port Madison) and the Eagle Harbor area are considered areas of interest, with respect to seawater intrusion, for increased monitoring.

3.2.2 Collected Chloride Concentration Data

Both new and historic chloride data are shown on the individual well plots in Appendix C. Only limited new data has been acquired since implementation of the GMP with one well in the Seabold area exhibiting an elevated chloride level. In the Eagle Harbor area, two wells were sampled on the south side, but no new data were obtained on the north side or at Head of the Bay.

3.3 Groundwater Production

Estimates of 2005 groundwater withdrawals are presented in Figure 12 by quarter-quarter section. Methodology is discussed in the Groundwater Baseline memorandum (Aspect Consulting, 2006a). Usage from all identified wells totaled 2,550 acre-ft per year, but did not include residential wells that were not included in the KPUD well database. An alternative estimate was calculated from a per capita residential and commercial use of 115 gallons per day (gpd) (EES, 2002) and a 2005 population of 22,500 (COBI, 2006). The alternative total 2005 usage is 2,900 acre-ft per year, a difference of 12 percent. The

115 gpd usage is from Bremerton, a more urban/industrial area than the largely residential Bainbridge area, and therefore probably over-estimates total production. Although actual water use may vary slightly from that depicted in Figure 12, the water use distribution was considered adequate for identifying monitoring locations.

Where available, the production data for monitored wells is presented in the plots for individual wells in Appendix C.

4 Early Warning Levels

4.1 Specification of EWLs

For the purpose of the GMP, an Early Warning Level (EWL) is a monitoring criteria that, if exceeded, would result in additional investigation in order to determine if a potential problem is developing. Possible actions could include additional data evaluation, expanded monitoring, and/or technical review and analysis.

The purpose of specifying EWLs is to provide quantifiable measures for initial evaluation of data that will provide timely warning of a developing issue before a problem becomes acute.

4.2 Seawater Intrusion

Chloride, because of its non-reactive behavior, is used as the indicator parameter for seawater intrusion. Washington State regulations (WAC 246-29-310) and USEPA specify a secondary maximum contaminant level[3] (SMCL) for chloride in groundwater of 250 milligrams per liter (mg/L) or parts per million (ppm). State law, in addition, includes an antidegradation policy that either limits or proscribes the degradation of natural groundwaters (WAC 173-200-040). Addition of about 1 to 1.5 percent seawater to typical, non-impacted groundwater would result in exceedance of the MCL for chloride. Seawater intrusion affects both water quantity and water quality.

Seawater intrusion has become an issue in Jefferson, Island, San Juan and Whatcom Counties and regulations have been implemented that have placed limits on well use and/or development in impacted areas within those jurisdictions. For example, Jefferson County has set 100 mg/L as a trigger level that places certain metering, monitoring, and/or hydrogeological assessment requirements on new wells within 1,000 feet of an impacted well. San Juan County uses 100 mg/L within 100 feet as criteria for “medium” risk. The draft Ecology (1990) Seawater Intrusion Policy, never implemented, specified 25 mg/L as the threshold level for requiring monitoring. These policies in Washington use conservative assessments and limits on development to prevent intrusion. In contrast, Hawaii and California follow an adaptive management strategy to optimize groundwater development while minimizing salt water intrusion. Extraction limits are based on an evaluation of aquifer safe yield typically developed from numerical models of the aquifer.

For WRIA 15, the Water Quality Technical Assessment (Golder, 2003) estimated background mean chloride concentration for all aquifers of 2-3 mg/L, with 90 percent of wells less than 10 mg/L. For 97 percent of wells, chloride was less than 20 mg/L. The Bainbridge Island data reviewed for this report had 90th and 97th percentiles of 11 and 15

[3] Secondary contaminants are those that are not health threatening at the SMCL, but cause cosmetic effects (e.g., skin or tooth discoloration), aesthetic effects (e.g., taste, odor, or color of the water), or technical effects (corrosion or staining).

mg/L, respectively, values very similar to the Kitsap County data set. For the subset of Island wells completed above sea level, the 90th and 97th percentiles were 13 and 30 mg/L. For screening purposes, Golder (2003) used a level of 10 mg/L chloride concentration and wells with 100 mg/L chloride concentration were judged as susceptible to seawater intrusion (Golder, 2003). The Groundwater Baseline memorandum used a screening level of 40 mg/L for Bainbridge Island data (Figure 3).

An appropriate background level for chloride should exclude most elevated readings caused by factors other than seawater intrusion. As noted, background levels on Bainbridge Island are low, generally less than 20 mg/L. For wells completed above sea level, the 97th percentile chloride value is 30 mg/L. A background level of 30 mg/L is recommended for use as an Early Warning Level for Chloride Condition 1 (Section 4.4.1.1).

4.3 Safe Yield

The EWL for safe yield is a qualitative test for any observable drop in water level that is not attributable to seasonal or year-to-year variations in precipitation. A useful tool is to compare well hydrographs with the cumulative rainfall departure (Section 3.1.2.2). Water levels that do not rise during wet periods or that decline during periods of near average precipitation would be cause for concern. Evaluation of potential impacts from long-term water level declines is best addressed through a numerical groundwater model.

While no quantitative comparison has been developed, a provisional decline rate of ½ foot per year or greater over a 10-year period is considered cause for follow-up actions. The EWL criteria should be evaluated using predictive simulations of the numerical model.

4.4 Monitoring Responses to Exceedances of EWLs

4.4.1 Chloride Concentration

The purpose of the Groundwater Monitoring Plan with respect to seawater intrusion is to match the observed elevated chloride concentration with an appropriate monitoring response. Towards that end, three Observed Chloride Conditions and three Monitoring Reponses were developed, which are to be applied as indicated in Table 2 and are discussed in detail below.

		Monitoring Response		
		A	B	C
Chloride Condition	1	✓	--	--
	2	✓	✓	--
	3	✓	✓	✓

Table 2 - Monitoring Responses for Chloride Conditions

4.4.1.1 Chloride Conditions

Criteria for evaluation of chloride concentration data and possible changes in monitoring include:

- chloride concentration,
- specific conductivity,
- trend over time,
- distance from the coast, and
- distance from a well with an elevated chloride level.

For chloride concentrations, a three-level screening classification is suggested—above background, 100 mg/L, and 200 mg/L—that is based on Ecology's draft Seawater Intrusion Policy (Washington DOE, 1990). A background chloride screening level of 30 mg/L is suggested until additional data on background levels for the different Bainbridge Island aquifers are acquired and evaluated.

Trends should be evaluated as decreasing, stable, increasing, or undetermined. A determination of increasing or decreasing trend would require 4 consecutive samples or samples taken over a 3-year period with seasonality taken into account. A stable trend would require examination of data over a 3-year period.

Three Chloride Conditions are proposed as follows:

1. Chloride concentration between background level and 100 mg/L;
2. Chloride concentration between 100 and 200 mg/L or chloride concentration between background level and 100 mg/L with an increasing trend; and
3. Chloride concentration above 200 mg/L or chloride concentration above 100 mg/L with an increasing trend.

