Appendix N. Wellhead Protection Plan for the Lower Issaquah Valley

CITY OF ISSAQUAH WASHINGTON

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Sammamish Plateau
Water and Sewer District

City of Issaquah

Lower Issaquah Valley Wellhead Protection Plan

Volume I - Report

Submitted by:

Golder Associates

In Association with
Carr/Associates and
The Barton Group

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Golder Associates Inc.

4104-148th Avenue, NE
Redmond, WA 98052
Telephone (206) 883-0777
Fax (206) 882-5498

Golder Associates

FINAL DRAFT REPORT

TO

SAMMAMISH PLATEAU WATER
AND SEWER DISTRICT

ON

LOWER ISSAQUAH VALLEY WELLHEAD PROTECTION PLAN

Prepared by

Golder Associates Inc.
Redmond, Washington

In Association with:

Carr Associates
and
The Barton Group

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EXECUTIVE SUMMARY

A Wellhead Protection Plan (WHPP) has been prepared for the Lower Issaquah Valley (LIV) as part of ongoing groundwater management activities in the area. The WHPP is a technical assessment of groundwater resources in the area with an emphasis on groundwater quality protection. Through an understanding of hydrogeologic conditions, current and future growth in the LIV can be managed without endangering a currently invaluable groundwater resource. The wells in the Lower Issaquah Valley supply potable drinking water to residents and businesses in both the City of Issaquah and Sammamish Plateau. Both these communities are isolated from the regional water-supply distribution system serving many other Eastside communities, and groundwater represents the sole source of drinking water both now and for the foreseeable future. An intertie to a regional water supply may be as many as 15 years away.

This document fulfills regulatory requirements for wellhead protection planning and groundwater quality protection. There are many facets to groundwater quality protection and the Wellhead Protection Plan is intended to serve as an on-going guide for local administrators to assess the potential impacts of land-use on groundwater quality in the LIV. Implementation of wellhead protection strategies offered in this document will take place through future activities within the governing jurisdictions in the LIV. In its present draft form, the WHPP does not present a detailed plan for implementation. The following executive summary discusses the main components and results of the WHPP.

Hydrogeology and Delineation of Wellhead Protection Areas (WHPAs)

The technical evaluation of the LIV aquifer consisted of a thorough review of available hydrogeologic and groundwater-quality data compiled from a number of different sources in addition to the collection of new data as part of the WHPP. The conceptual hydrogeologic model for the LIV aquifer is based on the geologic history of the LIV. The present-day LIV was once at the bottom of Lake Sammammish, and deltas were built out into the ancient lake. These deltas are composed of hundreds of feet of sand, gravel and silt, and lie beneath the present-day ground surface of the LIV. Delta deposits are exposed along the eastern margins of the LIV at the Lakeside Gravel Pit; on western Grand Ridge; and on the Lake Tradition Plateau. The delta deposits constitute the primary water-bearing aquifer for water-supply wells in the LIV. The deposits plunge beneath the ground surface in the LIV, and are tapped by production wells ranging from 100 to 250 feet in depth.

The LIV aquifer is estimated to be approximately 300 feet thick, and, on a regional scale, behaves as a single unconfined aquifer. Discontinuous silt layers exist at depth and may provide varying levels of locally confined or semi-confined conditions. However, it is difficult to differentiate multiple aquifers with certainty, and a single aquifer is a defensible conservative assumption based on existing data. It is conservative in that no protection from contamination is offered by stratigraphic layers within the aquifer. Aquifer properties have been estimated from pumping tests performed on SPWSD production wells and from near-field single well tests performed on various other wells in the LIV. Hydraulic conductivity of the aquifer is estimated to be between 200 and 300 feet per day.

Groundwater recharge occurs primarily along more permeable surficial sediments located along the margins of the LIV, including the western portion of Grand Ridge and Lake Tradition Plateau; the western portion of the LIV and possibly via infiltration from Issaquah Creek, upstream of Central Issaquah. Hydrogeologic conditions on the eastern upland areas are not well known. Horizontal hydraulic conductivities are estimated to be between 600 and 800 feet per day. Vertical hydraulic conductivities are estimated to be between 0.8 and 2.7 feet per day.

The importance of recharge from the eastern margins of the LIV (i.e. Grand Ridge and Lake Tradition Plateau) is demonstrated by water-level data collected over the course of 1991-1992; by water-balance estimates based on hydrologic information; and by the results of a groundwater flow model used in developing wellhead protection areas. Water-level data show a shift in groundwater flow direction which is consistent with a "pulse" of groundwater recharge into the LIV from the eastern highland areas. Water-balance calculations indicate that up to 30% of annual recharge to the LIV may originate from the eastern highland areas. Groundwater flow modeling indicates that observed water-level conditions in the LIV can be adequately reproduced with up to 90% of recharge originating from the eastern highland areas.

The conceptual model of the aquifer, based on the available data, was integrated into a simple steady-state groundwater flow model. This model was then used as a predictive tool for determining the likely paths and velocities of groundwater flowing towards the supply wells in the LIV. The computer model was developed using existing data for calibration, so that the model simulates actual groundwater flow in the LIV, as accurately as the available data permits. The computer model contains boundaries at the Issaquah Gap (near the Hobart Junction), along bedrock boundaries on the eastern and western margins o the LIV, and at Lake Sammamish. A flux boundary was used along Grand Ridge and Lake Tradition Plateau to represent the transition between the upland areas (elevation 500 feet) and the lower valley (elevation 70 feet). Fluxes were assigned to these boundaries that were consistent with available water-balance data from these sub-catchments. The computer model was "calibrated" to reproduce observed water-levels in wells within the LIV.

Once the computer model was calibrated, predictive simulations of pathlines and capture zones were run to determine wellhead protection areas. The pathlines and velocities predicted by the model form the basis for delineating time-based capture zones for individual wells. Theoretically, a "particle" of water found within a one-year capture zone will reach a well within one-year. The "particle" is a mathematical aspect of the computer model which is used to track and display the flow field generated by the computer. The 1-year, 5-year, and 10-year capture zones were determined and used as the basis for delineation of wellhead protection areas. This is consistent with standard WHPP guidelines used throughout the country.

In addition to the modeled wellhead protection areas, hydrogeologic mapping was used to supplement wellhead protection delineations. Deposits of permeable deltaic and coarse glacial sediments are mapped at ground surface, primarily along Grand Ridge and Lake Tradition Plateau, represent recharge areas to the LIV aquifer. Though not explicitly incorporated into the computer-generated WHPA's, these recharge areas should also be protected from contamination sources.

Figure 18 from the WHPP shows the composite wellhead protection areas based on computer modeling and hydrogeologic mapping. Land-use planning in these areas must consider impacts to groundwater quality. The consequences of severe groundwater contamination are serious because of the present dependence on groundwater as a water supply.

Groundwater Quality and Contaminant Source Inventory

There are a variety of contaminants that are a health concern for drinking water supplies. They are broadly categorized into organic contaminants and inorganic contaminants. Organic contaminants include various petroleum products used for a variety of applications such as gasoline (benzene, toluene, xylene), de-greasing solvents (trichloroethylene), dry-cleaning solvents (tetrachloroethylene), pesticides and herbicides. Some organic compounds are denser than water (DNAPL) and others are lighter than water (LNAPL). Inorganic contaminants include metals (e.g. lead, chromium, arsenic) and nitrate. All of these contaminants have associated health risks and established maximum contaminant levels (MCL's) in drinking water. Transport of contaminants in groundwater is a complex field, and a comprehensive treatment of all possible contaminants is beyond the scope of the WHPP. However, the rate of contaminant movement in groundwater is dependent on specific properties of individual contaminants. Many organic contaminants are degraded or transformed by naturally-occurring microorganisms in soil or groundwater. Many metals are preferentially adsorbed to soil particles and do not travel rapidly in groundwater. A general recognition of these complexities is necessary for proper planning and responses to sources of groundwater contamination.

Groundwater quality in the LIV is presently excellent and well below regulatory MCL's in all wells sampled as part of the WHPP. One shallow well detected low levels of organic contamination, but was still below regulatory limits. Several shallow monitoring wells not sampled as part of the WHPP have detected varying levels of contamination from lead, and several organic contaminants. Most of these wells have been associated with gasoline storage tank leaks within the City of Issaquah.