4.4.1.2 Monitoring Reponses

The three proposed Monitoring Responses are:

A. Confirm elevated chloride level by comparing chloride readings with specific conductivity values, increasing frequency of chloride testing to quarterly, and inspecting data for seasonality effects.

B. Determine lateral extent of elevated levels by adding monitoring well(s),
Collect metering data in the area of interest on a voluntary basis,
Characterize nature and extent of elevated readings,
Consult with DOE and state and Kitsap DOH as appropriate, and
Make recommendations for future actions.

C. Identify the nature and extent of the problem as best known,
Consult with DOE and state and Kitsap DOH as appropriate, and
Make recommendations for future management actions.

Response A is intended to confirm the data and ensure that reported values are not spurious. Confirmation should require four consecutive elevated readings.

Response B is to increase monitoring in order to characterize the nature and extent of elevated readings. New monitoring wells may need to be identified and added to the network. The initial focus would be to identify wells between the high chloride well and the coastline and the secondary focus would be on investigating lateral extent up and down the coast. Collection of metering data, if available, will be useful in future analysis. Appropriate analysis is dependent on the situation and may include comparison of well completion elevations and distances from the coast with chloride levels, refinement of hydrogeological interpretations, consultation with purveyors, neighborhood interviews, and/or comparison with results of groundwater modeling. Remedial measures should be developed appropriate to the problem analysis.

Response C is for situations where the secondary maximum contaminant level is being approached or trends indicate that the level may be exceeded. Response B is differentiated from Response C in that stronger remedial measures will be appropriate. Recommendations may include focused monitoring or groundwater modeling, as well as actions such as conservation or metering that would protect the aquifer from any additional degradation.

4.4.2 Water Level

An EWL for safe yield is tentatively proposed as a decline of ½ feet per year or greater over a 10-year period for drops in water level unexplained by seasonal or year-to-year variations in precipitation.

If water level data for a well indicate exceedance of the EWL, the following responses are recommended:

1. Analyze the data on an aquifer basis by comparing well hydrographs within the aquifer and with the cumulative rainfall departure curve;
2. Compare hydrographs with production data and acquire additional production data as necessary;
3. Determine the area of impact by water level observations and calculation of the zone of contribution;
4. Consider addition of monitoring wells to the existing network; and
5. Evaluate long-term impacts with the groundwater model.

In addition to the monitoring responses, the following additional actions should be pursued:

1. Develop recommendation for aquifer protection. These recommendations could include information dissemination, discussions with primary purveyors, encouragement of conservation, additional metering, and/or investigation of impairment of water rights.
2. Consideration of regulatory responses to protect the aquifer.

5 Discussion of Aquifer Conditions

This section presents an evaluation of historic and recently collected water level and chloride data by aquifer.

5.1 Perched Aquifer

The limited data available on Perched Aquifer wells is plotted in Figure 2. Two wells exhibit strong responses to precipitation trends, both seasonally and long-term. The responses to a series of wet years were increases of water levels from about 10 to 30 feet. No long-term declines are observed.

5.2 Semi-Perched Aquifer

Hydrographs for the Semi-Perched Aquifer (Figure 3) also show responses to seasonal and long-term precipitation history, but the magnitude of responses, less than 10 feet, is about one-half of that observed for the Perched Aquifer. The monitoring, however, does not include any wells north of Hidden Cove Road or south of High School Road. No long-term declines are apparent in the available data. Anecdotal evidence of a decline in the Meadowmeer area requires additional investigation.

Chloride levels have been measured in the High School Well #2/Commodore well and have generally been below the laboratory detection limit.

5.3 Semi-Perched Aquifer / Sea Level Aquifer

Only a single new monitoring well is in the SPA/SLA category (Figure 4). Chloride concentration was low.

5.4 Sea Level Aquifer

Figure 5 presents hydrographs for wells completed in the Sea Level Aquifer. This data set includes wells from Bill Point to Island Center, but lacks wells along the west side of the Island and also on the east side between Eagle Harbor and Fay Bainbridge State Park. Responses to long-term precipitation trends appear to be on the order of about 5 feet in magnitude, somewhat less than for the Semi-Perched Aquifer. No long-term trends in water level are observable.

Concern for seawater intrusion was previously noted in the north island areas of Seabold, Agate Point, and Port Madison and in the Eagle Harbor area. Samples at one well in the Seabold area in September and October 2006 had very high chloride levels, in excess of the SMCL. Following the protocols of Section 4, readings would first be confirmed and, if confirmed, followed by additional investigations to determine the extent of the high chloride concentrations. No elevated readings were found near Eagle Harbor, and it should be noted that no wells on the north side of the harbor were sampled.

Chloride readings for most SLA wells in the network were typically very low, around 5 mg/L. Two wells on the south shore of Eagle Harbor and one well east of Manzanita Bay were slightly higher, in the 5 to 12 mg/L range.

5.5 Glaciomarine Aquifer

Limited data is available for the three wells in the Glaciomarine Aquifer (Figure 6). No conclusions on water level trends can be drawn. Available chloride concentrations are low in all the GMA monitoring wells.

5.6 Fletcher Bay Aquifer

By comparing hydrograph patterns, the FBA wells were grouped into two sets–central wells (Figure 8) and peripheral wells (Figure 9). Similarity of patterns indicates that the Sands Road 1, Sands Road 2, Cool, KPUD North 9, and KPUD North 10 wells are in hydraulic communication. All these wells experienced a substantial and unrecovered drop in water level, 10 to 15 feet, when the Sands Road wells came on line in 1994. The 1994 decline observed in the FBA central wells is not seen in data for the Bloedel Deep, Fletcher Bay, or Island Utility wells.

Most water levels in wells in the Fletcher Bay Aquifer (Figures 7, 8, and 9) show seasonal responses to precipitation. A recharge response to long-term precipitation trends, specifically the wet period from 1996 to 1998, is clearly indicated in the Fletcher Bay Observation Well, while Bloedel Deep, Cool, and Fletcher Bay Observation wells appear to show small increases. During the same period, water level in North Bainbridge Well 9 dropped, but the subsequent trend is unclear. A flat trend is observed from 1996 to 1998 in the Island Utilities well. Trends for the North Bainbridge and Sand Road wells cannot be clearly interpreted with the available data set. Monthly collection of recovered water levels is recommended at the Sands Road wells.

Data from Island Utilities Well 1 indicates a long-term decline of over ½ foot per year. At this time, comparison with the EWL criteria indicates that the Fletcher Bay Aquifer in the Eagledale area has exceeded the criteria (½ foot per year for 10 years) and requires a response as outlined in Section 4.4.2.

Chloride concentrations for FBA wells were in the range of 7 to 18 mg/L, higher than observed in the other aquifers. The Fletcher Bay Production Well was an exception, typically exhibiting values less than 5 mg/L.

6 Recommendations

A framework for groundwater monitoring and data compilation has been developed under this study. As new data is collected and analyzed, the monitoring system will need to be refined and extended. At this time, the following items are recommended for immediate implementation:

1. Continue monitoring and data compilation. Provide for database maintenance.
2. Survey measuring points and ground surface elevations and geographic location at all wellheads.
3. Calculate distances from wells to coastline and enter into the database.
4. Add any historic water level data, which becomes available, to the database for wells included in the monitoring well network.
5. Investigate the extent of tidal influence on Island wells, following recommendations in Section 3.1.3. Notate tidally influence wells in the database.
6. Increase the monitoring well network with additional wells in strategic locations. Areas of interest include:
    - the west and east sides of the island that lack monitoring wells in the Sea Level Aquifer and
    - the Sea Level Aquifer in north island and Eagle Harbor areas that require definition of the lateral extent of elevated chloride concentrations.
7. Establish Early Warning Levels for Chloride Conditions as:
    - Chloride Condition 1 for concentrations exceeding background level, provisionally set at 30 mg/L,
    - Chloride Condition 2 for concentrations above 100 mg/L and for concentrations exceeding background that exhibit an increasing trend, and
    - Chloride Condition 3 for concentrations above 200 mg/L and for concentrations exceeding 100 mg/L that exhibit an increasing trend.
8. Establish an Early Warning Level as a drop in water levels, provisionally set at or above ½ foot per year over a 10-year period.
9. Implement monitoring responses for exceedances of Chloride Condition 1 in the Seabold area and of the EWL for safe yield in the Fletcher Bay Aquifer near Eagledale.
10. Determine background chloride levels for each aquifer unit. Investigate the relationships of chloride concentration with distance from the coastline and with elevation of well open interval for both spring and fall measurements. Identify any elevated chloride levels that may be due to factors other than seawater intrusion.

Determine the correlation of specific conductivity with chloride concentration for each aquifer unit. If necessary, revise the background chloride concentration used as an EWL for seawater intrusion.

11. Construct a groundwater model for Bainbridge Island. The model should answer the following questions:

- What are safe yields for Bainbridge Island aquifers?
- What are the limiting conditions on safe yields?
- What are the projected seawater intrusion impacts?
- What are the projected effects of future climate changes?

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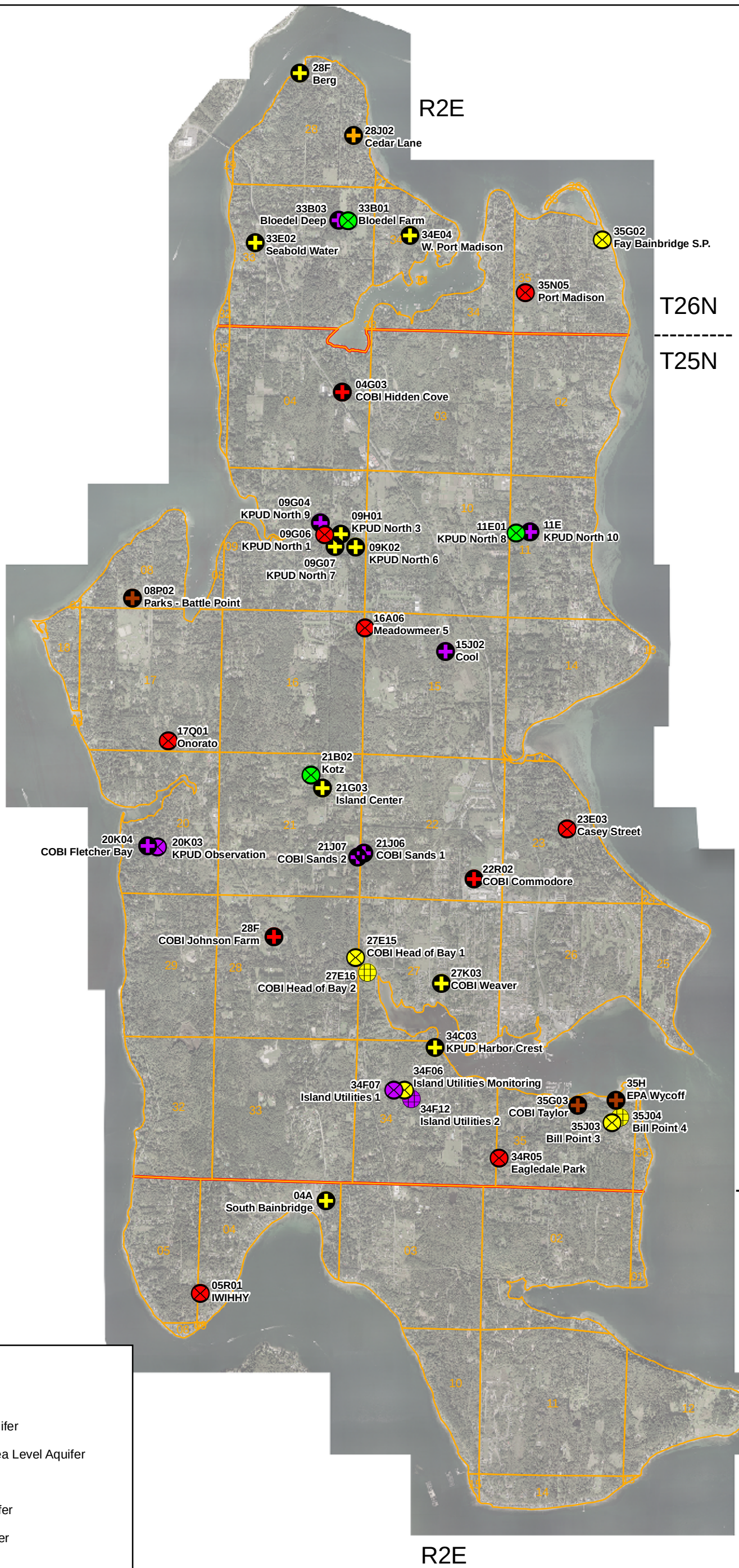
Limitations

Work for this project was performed and this report prepared in accordance with generally accepted professional practices for the nature and conditions of work completed in the same or similar localities, at the time the work was performed. It is intended for the exclusive use of City of Bainbridge Island for specific application to the referenced property. This report does not represent a legal opinion. No other warranty, expressed or implied, is made.



Aquifer

- Perched Aquifer
- Semi-Perched Aquifer
- Semi-Perched / Sea Level Aquifer
- Sea Level Aquifer
- Glaciomarine Aquifer
- Fletcher Bay Aquifer

Monitoring

- Water level monitored
- Water quality monitored
- Water level and water quality monitored
- Sections
- Township and range

0 4,000 8,000 Feet

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Groundwater Monitoring Well Network