An inventory of contaminant sources was conducted to establish the proximity of these sources to the capture zones determined from the hydrogeologic analyses. Sources of information for the inventory included WDOE databases, aerial photographs, land-use maps, and a telephone survey of area businesses. The LIV is not a major industrial area and relatively few potential point source contamination sites were identified:

- A total of 39 underground storage tanks containing petroleum products (e.g. gasoline) are present in the LIV. Of these 39 tanks, 16 are within the 5-year WHPA and contain approximately 350,000 gallons of product.

- A total of 16 businesses generate or store potentially hazardous contaminants such as solvents.

Chronic sources of contamination from urban run-off and other land-uses were evaluated based on mass loadings to groundwater:

- An estimated 2,600 kilograms of nitrate and 42 kilograms of lead per year are generated within residential and commercial land-uses from urban run-off and fertilizer applications. This contaminant load is equivalent to nitrate and lead concentrations in LIV production wells which are below the MCL for nitrate. Low levels are confirmed by direct sampling.

Contamination from transportation corridors was also evaluated. An estimated 70 million gallons of stormwater annually are discharged to the ground surface or stream network from Interstate 90. Although chronic long-term contamination has not been detected, the lack of a stormwater collection system significantly increases the risk of groundwater contamination from a traffic-related spill on the interstate. Accident rates on I-90 have increased steadily since 1988, though a serious contamination event has not yet occurred.

A simple risk screening using an EPA methodology was also carried out. Presently, there exists only low or moderate risks to groundwater quality, with transportation spills posing the highest risk relative to other contamination sources. The presently excellent groundwater quality, low contaminant loads and low to moderate risk of present sources indicates that future land-use probably represent the greatest risk to groundwater quality in the LIV.

Future Land-use Impacts to Groundwater Quality

Future land-use in the LIV is not yet well established. Continued development in the LIV, however, does pose a threat to existing groundwater quality. A variety of projects, such as the Grand Ridge MPD, Western Grand Ridge Urban Zone, East Sunset Bypass, and general increased commercial development in the City of Issaquah, could affect overall groundwater quality or directly contaminate the aquifer. Additional sources of contaminants, such as UST's or solvent use in commercial or industrial zoning should be managed carefully. Increased residential and commercial development on the eastern upland areas should address impacts to groundwater quality and recharge. Nitrate loads to the aquifer were estimated using available USGS, EPA, and King County data on stormwater run-off and residential applications. The results of these loading calculations indicate that the addition of 1,160 homes on the eastern recharge areas, using 1-acre lots and septic systems, causes excessive nitrate loads to the LIV aquifer and may result in nitrate levels above 5 mg/L (one-half the maximum contaminant level for nitrate). Development at 5-acre density reduces the nitrate load, but degradation of groundwater quality still occurs. Development on the recharge areas of Grand Ridge and Lake Tradition Plateau will require a carefully managed combination of open-space, municipal services, advanced engineering designs (e.g. stormwater infiltration) and prudent land-use policy in order to preserve groundwater quality.

Wellhead Protection Strategies

A variety of wellhead protection strategies are available to manage land-use, prevent groundwater contamination, and respond to groundwater contamination if it occurs. Administrative and planning aspects of Wellhead Protection need to be integrated and coordinated with ongoing state and county programs for groundwater quality protection. These include state hazardous waste programs, state anti-degradation policy and the soon-to-be-released Groundwater Management Plan for the Issaquah Basin. The strategies offered in the WHPP are presented in a general context and are intended to be embellished, discussed and refined in a public forum as groundwater management issues become more focused in the area. High priority recommendations for Wellhead Protection are summarized as follows:

- A Wellhead Protection administrative position should be created to specifically address groundwater quality issues in the LIV and serve to interface with planning, public works, environmental, and surface-water management departments of King County, the City of Issaquah, and SPWSD;

- A Wellhead Protection Committee (WHPC) should be created to address local groundwater management issues. Regional groundwater management issues in the Issaquah Basin should continue to be addressed by the Groundwater Advisory Committee (GWAC). The WHPC should maintain sufficient autonomy to resolve issues which specifically affect wellhead protection areas in the LIV.

- The City of Issaquah should begin developing emergency spill response capabilities as a pre-cursor to a detailed spill response plan involving City, State, and County emergency responders. Spill response training of City Fire Department personnel, purchase of basic spill response materials, and contracting with a clean-up contractor are immediate needs. More detailed aspects of spill response planning, such as hazard analyses and agency coordination, can be addressed in a more detailed spill response plan.

- Contingencies for groundwater supply should continue to be developed. The recent intertie between SPWSD and the City of Issaquah now provides additional source-redundancy should one or more wells be impacted by contamination. Additional contingencies such as wellfield operation strategies, artificial recharge, and identification of additional groundwater sources should be evaluated. Water rights issues surrounding hydraulic continuity of groundwater and surface water should continue to be addressed.

- Public involvement in Wellhead Protection Planning should begin immediately and should become a regular feature of City and County programs aimed at water quality. Consistent and persistent messages should be conveyed regarding the value of the groundwater resource and the rationale behind management strategies.

Detailed strategies for wellhead protection include land-use restrictions or prohibitions, changes in zoning, special permit requirements, site or project design specifications, contaminant inventory programs, and long-term monitoring. Preferred alternatives, detailed recommendations, or example ordinance/policy statements have not been provided in the WHPP at this time. The WHPP will continue to evolve as more technical information is collected and more detailed strategies are developed and implemented.

The Wellhead Protection Plan was developed for the Sammamish Plateau Water and Sewer District, which has no jurisdictional control over land-use in the LIV. The WHPP itself has no binding regulatory content, though it brings the need for decision-making regarding groundwater quality management into the proper forum. Decisions regarding preferred strategies, recommended ordinances, or permit requirements will remain firmly in the control of the City of Issaquah and King County. However, based on the information presented in this WHPP, the following observations are offered:

- The dependence on groundwater in the LIV is substantial and is likely to continue for some time. The implications of losing supply capacity in the face of accelerated development and growth are significant;

- The LIV aquifer is complex, and further refinement of the hydrogeologic understanding of the aquifer will not likely keep pace with the land-use pressures on the area. Decisions on groundwater management should therefore be made using conservative assumptions; and

- Restrictive land-use policies in some form are likely, but they can possibly be supplemented with special permitting which would ensure that wellhead protection and groundwater quality management goals are met while offering flexibility and design innovations to landowners. This also provides the opportunity for additional technical information on the aquifer to be collected and incorporated into the existing conceptual model of the aquifer system.

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1. INTRODUCTION

Wellhead protection is a federally-mandated, State-implemented program designed to protect groundwater-based drinking water supplies. The Federal mandate is provided under Section 1428 of the 1986 Safe Drinking Water Act Amendments, and the State Wellhead Protection Program is managed by the Washington State Department of Health (WDOH). The intent of the State's Wellhead Protection Program (WHPP) is to protect potable groundwater supplies through resource management strategies aimed at pollution prevention. The State WHPP operates in conjunction with the Groundwater Management Area (GWMA) Program, Aquifer Protection Program, Critical Aquifer Recharge Area (CARA) Protection Program, and State point and non-point pollution control programs. There are currently no requirements for wellhead protection in the Washington Administrative Code (WAC). However, Water System Plans required under WAC 246-290-100 and WAC 246-290-410 will require wellhead protection plans following a proposed modification to the State Board of Health's Drinking Water Regulations due in the summer of 1993.

The need for wellhead protection manifests itself in a number of ways. The demand for groundwater continues to increase in the Pacific Northwest and in particular Puget Sound and East King County. However, groundwater is an increasingly difficult resource to develop because of competing uses and potential environmental impacts. Thus, existing groundwater resources represent a resource with substantial present value which would be difficult and costly to replace, if damaged.

Public water purveyors have primary responsibility for developing and implementing local wellhead protection programs. Because of the purveyors often limited jurisdictional control, integration and coordination with state, county and local agencies involved in water-resource issues is essential. However, a key aspect of wellhead protection is the emphasis on local control of the wellhead. The nature of wellhead protection is such that local conditions, whether geologic or political, are key in developing working management strategies to protect a well or wells supplying drinking water.

The Lower Issaquah Valley (LIV) is a growing urban/rural area that relies solely on groundwater for drinking water supplies. Groundwater from the LIV is used by residents of the City of Issaquah and the Sammamish Plateau. The Wellhead Protection Plan for the LIV was initiated by the Sammamish Plateau Water and Sewer District (SPWSD), in conjunction with the City of Issaquah. The program was funded by both SPWSD and the City, with a matching grant from the Washington Department of Ecology (WDOE) Centennial Clean Water Fund.

1.1 Study Area

The Issaquah Basin encompasses approximately 61 square miles southeast of Bellevue, Washington (Figure 1). The basin is made up of eight-sub-basins as shown on Figure 2. The Lower Issaquah Valley (LIV) as defined in this report, encompasses approximately 40 square-miles area including four of the eight sub-basins of the Issaquah Basin (see Figure 2). The study area extends from the Issaquah-Hobart Gap to Lake Sammamish, and from Grand Ridge to Tibbetts Creek.

1.2 Background and Major Issues

The two jurisdictional entities in the LIV are the City of Issaquah and King County. The Tahoma and East Sammamish Planning Areas include portions of the LIV (Figure 3). The SPWSD wells are within King County jurisdiction and the City of Issaquah's wells are within City jurisdiction. The SPWSD and City of Issaquah have developed a good working relationship in developing this Plan, and on other water-related issues.

One of the major issues surrounding water resource management in the LIV is the complex interplay of growth management and water resource development. Groundwater represents the sole source of potable water for the City of Issaquah and residents on the Sammamish Plateau. At the same time, the Plateau area and City of Issaquah are growing rapidly and additional water supplies will be needed to meet projected population increases. The geographic location of the LIV, however, is such that inter-ties with regional water sources such as those that serve the City of Seattle and Bellevue are many years away, and may not be feasible in the near term. Thus, the implications of groundwater contamination in the LIV aquifer are serious.

More specific concerns regarding groundwater quality include:

- **Transportation:** The wells serving the City of Issaquah and SPWSD are directly adjacent to Interstate-90. A traffic-related spill of hazardous materials could jeopardize the wells and is a significant concern;

- **Underground Storage Tanks:** There are over 100 underground storage tanks (UST's) in the Issaquah area which store predominantly gasoline products. The impetus for initiating wellhead protection planning was provided in large part by a leaking underground storage tank (UST) in April 1990 at a gasoline service station in the City of Issaquah. The proximity of the spill to SPWSD wells 7 and 8 highlighted the vulnerability of the District's production wells to surface contamination. The District's well 8 has been used very sparingly since 1990, and no contamination has yet been detected in the well. Other UST leaks have occurred in the LIV, and several groundwater investigations, tank removals, leak-detection systems, and even an air-stripper have resulted;

- **Stormwater/Urban Run-off:** Increasing urbanization has resulted in increased stormwater run-off in the LIV. Surface-water studies have examined the effects of stormwater, and have focused on flooding impacts and water quality impacts to streams and wetlands. However, stormwater (when infiltrated to the subsurface) is also a potential chronic source of groundwater contamination, particularly nitrates, metals and petroleum products.

- **Zoning/Density:** Increased growth in the area will result in proposed changes in zoning or density which could affect groundwater quality. The present debate over the proposed Grand Ridge Development is an example of zoning issues. The development is presently within King County's rural zoning designation, with some urban zoning on the western margin. The question of jurisdictional control over land-use in this area is becoming increasingly important and involves some wellhead protection issues.

1.3 Objectives and Scope

There are multiple objectives to the Wellhead Protection Plan (WHPP), summarized as follows:

- Develop and document a technical hydrogeologic evaluation of the Lower Issaquah Valley using existing and newly collected data;
- Perform wellhead protection area delineations for the three existing production well pairs in the LIV;
- Extrapolate possible future WHPA's using projected groundwater withdrawals;
- Perform a land-use and contaminant inventory within the WHPA's;
- Develop a working database for hydrogeologic, water quality, and land-use/contaminant data;
- Identify and rank potential threats to groundwater quality within the WHPA's; and
- Identify management strategies that will reduce the threat of contamination to the LIV aquifer system.

The emphasis of the wellhead protection plan, at this time, has been placed on technical issues and general management recommendations. Specific management issues such ordinances, zoning changes or special permanent requirements are presented in a general context. Specific issues will be addressed in a more formal, jurisdictional forum, as wellhead protection planning matures in the future; becomes integrated into other planning activities in the LIV; and receives more public involvement.

2. SUMMARY OF DATA AND ANALYSES

There have been a number of technical reports and evaluations of the geology and water-resources of the Lower Issaquah Valley. In addition to previous studies, development of the Wellhead Protection Plan entailed a number of field investigations to further refine the understanding of the hydrogeology. The purpose of this section is to summarize the data used in developing the interpretations and summaries presented in the Sections 3 and 4. Section 3 and 4 form the basis for the discussion of wellhead protection area delineation.

There are over 50 wells in the LIV, including high-capacity production wells, domestic wells and environmental monitoring wells. A diverse range of well names have been assigned to the wells in various studies. Because the local names of these wells are most familiar to those involved with the groundwater issues in the LIV, no attempt has been made to re-assign well names or numbers. However, in developing the database, universal well identifiers have been assigned to each well to facilitate data transfer and database management tasks. In the body of the report, the local names of the wells are used.

Figure 4 shows the locations and types of wells present within the lower Issaquah valley and surrounding areas. The breakdown of wells is as follows:

- The City of Issaquah and SPWSD operate seven high-yield production wells (City wells: COI1, COI2, COI4, COI5; and SPWSD wells: SP7, SP8);
- Approximately six high-yield private wells, including Darigold, Lakeside Sand and Gravel, Bell, and Overdale wells;
- Approximately 10 small private wells also exist within the Lower Issaquah Valley;
- Nine monitoring wells were installed as part of a cooperative program between SPWSD and the City of Issaquah. These monitoring wells are comprised of a series of piezometers which are screened across different intervals. They are used for monitoring water-levels and collecting water quality samples from specific water-bearing zones.
- As part of the wellhead protection program, three additional wells were installed for the purposes of water-level and water-quality monitoring, in addition to providing further geologic information.

Table 1 presents the construction details of all of the wells described above. Appendix A contains selected well logs.

2.1 Data Sources

The data used in this study was obtained through a number of existing and on-going studies in the Issaquah Basin and from new data collected as part of the Wellhead Protection Plan. These data sources have been broken down by the agency, or independent group responsible for initiating the study. Consultants are noted as authors of many of the studies.

Sammamish Plateau Water and Sewer District (SPWSD)

Groundwater exploration and development by SPWSD has entailed several studies including:

Well 7/8 Installations & Testing, Carr Associates, 1982-1985. During this period, SPWSD installed and tested two high-capacity production wells in the LIV. Wells SP-7 and SP-8 are completed at depths of between 83 and 148 feet, and 105 and 179 feet below ground, respectively.

Lower Issaquah Valley Resistivity Survey, Carr Associates, 1987. A total of 17 shallow resistivity soundings were performed across the LIV, north of Interstate 90. A Wenner array was used with a maximum a-spacing of 190 feet. Data were somewhat noisy because of electrical and powerline noise.

VT-Series Well Installations, Carr Associates, 1989. A series of monitoring wells (VT-1 through VT-8) were installed as part of ongoing water-supply investigations by SPWSD. Several of these wells were installed in conjunction with the Issaquah Groundwater Management Area (GWMA) program.

SPWSD Well 8 72-hour Pumping Test, Carr Associates, 1990. Wells SP-7 and SP-8 were tested at a combined rate of 5,600 gpm in September, 1990. Water-levels were measured in 17 wells or piezometers and six surface water gages.

SPWSD Well 9 Installation and Testing, Carr Associates, 1993. A new production well (SP-9) was installed near the Lakeside Gravel Pit in 1991. The well is completed at a depth of between 194 and 219 feet at 24-inch diameter and is capable of yielding about 3,200 gpm. Water rights are pending on the well and it is not presently in service. A detailed pumping test was performed in 1992. The well was pumped at a rate of 2,340 gpm for 9 days in July 1992. Water-levels were monitored in 55 wells or piezometers and 15 surface water gages.

SPWSD Wells 7/8 Water Quality Monitoring, Carr Associates, 1991-1992. Regular monitoring of wells SP-7 and SP-8 for volatile organic compounds has been performed since April 1990, when a leaking UST was discovered at a nearby gas station.