Bainbridge Island, Washington

DATE: Oct 2006	PROJECT NO. 060016
DESIGNED BY: ACM	
DRAWN BY: ACM	FIGURE NO. 1
REVISED BY: ACM	

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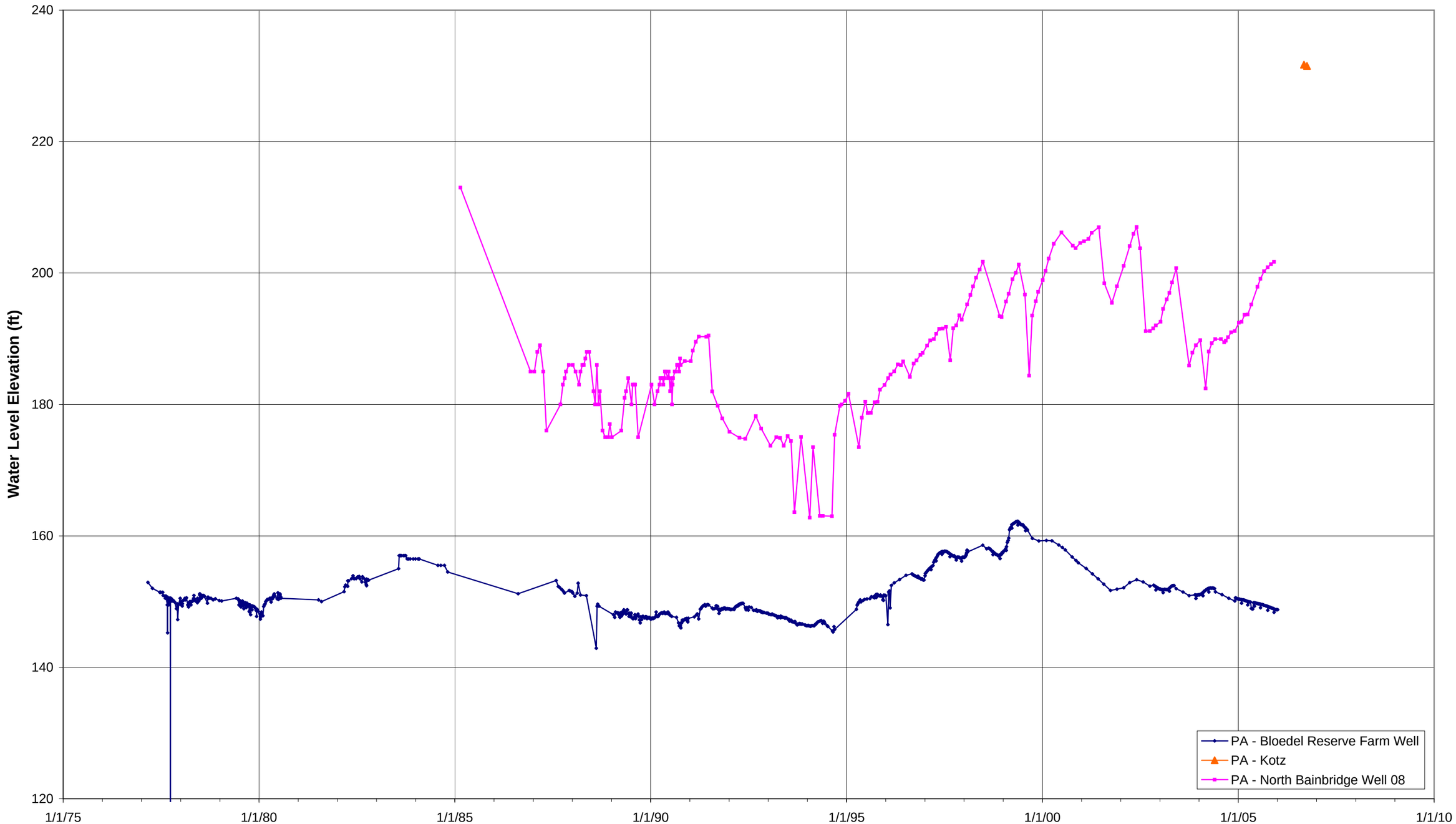

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Figure 2 Perched Aquifer Hydrographs
Groundwater Monitoring Program, Bainbridge Island, WA

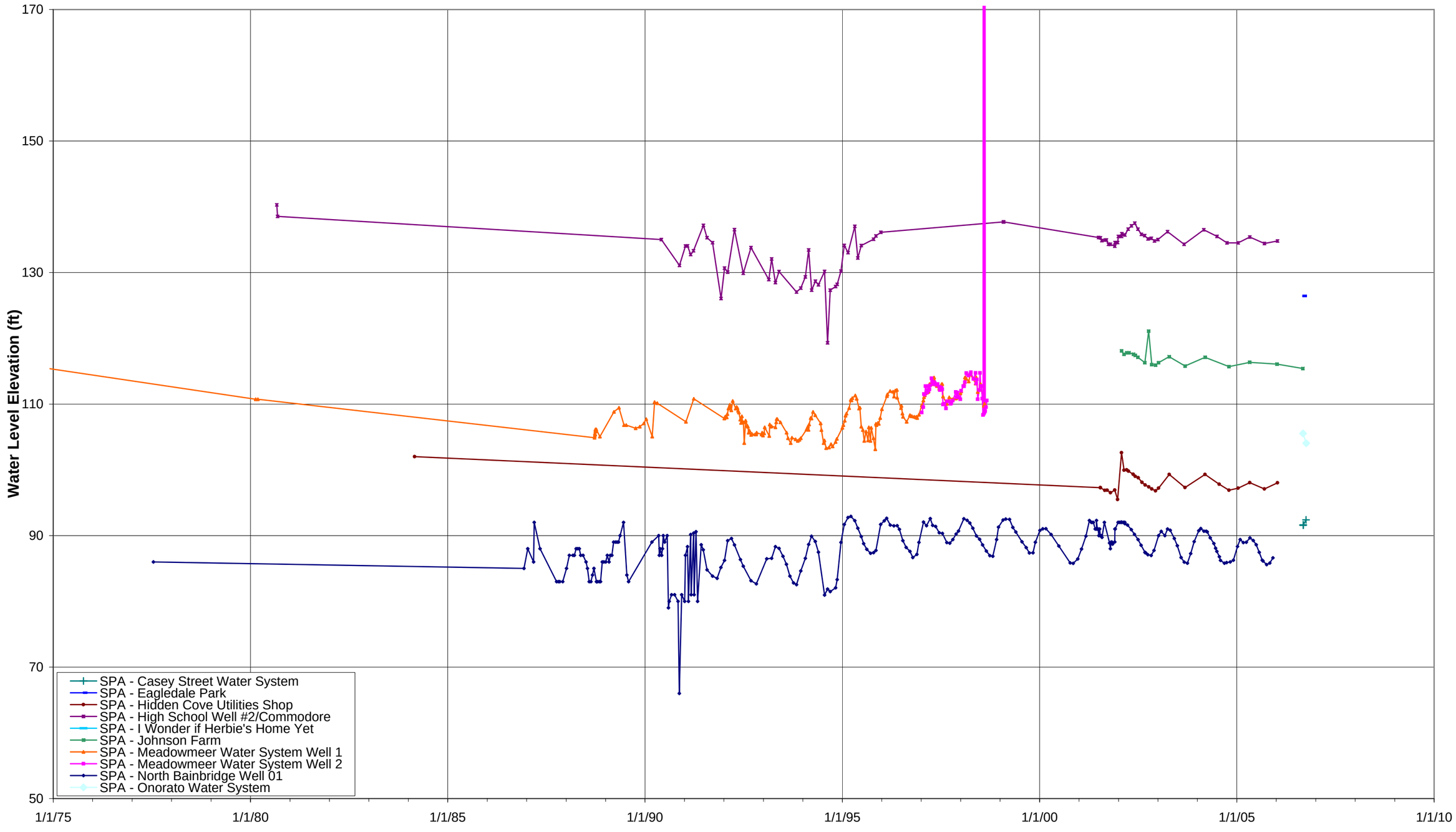

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Figure 3 Semi-Perched Aquifer Hydrographs
Groundwater Monitoring Program, Bainbridge Island, WA