Water Supply Contingency Plan, Kennedy Jenks Chilton, 1991. A contingency plan was prepared to identify water-supply options in light of possible limitations related to either aquifer contamination or administrative restrictions on water rights. Fourteen permanent alternatives were evaluated.

Puget Sound Power and Light

Tradition Lake Plateau, Jones Associates 1978. A study conducted for Puget Sound Power and Light investigated the potential impacts from a proposed electrical switching station near Lake Tradition. Field investigations included 11 test pits, six borings up to 54 feet in depth, surficial geologic mapping, and surface water quality sampling. No permanent wells were installed, but groundwater flow directions were inferred based on the exploration program.

Issaquah Basin Groundwater Management Area Program (1986-ongoing)

The Issaquah Basin Groundwater Management Area (GWMA) Program was started in 1986. A draft report on the hydrogeology of the Basin (Task 5) was prepared in March, 1993. Hydrogeologic investigations carried out as part of the program have included the following:

Development of a well log database;

One round of water quality sampling in the basin, including two wells in the LIV;

Water-level monitoring in the basin between 1989 and 1992, including wells located within the LIV;

Installation of one monitoring well at the Issaquah Gap;

Precipitation monitoring within the basin, including six stations in the LIV; and

Stream monitoring within the basin, including five gages within the LIV.

King County Surface Water Management

King County SWM have been active in water-resource related activities in the Issaquah area, focusing primarily on surface water. Two important studies recently completed by SWM include:

Current/Future Conditions & Source Identification Report (1991). This report documents surface water conditions in the Issaquah Creek basin planning area. Field investigations and hydraulic simulation modeling were performed during 1990 and 1991 to document current conditions and predict future conditions resulting from land-use changes.

Issaquah Basin Non-Point Pollution Plan, Draft, February, 1992. This plan is a combination of a basin plan and a non-point action plan. Basin planning aspects include stormwater management and stream and wetland habitat protection. Non-point pollution aspects include identifying actions to prevent and remedy pollution from non-point sources. The plan systematically identifies goals and approaches to solving various problems (e.g., flooding, water quality) and proposes specific recommendations for the basin as a whole and for specific sub-basins. Some of these approaches and recommendations overlap with WHPP elements.

Lakeside Sand & Gravel

Exploration associated with mining of the gravel pit has resulted in a number of boreholes on the western margin of Grand Ridge, and conceptual discussions of geologic processes in the area. Specific reports include:

Cascade Testing 1978: This study presented a geologic history and conceptual geologic model of the gravel pit area. A total of 12 borings were drilled up to 120-feet in depth to determine the extent of gravel materials and depth to till.

Meriwether Leachmen 1984: This study summarized previous work and updated the conceptual geologic model. A total of 11 borings were drilled up to 160 feet in depth to determine the extent of gravel materials and depth to till.

Other Studies: Additional geologic work at the gravel pit has included a geophysical survey, (Koenen 1980), and miscellaneous letters and reports relating to sand and gravel reserves.

Blackhawk/Port Blakely - Grand Ridge 1992

The proposed Grand Ridge Master Plan Development (MPD) has involved geotechnical and surface water investigations of the area. Finalized reports of these investigations are not yet complete but data and information collected on Grand Ridge has been provided by the property owner for use in developing the Wellhead Protection Plan. This information includes surface geologic mapping, well logs for eight monitoring wells, results of single well hydraulic tests (slug tests) in five of the eight monitoring wells, and water-level measurements in eight wells during November, 1992 and January, 1993. In addition, a geographic information system (GIS) was developed and provided to the WHPP containing graphical database information on geology, wetlands, soils, and topography.

Arco Corporation 1990-1992

The leakage of an unknown quantity of gasoline from an underground storage tank at the Arco station at the corner of Gilman Boulevard and Front Street resulted in a comprehensive evaluation of groundwater conditions and water quality at the site. Interim reports, water quality data and final assessments of the site were provided by the site owner to the Wellhead Protection Program. The cleanup action at the site included:

- Removal of six UST's and replacement with double-walled systems;
- Removal of 84,000 gallons of groundwater from the excavation;
- Removal of 1,540 cubic yards of soil;
- Installation, water-level monitoring, and water-quality sampling of 21 monitoring wells;
- An eight-hour pumping test;
- Installation of two recovery wells and pumping of 4 million gallons of groundwater; and
- Installation of a bio-venting system to remove hydrocarbons from soils.

Lower Issaquah Valley Wellhead Protection Plan 1991-1993

The Wellhead Protection Program involved a comprehensive hydrogeologic evaluation of the LIV based on extended monitoring, field data collection and groundwater modeling. The data collection activities carried out as part of this Plan include:

Monitoring Wells — Three monitoring wells were installed during August 1992 for the purpose of establishing groundwater quality monitoring capabilities in previously un-monitored areas that could potentially be affected by contamination. One well (WH-1) is located on East Sunset Way, along the eastern boundary of the LIV, and was positioned to monitor groundwater influx from the East Fork Issaquah Creek Valley. Two wells (WH-2 and WH-3) are located along Gilman Avenue, and were positioned to monitor groundwater flowing southwest through the commercial Central Issaquah area. Well logs are presented in Appendix A.

Water-level Monitoring — Water-levels have been measured from 26 wells throughout the lower Issaquah valley area. Five wells have been monitored regularly since 1989 or 1990 (COI1, COI2, COI4, COI5, SP-7, SP-8 SPVT3) through the GWMA program. Water-levels were also collected from a number of private domestic wells, private production wells, and monitoring wells. Water-levels in some of the wells were measured automatically using pressure transducers and data loggers. Water-levels in the remaining wells were measured by hand. Water-levels from monitoring wells installed near the ARCO service station were also supplied to the WHPP. Table 2 presents a summary of the water-level monitoring data collected from the wells throughout the LIV, and Figure 4 shows the well locations. Water-level hydrographs are presented in Appendix B.

Hydraulic Tests	Short-term single well permeability tests were performed in eight wells to determine near-field hydraulic conductivity. These data were used in conjunction with large-scale pumping test data to evaluate the hydraulic properties of the aquifer. Table 3 summarizes the hydraulic testing activities conducted as part of the WHPP. The results of these analyses are presented in Appendix C.
Geophysical Logging	Borehole geophysical logs were run in wells VT-5, VT-6, VT-7 and VT-8, in order to evaluate the geo-electrical properties of the underlying sediments. A Geonics EM-39 borehole induction EM tool was run in these boreholes to determine the relative electrical conductance of the sediments outside the borehole. The logs provided a basis for determining the feasibility of a comprehensive surface geophysical survey to map the location of potential low-permeability layers within the aquifer at depth. The results of these analyses are presented in Appendix D.
Resistivity	Six deep-penetration resistivity soundings were performed around the eastern margin of the LIV and on Grand Ridge to evaluate possible bedrock depths. The locations and results of these soundings are presented in Appendix D.
Stream gaging	A one-day stream gaging survey was carried out in May, 1992 to evaluate relative streamflows along the East Fork, North Fork, and Lower Fork of Issaquah Creek. The results of these analyses are presented in Appendix E.
Mini-piezometers	Shallow "mini-piezometers" were installed at six locations along the North Fork and Lower Fork of Issaquah Creek. These piezometers are designed to monitor water-level conditions directly beneath the stream, and provide information on the interaction between surface-water and groundwater. The location, design, and results of these installations are summarized in Appendix E.
Water Quality Monitoring	Water quality was monitored in a total of 25 wells during three sampling rounds conducted in May, 1992, August, 1992, and March 1993. The analyses and analytical procedures are summarized in Appendix F, and included priority pollutant metals, volatile organic compounds, pesticides, herbicides, basic cations and anions, and field parameters. All samples were collected according to QA/QC procedures outlined in the QA/QC and DCAP prepared for the WHPP Work Plan. Table 4 summarizes the water quality monitoring activities conducted as part of the WHPP. The results of these analyses are presented in Appendix F.
Dissolved Oxygen	Field analysis for dissolved oxygen was performed on 10 wells in August, 1993 to assess the potential for biological activity within the

aquifer that could be responsible for aerobic breakdown of dissolved hydrocarbon in groundwater. Table 4 summarizes the water quality monitoring activities conducted as part of the WHPP. The results of these analyses are presented in Appendix F.

2.2 Data Analysis Products

Analysis of the data described in Section 2.1 produced a number of interpretive results which form the basis for the delineation of wellhead protection areas. These analysis products include:

- Conceptual model of hydrogeologic processes in the LIV;
- Geologic cross-sections;
- Water-level elevation maps;
- Water-level hydrographs for wells in the LIV;
- Streamflow analysis of the Lower Issaquah Basin, North Fork Basin and East Fork Basin; and
- Analysis of horizontal and vertical hydraulic gradients;
- A water balance for the LIV;
- A groundwater flow model, calibrated to existing data and consistent with the conceptual hydrogeologic model; and
- A water-quality assessment of the LIV.

Much of the information utilized in this study was maintained in a geographic information system (GIS). A GIS provides capabilities for evaluating a variety of types of information in a map format, or as a relational database. An ArcInfo GIS was used to store, display, and review the following datasets or layers:

- Township, Range and Section;
- Northings/Eastings (NAD 87);
- Geology;
- Land-use;
- Transportation/Roads;
- Streams and Lakes;
- Wetlands;
- Wells; and
- Chemical Handlers/Underground Storage Tanks.

Many of these datasets were provided to the WHPP in a digital format and merged into a single GIS system. Overlays of various layers or queries regarding relational data were used in WHPP analyses. The GIS can constitute a basis for continued database management and presentation for on-going wellhead protection activities.

3. HYDROGEOLOGIC SETTING OF THE LIV AQUIFER SYSTEM

The hydrogeologic setting of the Lower Issaquah Valley forms the basis for the delineation of wellhead protection areas and an assessment of strategies for aquifer protection. The hydrogeology of the LIV is complex. Complexities arise from the topographic, geologic and hydrogeologic conditions that control groundwater flow in the Valley. The data collected for the WHPP provides a more complete understanding of the area, but uncertainty and data gaps remain. The scope of the Wellhead Protection Program, though broad, cannot address all remaining uncertainty. In order to propose conservative, consistent and manageable strategies for wellhead protection, simplification of the system is necessary. The purpose of this section is to summarize the geology and hydrogeology of the LIV based on existing information, and to outline the simplified conceptual models used in developing the Wellhead Protection Areas.

3.1 Geology

Glaciations that occurred throughout the Puget Sound area are largely responsible for the geologic features occurring in the Issaquah area. As such, glacial stratigraphy and depositional environments dominate the discussion of the geology. A geologic map of the LIV is presented on Figure 5.

3.1.1 Stratigraphic Units

Stratigraphic relationships are important in defining the hydrogeology of the LIV. The names assigned to various units provide a means of clearly describing the geology and hydrogeology of the area.

The pre-glacial bedrock geology of the LIV area consists of Tertiary-aged sandstones and volcanic rocks. This bedrock is exposed primarily in the higher elevations, on Squak Mountain and Tiger Mountain (south of Issaquah), on Grand Ridge (east of Issaquah), and in the area just north of the North Fork of Issaquah Creek.

Sediments deposited during the glacial and interglacial episodes are the most prevalent in the LIV and include:

- Coarse sands and gravels, termed outwash and ice-contact deposits, which are deposited at the front and sides of the advancing or retreating glacier;
- Glacial till which is deposited at the base of the glacial ice sheet; and
- Fine-grained silts and clays, which are deposited in lakes at the margins of the glacier.

Alluvial sediments deposited since the last glacial period range from sands and gravels to fine-grained silts and clays.

A recent study of the surficial geology of the Issaquah area (Booth, 1990) serves as the basis for the classification of the geologic stratigraphy of the Issaquah area. For the purposes of this work, the geology of the area has been grouped into seven units, including bedrock, recent Alluvium, Vashon Recessional Outwash, Vashon Till, Vashon Advance Outwash, older Nonglacial deposits, and older Undifferentiated Glacial deposits. The geologic stratigraphy of the LIV is summarized on Table 5.

3.1.2 Structural Features

The dominant bedrock structure in the area is the trough now occupied by Lake Sammamish. Prior to the glaciations, Tertiary-aged bedrock was faulted and folded by the tectonic forces responsible for the formation of the Cascade Mountain range. The trough now occupied by Lake Sammamish was formed by tectonic deformation and erosion prior to glacial activity (Curran, 1965). Another major structural feature is an inferred major bedrock fault trending east-west from Bainbridge Island to the East Lake Sammamish Basin (Gower and others, 1985). The fault creates one of the largest gravity anomalies in the country and is thought to plunge steeply to the north.

Glacial and unconsolidated deposits within the LIV area have been penetrated to depths of over 600 feet in the central portion of the valley. Glacial sediments occur along the margins of the valley to depths of at least 300 feet in places. Unconsolidated sediments thin eastward toward the higher elevations. The thickness of the unconsolidated deposits decreases southward towards the Issaquah Gap, and the study area boundary. Bedrock is encountered at depths of less than 100 feet in this area.

3.1.2 Geologic History

Glacial ice entered the Puget Sound in late Pleistocene time (maximum extent about 15,000 years ago). The ice that occupied the Puget Sound area is known as the Puget Lobe of the Cordilleran Ice Sheet, which occupied northwestern North America in the early to late Pleistocene. Within the Issaquah area, only deposits of the final glaciation, known as the Vashon Glaciation, can be differentiated with certainty. The Vashon glacier originated in British Columbia, and flowed in a southern to southeastern direction through the Issaquah area (Curran, 1965). A proglacial lake of limited extent formed in front of the advancing glacier. Melt waters flowed south through channels east and west of Squak Mountain, depositing sand and gravel. As the glacier advanced, it modified the previously existing topography and deposited glacial till. Outwash sediments in front of the advancing glacier were often destroyed and reworked by the glacier. At its maximum extent, the glacier extended far south of Issaquah and may have been more than 3,000 feet thick in the Issaquah area.

The glacier is thought to have begun receding approximately 13,000 years ago. The recessional phase of the Vashon Glaciation is the most important to the geologic history of the LIV. Based on evidence of a series of drainage channels, deltas, and ice-contact topography within the Issaquah area, Curran, 1965 reconstructed the recessional history of the Vashon glacier, which is summarized graphically on Figure 6 and discussed briefly below.

During recession of the Vashon Glacier, several episodes of ice stagnation occurred, which established stream drainages and associated depositional features and sediments. Curran (1965) recognizes seven periods of ice stagnation. Three of these stages are presented on Figure 6. During these periods of ice stagnation, depositional features formed within the LIV. Booth (1990), recognizes five depositional stages summarized as follows:

- Stage 1 (oldest): Consists of valley-wall and ice-contact sediments, located near the south end of Lake Sammamish, which were deposited when the glacier still occupied the Sammamish trough. Meltwater drainage was to the south along Issaquah Creek and Tibbetts Creek;

- Stage 2: As the glacier receded farther north through present-day Issaquah, Glacial Lake Sammamish formed in what is now the LIV. Melt waters flowed from the east along the North and East Forks of Issaquah Creek and deposited large deltas as they entered Glacial Lake Sammamish. Drainage out of Glacial Lake Sammamish at this time was still directed to the south through the Issaquah Gap and through Tibbetts Creek valley;

- Stage 3: The glacier continued to recede, and meltwaters entering Glacial Lake Sammamish through the North Fork of Issaquah Creek, where a large delta formed. The outlet drainage of Glacial Lake Sammamish continued to shift to the northwest through the Cedar Grove, Kennydale, and Eastgate Channels (now occupied by I-90). The deltas along the eastern shore of Glacial Lake Sammamish continued to form at this time;

- Stage 4: The glacier receded still farther, and the outlet drainage continued to shift farther to the north to the Inglewood channel. Streamflow through the eastern melt-water channels along the present North and East Forks of Issaquah Creek decreased substantially, as meltwaters began entering the lake from channels farther north. At this time, the lake occupied all of the present lake area and also the lower Issaquah valley area; and

- Stage 5 (Youngest): This deposit consists of a low delta located just south of Issaquah occurring at elevations of between 100 and 150 feet msl, which formed during the last stage of glacial recession.

The glacier continued to recede until melt waters eventually ceased entering the lake, and the present drainage to the north was established. Lake Sammamish reduced in size to near its present configuration during this time.