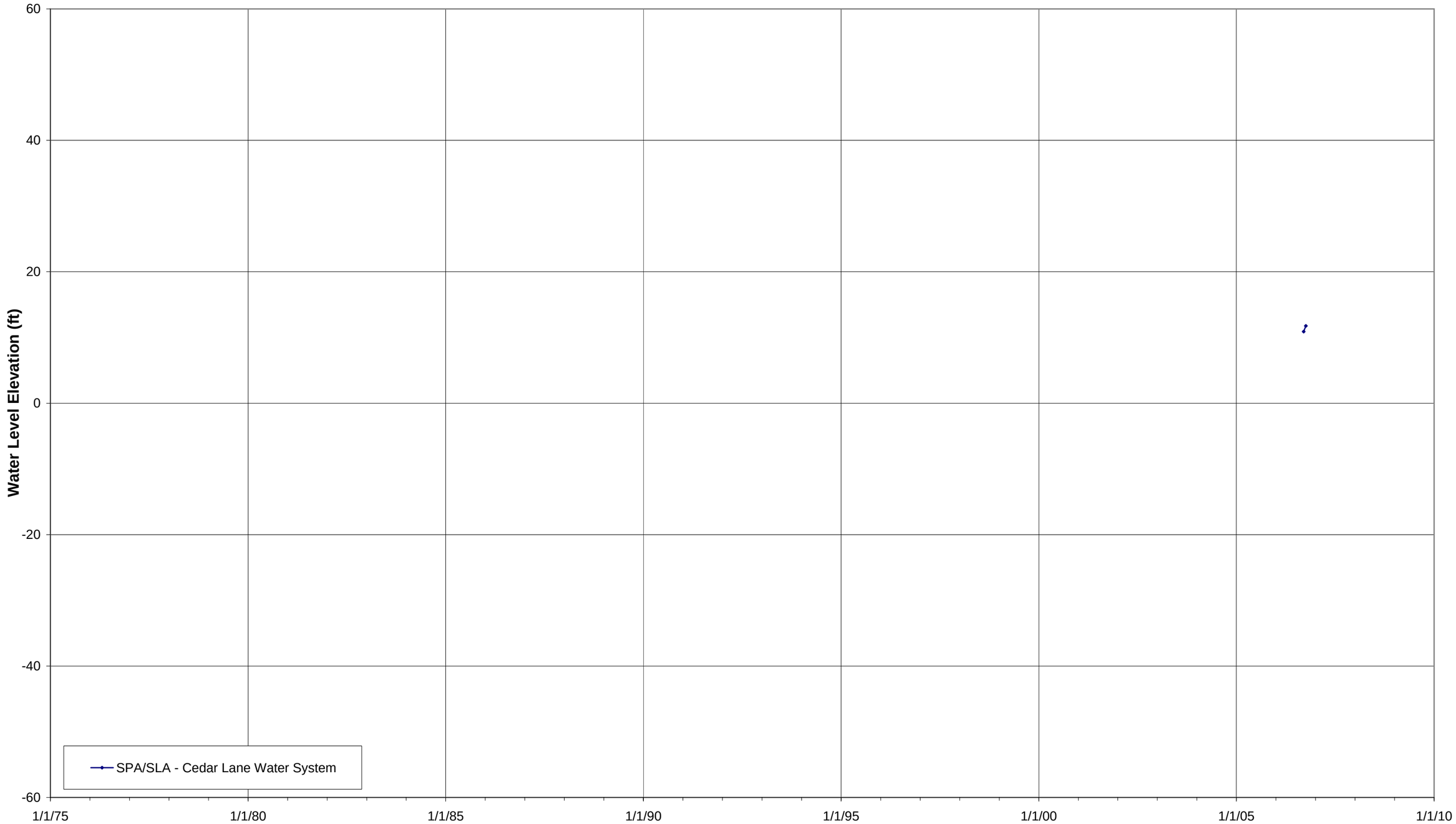

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Figure 4 Semi-Perched/Sea Level Aquifer Hydrographs
Groundwater Monitoring Program, Bainbridge Island, WA