3.1.4 Surface and Sub-surface Geology

The surface geology in and adjacent to the LIV is shown on Figure 5. The map shows the surficial distribution of sediments in the LIV area. Of particular importance to this study is the distribution of recessional outwash and ice-contact deposits (shaded green). These coarse-grained high permeable materials readily transmit infiltration downwards to underlying aquifers. In the lower Issaquah valley area, a relatively thin veneer of alluvium occurs in association with the major streams and lowland areas. Beneath these sediments exist a complex series of sand and gravel units, separated by silt and finer-grained units. There is no indication of glacial till in logs of wells in the Valley floor.

Along the western margin of the lower Issaquah valley, older Undifferentiated pre-Vashon glacial sediments have been mapped near Tibbetts Creek.

Along the eastern margin, investigations at the Lakeside Gravel Pit have provided information on the nature and stratigraphy of the delta and older glacial deposits in the areas. Early exploratory drilling indicated the presence of older glacial sediments and a non-glacial interval at the site. A sequence of older glacial drift, inter-glacial sands, gravels and shallow lake deposits was hypothesized as underlying the Vashon deposits (Cascade Testing Laboratory, Inc., 1978). Later reports indicated that mining was depleting the deltaic materials and that recessional outwash materials (overlying the till) became the predominant material extracted from the pit. More recent investigations in the northeastern quarter of Section 27, suggest that the thickness of the recessional deposits which overlie Vashon till varies significantly (Meridian Mineral Company, 1985). The till occurring at ground surface in this area has been described as a sandy till in the exploration borehole logs. This till may be an ablation till which formed from materials occurring within and on top of the snout of the glacier. As such, this till may be considerably more permeable than the basal till which is typically over-consolidated as a result of compression by overriding ice.

Three geologic cross sections for the LIV are shown on Figures 7, 8 and 9. Cross-sections A-A' and B-B' are constructed east-west, across the deltaic landform. Cross section C-C' is constructed along the axis of the LIV from the Hobart Gap to Lake Sammamish. The general dip of sand and gravel units is from the east to the west at approximately 20 degrees. This is interpreted as forest bedding of the deltas that once formed at the mouths of the North and East Forks of Issaquah Creek. The interbedded sand, gravel and silts encountered between 240 and 450 feet in COI-TW is consistent with the dip of the forest beds of the delta. This suggests that the deltas may have extended into the LIV trough by as much as 3,000 feet.

The cross-section on Figure 9 shows the interpreted bedrock configuration, with an increase in depth to bedrock north of the East Fork of Issaquah Creek. There also appears to be a general decrease in coarse-grained sediment towards Lake Sammamish. This is consistent with increased deposition of lacustrine sediments in Glacial Lake Sammamish, at greater distance from the eastern stream inlets and their associated coarser-grained deltaic deposits.

3.1.5 Conceptual Geologic Model

The conceptual geologic model for the area is based on the depositional environments present within the LIV during the Vashon Glaciation.

The main components of the model are as follows:

- The pre-glacial bedrock (Sammamish trough) forms a deep bowl in the LIV between the East Fork and Lake Sammamish. This structure received large amounts of sediment from the North, East and Lower Forks of Issaquah Creek during glacial periods. Between the East Fork and Hobart Gap, bedrock depths are shallower and more uniform, typical of an erosional river channel;

- The receding glacial ice created a complex sequence of channel features and pro-glacial lakes in the LIV. Lake levels varied, but were as much as 450 feet above sea-level during recession of the glacier. Deltas prograded into the LIV along the North Fork and East Fork drainages, depositing coarse sands and gravels as well as finer silts and fine sands. The deltaic deposits plunge beneath the present valley floor, extending as much as 3,000 feet into the LIV. The deltaic sediments interfinger with finer-grained lacustrine deposits to the west and north;

- Continued glacial retreat lowered lake levels in the LIV and reduced the amount of sediment entering the LIV as alternative drainages were established to the north towards Redmond. Sediments deposited at this time overlie the deltaic sediments within the LIV. Post-delta sediments are highly variable, but generally finer grained than the deltaic deposits;

- Recent alluvial stream deposits, were finally deposited over most of the LIV and range from coarse sands and gravels to finer sands and silts; and

- The complexity of the stratigraphy within the valley is due in part to frequent changes in the level of Lake Sammamish and to changes in the discharge rates and sediment loads of the inlet meltwater streams.

3.2 Hydrology

This section summarizes the hydrologic characteristics of the Lower Issaquah Valley. More detailed studies of the surface-water hydrology of the area have been carried out by King County SWM and METRO (SWM, 1991; SWM, 1992, METRO, 1981). The intent of this section is to provide a brief overview of the conditions in the LIV.

The Issaquah basin covers a 61 square-mile area including Issaquah Creek and Tibbets Creek. There are seven precipitation gages in the Issaquah basin, six of which are in or near to the LIV. Annual precipitation within the LIV ranges from 50 to 60 inches per year, based on 1988 data collected as part of the Issaquah GWMA. Mean precipitation at the nearest long-term gage at Landsberg is 57 inches. In general, precipitation increases with elevation.

There are ten operating stream gages within the Issaquah Basin, four of which are within the LIV study area (Figure 10). Figure 10 shows the mean annual flow at these gages. These flows were developed by SWM during HSPF simulation modeling of the Issaquah Basin. The detailed analysis by SWM of long-term hydrologic data incorporates important variations in precipitation and run-off and is considered the most representative description of average current hydrologic conditions in the basin. Unit area discharges range from 0.06 to 0.12 cfs/acre (SWM, 1990). These are relatively large due to high precipitation, steep topography and impermeable bedrock and till exposures.

A summary of 1990 monthly average flows for these four gages (46A, 14A, 67A, and 25C) is presented in Appendix E. Average 1990 monthly flows on the North Fork (gage 46A) range from 1.26 cfs in August to 38.67 cfs in January, with an annual average flow of 9.34 cfs. Average 1990 monthly flows on the East Fork (gage 14A) range from 3.89 cfs in September to 72.25 cfs in February, with an annual average flow of 26.9 cfs. Average 1990 monthly flows on the Main Fork near the Issaquah Gap (gage 25C) ranged from 1.6 cfs in September to 36.4 cfs in January, with an annual average flow of 14.26 cfs. Average 1990 monthly flows on the Main Fork near the mouth at Lake Sammamish (USGS gage) ranged from 28.4 cfs in September to 334 cfs in January, with an annual average flow of 133 cfs. This gage is located nearly one mile south of the mouth of Lake Sammamish, above the wetland area. There is no gaging data on the Main Fork of Issaquah Creek near its confluence with the East Fork.

The availability of streamflow data and hydrologic modeling in the basin allows an estimation of groundwater recharge based on hydrologic data for the individual sub-basins. Evaluation of individual sub-basins indicates that there is significant recharge to groundwater on an annual basis, which can be calculated as a residual hydrologic component based on precipitation, run-off and average streamflow using the following equation:

$$Q_r = P * F - \frac{Q_S}{A} - ET$$

Where

Q_r = Recharge to groundwater (ft)
P = Long-term Annual Precipitation at SeaTac (ft)
F = Precipitation Adjustment for elevation of sub-basin
A = Area of sub-basin (ft^2)
ET = Evaporation based on pan measurement at Puyallup (ft)
Q_s = Annual streamflow volume at outlet of sub-basin (ft^3)

Using the data developed by SWM, recharge rates for each sub-basin were calculated (See Appendix E). These infiltration estimates, based on streamflow and climatic data, are as follows:

- North Fork Sub-Basin (area = 2,855 acres): 1.3 cfs
- East Fork Sub-Basin (area = 5,606 acres): 4.6 cfs
- Lower Fork Sub-Basin (area = 35,080 acres): 16.2 cfs
- Tibbets Creek Basin (area = 3,460 acres): 0.3 cfs

Total annual groundwater recharge is therefore estimated at 22 cfs based on hydrologic analysis. This value is similar to other estimates (CH2M Hill, 1993; Carr Associates, 1993). Increased streamflows caused by increased run-off within a sub-basin will reduce groundwater recharge. The SWM analysis evaluated the effect of future land-use on peak flows and flooding in the basin and concluded that peak flows could increase 14 to 78 percent. An analysis of the possible increase in mean annual flow was not carried out, but similar increases are possible, resulting in similar decreases in groundwater recharge.

3.3 Hydrogeology

This section summarizes the hydrogeologic characteristics of the LIV based on available data.

3.3.1 Hydrogeologic Units

The sediments occurring within the LIV consist of stratified silt, sand, and gravel deposits of fluvial, glacial, and lacustrine origin. In an attempt to understand the hydrogeology of the area, the geologic materials were organized into hydrostratigraphic units which have similar hydraulic characteristics, as summarized on Table 5. The hydrostratigraphy has been grouped similarly to the geologic stratigraphy into 7 separate units: Alluvium, Recessional Outwash, Delta, Till, Lacustrine, Undifferentiated Glacial Drift and Bedrock. This hydrostratigraphy differs from the geologic stratigraphy in that the recessional deposits are sub-divided into deltaic and non-deltaic sediments. The general characteristics of each unit are shown on Table 5. A discussion of the hydrogeologic characteristics of each unit follows.

> Alluvium occurs near ground surface to depths of 20 feet or more. It is associated with recent fluvial (stream) activity and also occurs throughout the lowland areas. Saturated alluvium may constitute a shallow perched aquifer, or may be continuous with a more extensive unconfined aquifer within underlying recessional and deltaic deposits.

Recessional Outwash occurs in the elevated terrain on each side of the LIV, particularly throughout the eastern area (Grand Ridge and Lake Tradition Plateau). It occurs at or near ground surface and may reach depths of more than 100 feet in places. Water-levels and aquifer properties of the Recessional Outwash are not well known since only a few wells are completed in this material. Saturated recessional outwash may form locally perched aquifers on the upland areas depending on the underlying materials. It may also constitute part of a more extensive unconfined aquifer.

Delta Deposits are geologically and chronologically consistent with recessional outwash and are not subdivided in geologic studies. However, the delta deposits constitute a distinct hydrogeologic unit because of their distribution, extent and hydraulic properties. Deltaic sediments occur along the eastern edge of the valley, and plunge beneath the valley floor to the west. They are the result of fluvial deposition from the North Fork and East Fork glacial drainages. Delta deposits form the high-permeability aquifer tapped by the City's and District's wells. Saturated deltaic deposits may constitute locally confined to semi-confined aquifers, due to interfingered fine-grained lacustrine and alluvial deposits. However, continuous confining layers are unlikely within the delta deposits, and therefore on a regional scale the delta deposits constitute an unconfined aquifer.

Till occurs in the eastern and western elevated terrain, either near ground surface or below Recessional Outwash. Till is not present in the central portion of the Valley or at its margins because it was eroded and re-worked by glacial processes in the Sammamish trough. The till may act as a low-permeability perching layer on the upland areas which creates small perched aquifers within the Recessional Outwash. On the Tradition Lake Plateau, Lake Tradition is likely perched, in part, by an underlying till layer. Till is not generally considered an aquifer, but it is capable of transmitting groundwater. The Lake Tradition and Grand Ridge uplands, though "perched" above the till, transmit recharge to the LIV through the till or through erosional windows within it. Similarly, the more permeable sandy ablation till on Grand Ridge may transmit more groundwater than silty/tills located elsewhere.

Lacustrine sediments interfinger with the Delta deposits, and may form regionally extensive clay/silt layers in the lower portion of the valley near Lake Sammamish. Lacustrine interbeds within the deltaic deposits are typically discontinuous and difficult to correlate between borings. There is little supporting geologic or geophysical evidence for extensive clay/silt layers could constitute regional aquitards.

Undifferentiated Glacial Drift is inferred to exist in places beneath Vashon Glacial till in the eastern elevated terrain, and, for simplicity, is assumed to include Vashon Advance Outwash materials. Little is known of the hydraulic characteristics, or the thickness or extent of these deposits. This pre-Vashon drift may overlie bedrock in the eastern highland area.

Bedrock occurring within the study area is believed to have much lower permeability than most of the unconsolidated deposits. In comparison to the unconsolidated materials, very little groundwater is expected to move through the bedrock.

3.3.2 Hydrogeologic Boundaries

Hydrogeologic boundaries can restrict groundwater flow (e.g. bedrock boundaries) or can enhance groundwater flow (e.g. stream boundaries). They also constitute the ultimate source areas and discharge areas of the aquifer system. The boundaries recognized in the LIV aquifer system are as follows:

- The LIV aquifer is bounded below by low-permeability bedrock, and by bedrock outcrops occurring in the higher elevations along the margins of the groundwater basin. The assumed low permeability of the bedrock constitutes a no-flow boundary to the base of the aquifer;

- The LIV aquifer is bounded on the north by Lake Sammamish, which is a regional discharge area for the aquifer. All groundwater flowing through the LIV aquifer ultimately discharges to Lake Sammamish, the wetland area directly south of the Lake, or to Issaquah Creek which drains into Lake Sammamish;

- The LIV aquifer is bounded on the south by shallow bedrock at the Issaquah Gap;

- The uppermost boundary to the LIV aquifer is the most complex, consisting of wetlands, streams, lakes, open-space (recharge areas), and urbanized areas. The water entering the groundwater flow system originates from precipitation within the confines of the groundwater basin. Streams may "lose" water to the aquifer, "gain" water from the aquifer, or have no interaction with the aquifer. Lake Tradition likely contributes water to the aquifer through vertical infiltration from the Tradition Lake Plateau to the LIV aquifer. Urbanized areas tend to reduce the natural infiltration to the aquifer through stormwater collection. Undeveloped open areas and rural residential areas represent potential recharge areas to the aquifer.

3.3.3 Groundwater Elevations

Groundwater elevations, or water-table elevations, determine, in part, the rate and direction of groundwater flow. Elevations are referenced to mean sea-level (msl). Groundwater flows from high elevations to lower elevations, at a rate proportional to the slope of the water-table and the hydraulic characteristics of the aquifer. Groundwater elevations fluctuate in a somewhat predictable fashion because of annual fluctuations in precipitation and groundwater recharge. The annual high and low groundwater elevations are typically used to evaluate the general behavior of the aquifer. The high and low water-table configuration based on observed water-levels is shown on Figure 11. Water-level elevations are extrapolated to the western portion of the Valley based on assumed conditions. There are very little data regarding groundwater conditions in the western LIV.

Seasonal high groundwater elevations in the LIV occur in February, based on 1992 data, and range from 150 to 200 feet in the South Issaquah/Hobart area to approximately 50 feet about two miles south of Lake Sammamish. Groundwater elevations in the immediate vicinity of Lake Sammamish are uncertain, because no wells exist in this area. However, groundwater elevations are expected to approach 25 feet near the lake, which is the average elevation of Lake Sammamish. Seasonal high groundwater elevations in the central valley area, where most of the wells are located, vary from approximately 60 to 70 feet. Groundwater elevations increase to the east to as much as 80 feet or higher.

Seasonal low groundwater elevations occur in August and September, based on the 1992 data, and range from 150 to 160 feet in the South Issaquah/Hobart area to approximately 47 feet approximately two miles south of Lake Sammamish. Seasonal low groundwater elevations in the central valley area, where most of the wells are located, vary from approximately 55 to 60 feet.

Little data are available on Grand Ridge and Tradition Lake Plateau. Recently installed shallow wells at the proposed Grand Ridge development indicate that groundwater elevations vary from about 400 feet to over 800 feet, and are likely representative of shallow perched aquifers over low-permeability bedrock or till. Groundwater-levels in a private well (Dean Well) located west of the proposed development are relatively constant at approximately 338 feet. This well is completed below till.

3.3.4 Groundwater-Level Fluctuations

Fluctuations in groundwater-levels are often indicative of the overall behavior of the aquifer, the location of recharge/discharge areas, and the response to recharge/infiltration.

In general, the LIV aquifer responds very quickly to precipitation events. These water-level responses are seen in both shallow and deep wells. This response suggests continuity with the ground surface and/or stream network. Additionally, the wells in the LIV respond to pumping of the various production wells in the area. Short-term fluctuations are clearly observed in response to the Lakeside Gravel Pit, which operates wells on an eight-hour work-day schedule. Figure 12 shows a hydrograph of one shallow monitoring well at the ARCO site. The hydrograph shows the short-term fluctuations in water-level caused by pumping at Lakeside, short-term and longer term declining and rising water level trends due to climate, and the effect of pumping at SPWSD well 9. The various responses result in "noise" in long-term water-level observation caused by these short-term effects.