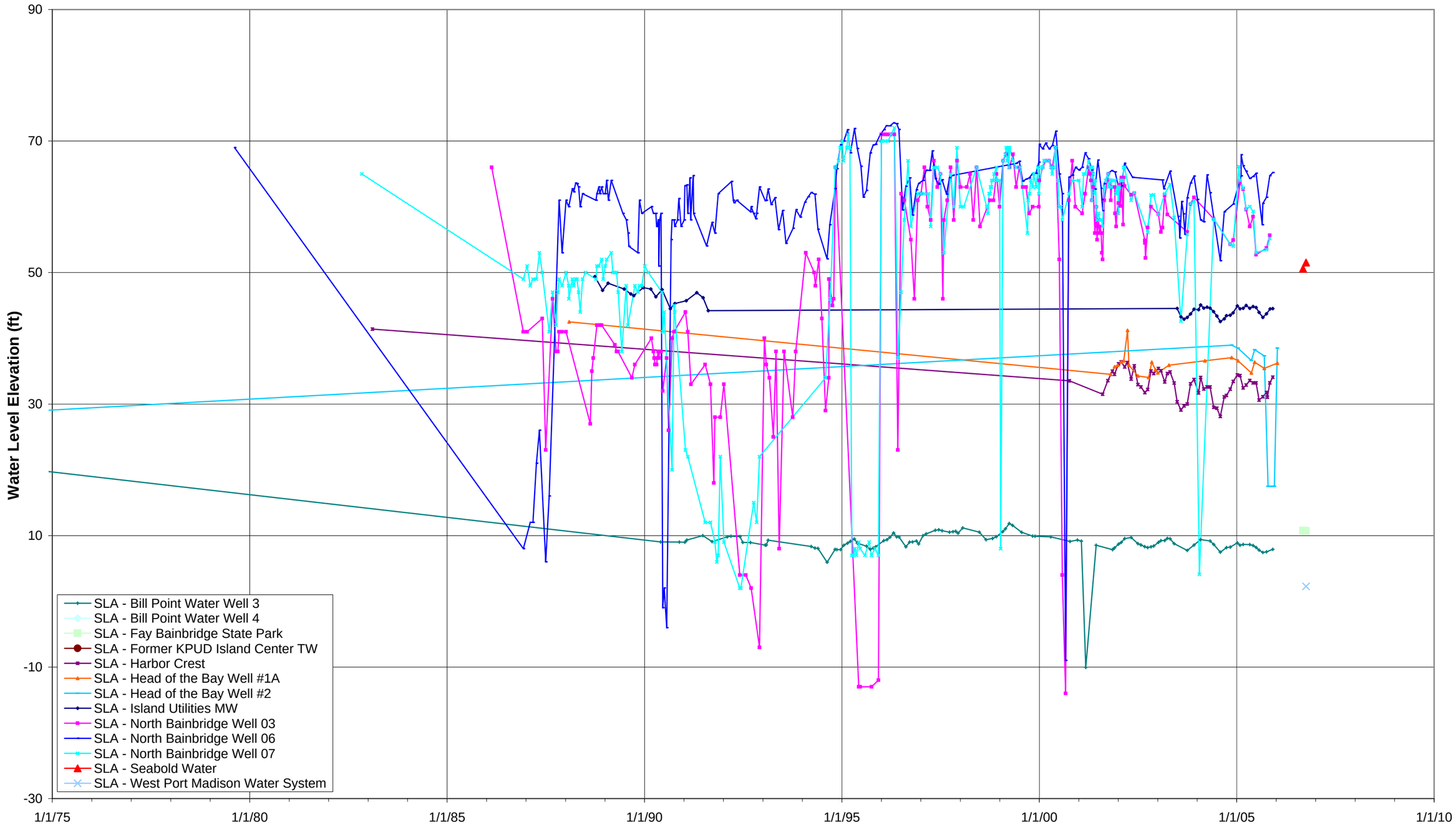

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Figure 5 Sea Level Aquifer Hydrographs
Groundwater Monitoring Program, Bainbridge Island, WA

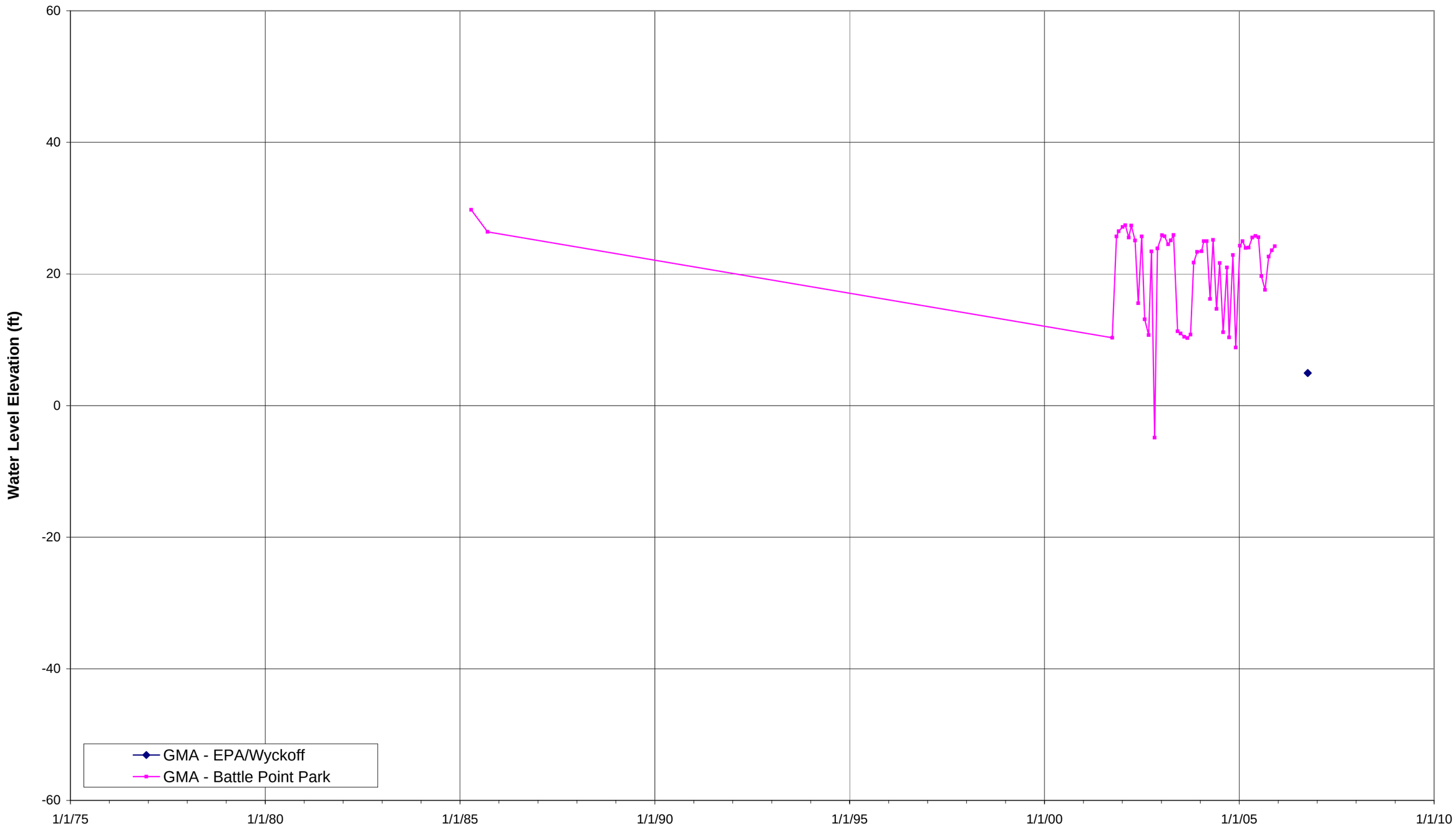

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Figure 6 Glaciomarine Aquifer Hydrographs
Groundwater Monitoring Program, Bainbridge Island, WA

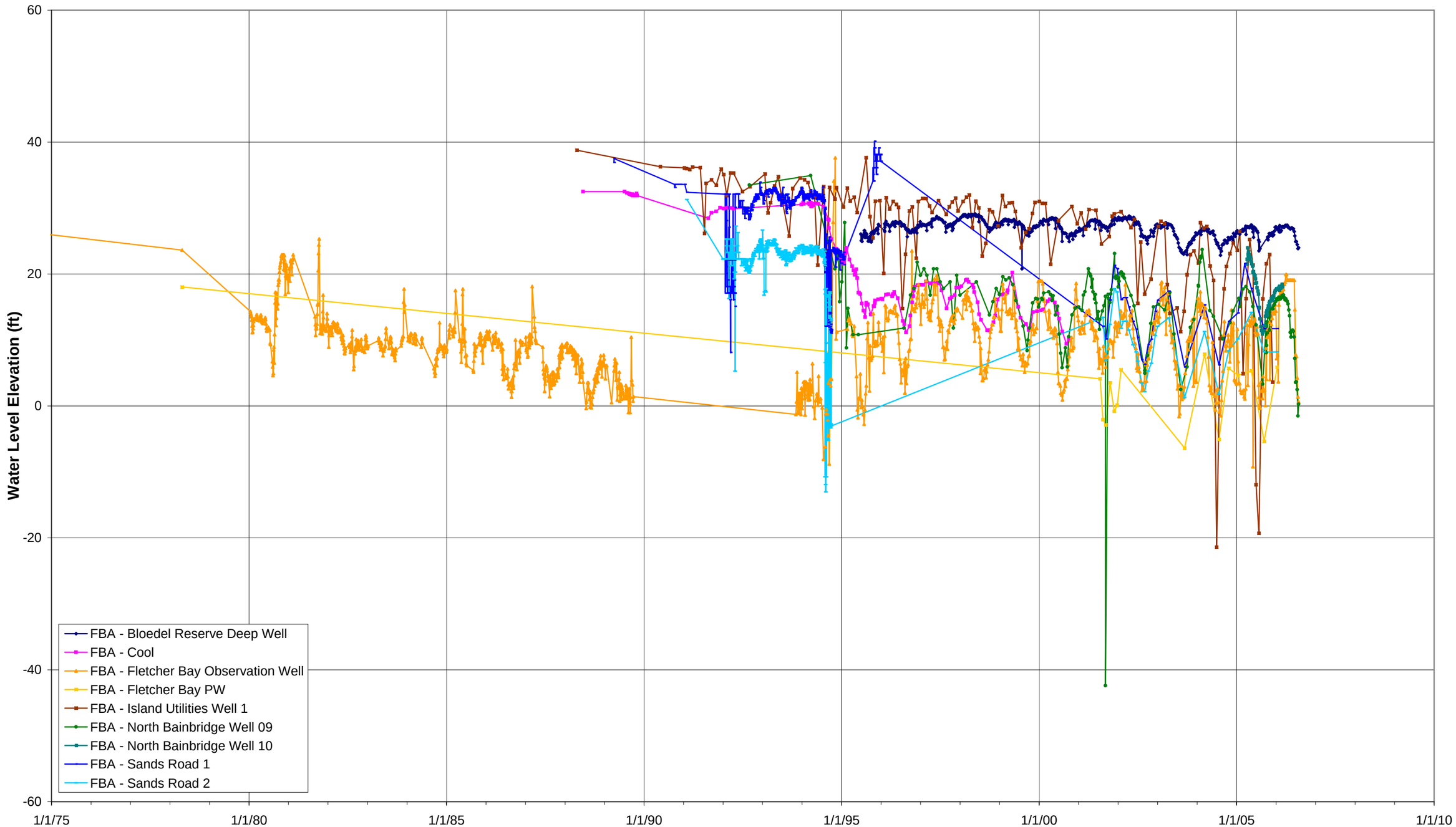

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Figure 7 Fletcher Bay Aquifer Hydrographs
Groundwater Monitoring Program, Bainbridge Island, WA

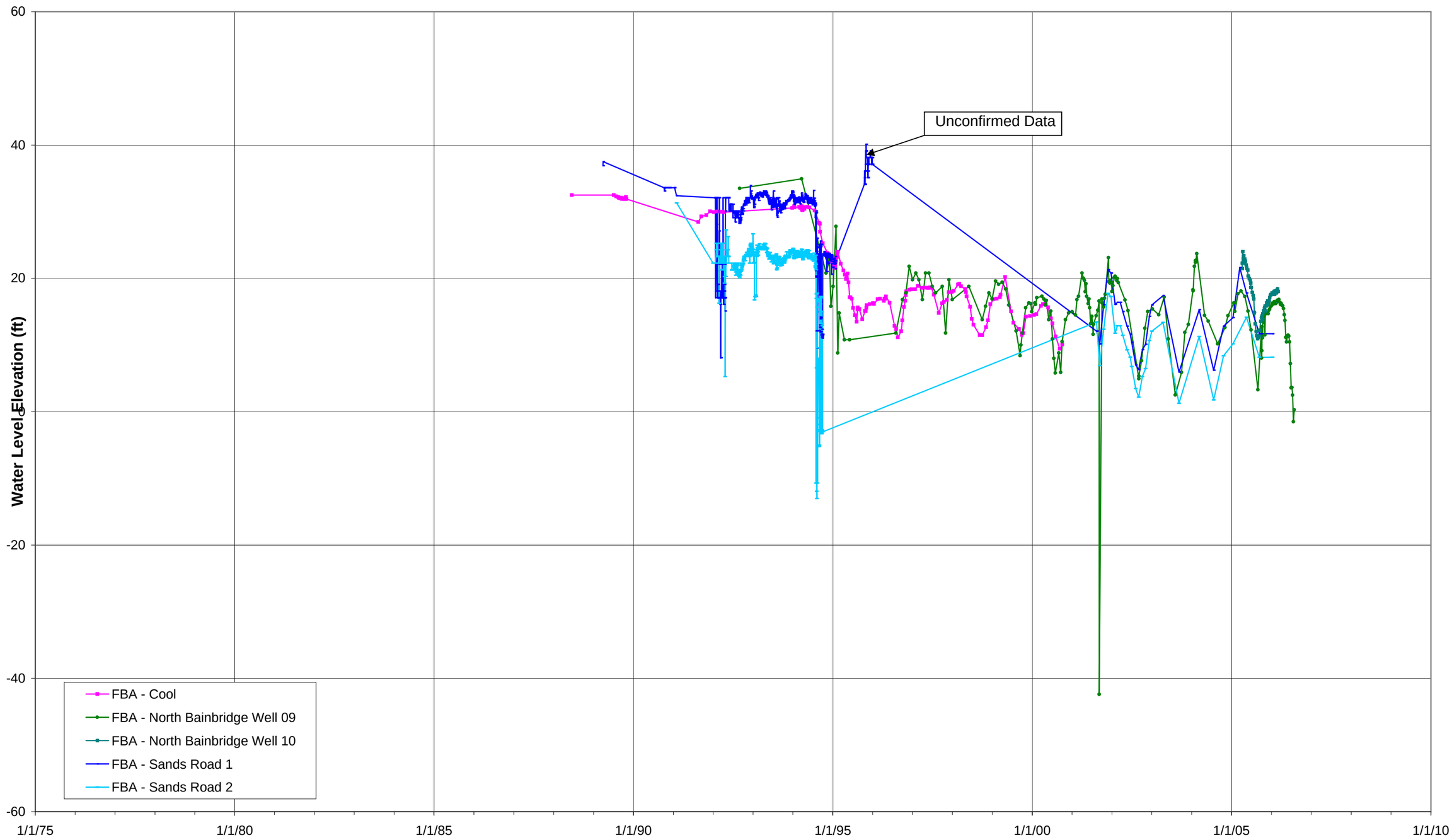

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Figure 8 Fletcher Bay Aquifer Hydrographs - Central Wells
Groundwater Monitoring Program, Bainbridge Island, WA

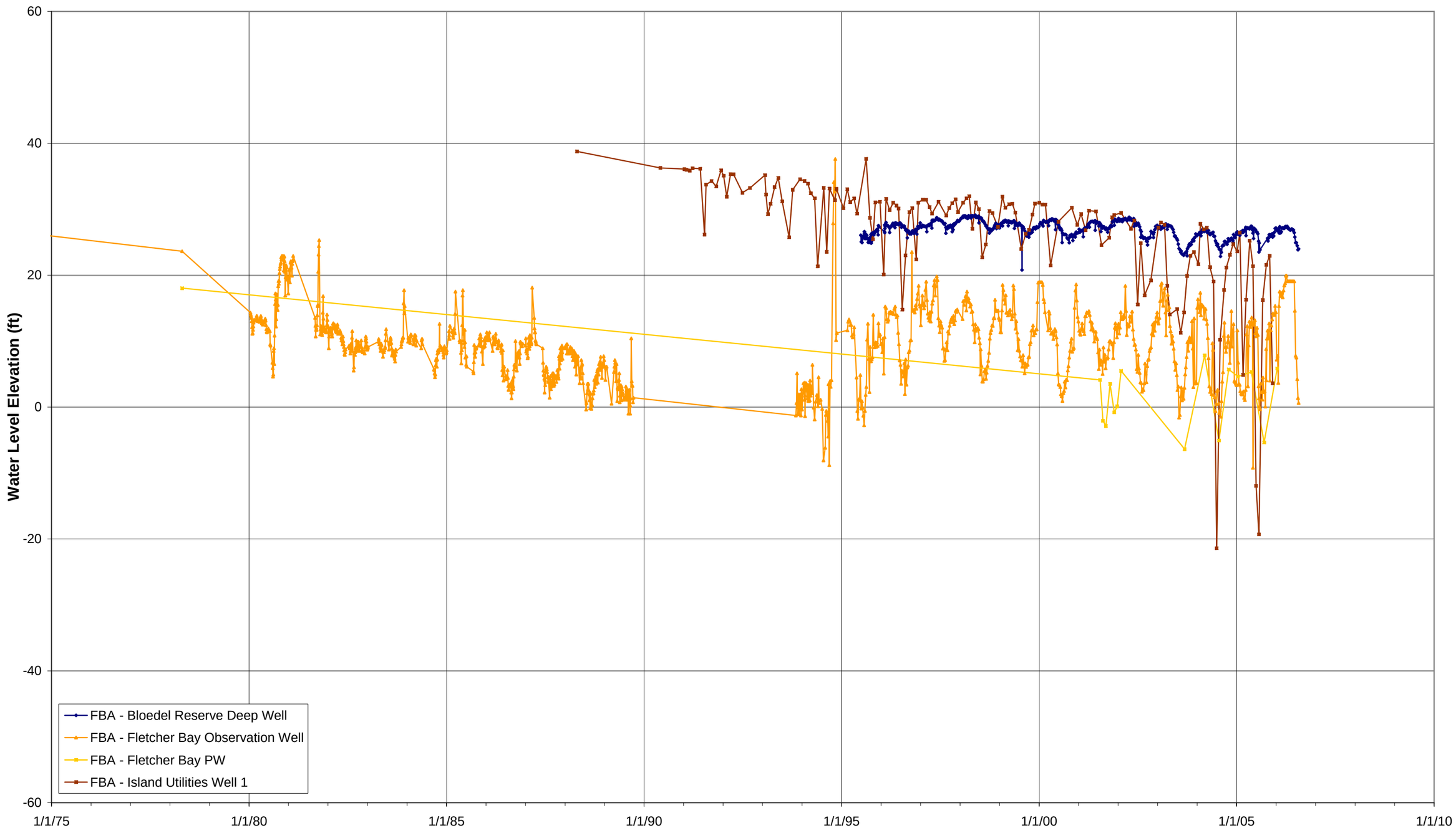

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Figure 9 Fletcher Bay Aquifer Hydrographs - Peripheral Wells
Groundwater Monitoring Program, Bainbridge Island, WA

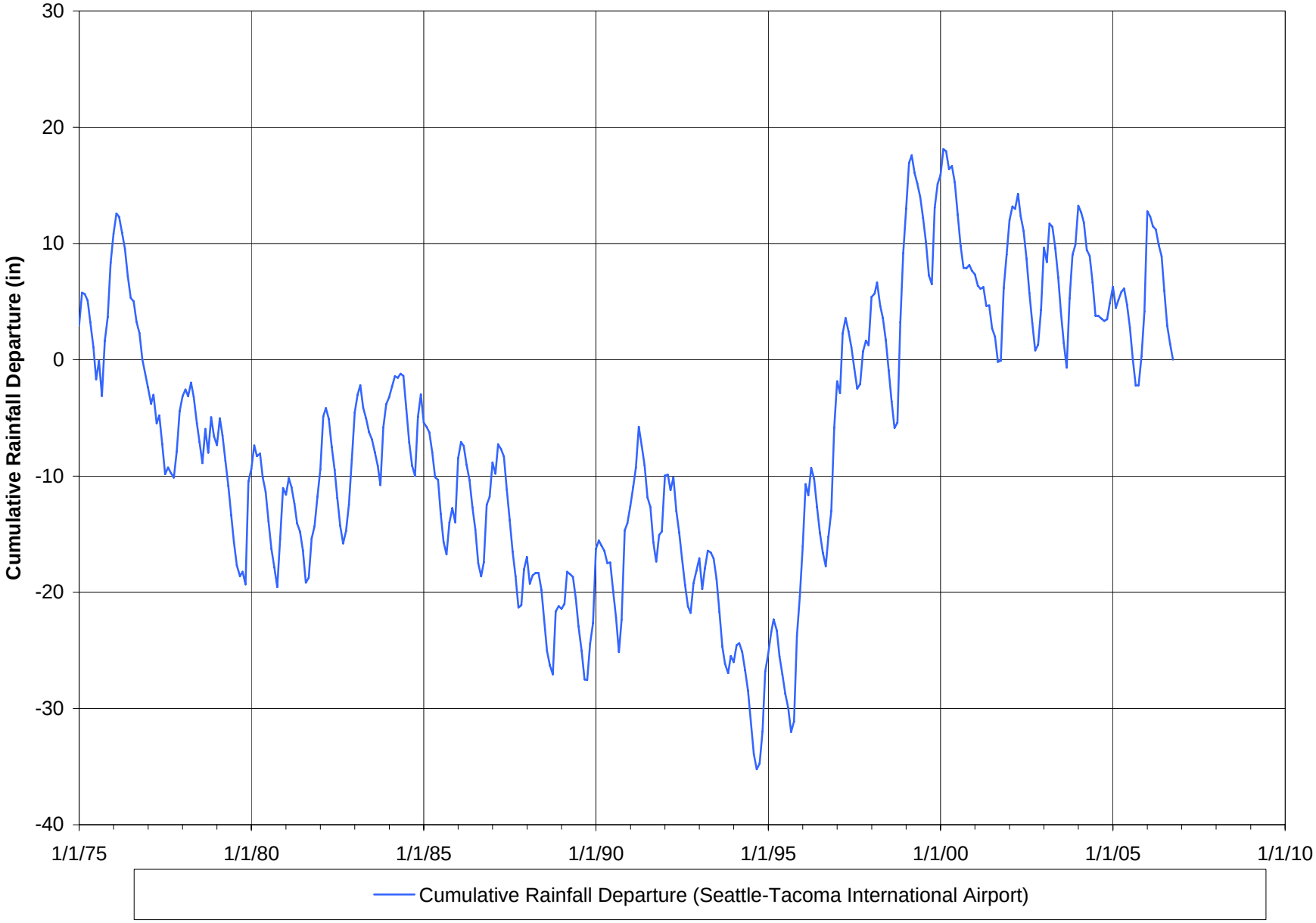

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Figure 10 Cumulative Rainfall Departure
Groundwater Monitoring Program, Bainbridge Island, WA