Within the valley area, the annual change in groundwater elevations was between 7 and 10 feet in 1992. Greater annual fluctuations of up to 15 feet occurred in the vicinity of SPWSD-7/8. The annual change in water elevations appears to decrease to 7 feet or less north towards Lake Sammamish, while higher annual water-level fluctuations of 10 feet or more occur south and east of the central valley area.

Although, the annual groundwater-level fluctuations observed in 1992 appeared to be greater in the south and less in the north, there are no apparent differences in the magnitude of fluctuation associated with the depth of the wells and piezometers. For example, the same annual water-level fluctuation was observed in each piezometer installed in SPVT-7. Furthermore, each monitored zone appears to respond at the same time to recharge and discharge, with the exception of some of the wells located towards the south (COI1/2). This suggests that the permeable zones encountered at various depths all respond in a similar fashion to recharge and discharge, and thus, on the large-scale, essentially behave as a single aquifer unit.

3.3.5 Directions of Groundwater Flow

Groundwater generally flows northwestward through the LIV area and discharges to Lake Sammamish, or the wetland area immediately south of the Lake. Groundwater flow converges on the central valley area from the North Fork, East Fork and Lower Fork Sub-Basins of Issaquah Creek. Flow directions in the Wester LIV (near Newport Way) are not well known. The deltaic sediments of the North and East Forks readily transmit groundwater downwards into the LIV from the upland areas, causing steep hydraulic gradients at the margins of the valley then flatter within the delta itself.

Groundwater flow directions in the Grand Ridge and Tradition Lake areas are less certain, because of a lack of wells and water-level measurements. It is presumed that flow mimics topography and is primarily westward toward the Issaquah Valley, with components of flow directed towards the North Fork (particularly the wetland areas) and the East Fork valleys. Near the western margins of these areas, vertical infiltration through the deltaic sediments probably dominates. Quasi-horizontal flow may occur along distinct delta strata, but the continuity of individual strata within deeper zones in the LIV aquifer cannot be substantiated.

Groundwater elevations vary throughout the year in response to winter and spring recharge. The direction of groundwater flow within the valley appears to shift from a primarily northern direction during the summer and fall, to a northwestern direction during the winter and spring (see Figure 11). This is noted in the WHPP wells as well as the monitoring wells at the ARCO site (Geraghty and Miller, 1991). This westward shift in flow direction indicates a large influx of groundwater from the east during the winter and spring. This has important implications with regard to the source of recharge to the aquifers within the valley, and well capture zones.

3.3.6 Hydraulic Gradients

Hydraulic gradients are indicative of the rate of groundwater movement and are important in determining the time of travel (TOT) typically used in delineating wellhead protection areas. Gradients are unitless parameters, equivalent to a slope.

The average horizontal hydraulic gradient within the central valley area, based on 14 wells, is relatively flat at between 0.001 and 0.002. Hydraulic gradients are less well known on Grand Ridge and Tradition Lake area. Within the proposed Grand Ridge development, the horizontal gradient is about 0.067, one order of magnitude higher than in the Lower Valley.

Vertical gradients are also important since they indicate the upward or downward component of groundwater flow. In general, downward gradients are expected in recharge areas and upward gradients are expected in discharge areas.

The vertical hydraulic gradients vary considerably (orders of magnitude) throughout the Lower Valley area from a magnitude of 8.9×10^{-6} to 1.7×10^{-1}. In general, the vertical gradient is, as expected, directed upward in the northern area near Lake Sammamish. Primarily downward vertical gradients occur in the central valley area, probably as a result of the high-volume pumping within this area. Locally, both upward and downward gradients may be created because of the completion interval of the production wells, which may induce downward leakage from above and upward leakage from below. At SPWSD 7/8, the vertical hydraulic gradient appears to be downward from the surface to the 117-foot completion interval and upward from the deeper 177-foot completion to the 117-foot completion interval.

Vertical gradients on Grand Ridge and Tradition Plateau are unknown. However, the vertical gradient is directed upward along the flanks of the Tradition-Lake area (near WH-1, and COI1/2). The upward gradients in this area may be the result of infiltration originating from higher elevations at a high head and discharging to the lower valley area.

In general, the vertical hydraulic gradients observed within the LIV in 1992 appeared to remain relatively constant throughout the year, with the exception of wells COI1/2 and SPVT6. At these sites, the vertical gradient decreased between the winter/spring recharge period and summer/fall period, when the vertical gradients are at a minimum. This trend suggests that recharge to the deeper sediments during the winter/spring may increase the upward vertical gradient in places and then decay during the ensuing dry period.

3.3.7 LIV Aquifer Characteristics

Geologic logs within the LIV are insufficient to fully delineate the thickness and extent of the LIV aquifer system. The present understanding of the system indicates that total sediment thickness ranges from over 600 feet the central LIV near COI 4/5; to 300 feet at the Grand Ridge margin of the LIV (SPWSD 9); to 150 feet at the Lake Tradition margin of the LIV (WH-1); to 63 feet at the Hobart Gap (RP-1). Actual aquifer thicknesses are assumed to be similar to sediment thicknesses, since there is little regional geologic continuity between strata.

Production wells within the LIV tap highly permeable aquifers. Testing of these wells has provided data on the hydraulic characteristics of the aquifer. These aquifer characteristics are summarized on Table 3.

Carr/Associates conducted a 3-day pumping test of Wells 7 and 8 between September 12 and 15, 1990. The wells were pumped at a combined rate of 5,600 gpm. During the test, water-levels were monitored in 17 wells and at 6 surface water stations. The 17 monitoring wells included 11 piezometers and 6 production wells. During the test water-levels in the observation wells were drawdown between 1 and 3 feet, and the cone of depression extended a distance of approximately 7,000 feet from the pumping wells. Analysis of the pumping test was complicated to some degree by interference resulting from the pumping of other production wells, and by the complex hydrogeologic environment of the valley. Based on the test, a transmissivity of approximately 67,000 ft^2/d was calculated (Carr/Associates, 1991). Assuming an aquifer thickness of between 200 and 300 feet, a bulk hydraulic conductivity of between 220 and 330 ft/day for the aquifer is estimated. The calculated storativity varied from 0.2 to 1×10^{-4}. During the test, there was no direct evidence of impact to shallow surface water bodies.

A long-term pumping test of Well 9 was conducted at a rate of 2,340 gpm for about 9.5 days by Carr/Associates in July, 1992. During the test, water-levels were monitored in 55 observation wells. In addition, 15 surface water monitoring stations were established and monitored. The test was designed to minimize interference from surrounding, pumping wells and attempt to achieve steady state conditions in the aquifer through an extended test length. Analysis of the well 9 test (Carr Associates, 1993) suggests the following:

- Well 9 is completed in a thin (50-foot) isolated aquifer zone (termed Zone C); with a high transmissivity, separated from the overlying sediments by a leaky aquitard;
- Pumping of Well 9 caused drawdowns of between 1.4 and 0.2 feet in shallower zones of the aquifer;
- Chemical analyses and streamflow monitoring suggest that test pumping of the well had no measurable influence on surface-water; and
- Flow paths towards Well 9 do not intersect the known contamination at the ARCO site.

Analysis of the test performed for this WHPP suggests that:

- Steady-state conditions were not achieved;

- Transmissivity of the aquifer as a whole is similar to that observed at wells 7/8 at 70,000 ft^2/day based on a late-time drawdown analysis of all wells monitored; and

- Strong, downward vertical gradients are established from the water-table towards the deeper portions of the aquifer.

In July 1992, Golder Associates conducted a series of slug tests in the monitoring wells. The tests were analyzed using the Bouwer/Rice (1967) method and the method of Van der Kamp (1976). Results of the slug tests are summarized in Table 3. The hydraulic conductivity calculated from the tests ranged from 100 to 470 ft/day, which is consistent with the pumping test results.

3.3.8 Stream/Aquifer Interaction

Stream-aquifer interaction is important in an aquifer system and can be a source of recharge to the aquifer. It is often difficult to measure the "hydraulic continuity" between a stream and aquifer and, in most cases, indirect assessments of stream-aquifer interaction are necessary. The parameters controlling stream-aquifer interaction are:

- The elevation difference between the stream and the groundwater; and

- The hydraulic characteristics of the streambed.

In the LIV, there are three major streams traversing the area. The North Fork and East Fork Issaquah Creek descend from elevated upland areas into the LIV, losing more than 200 feet of elevation over a relatively short distance. The Lower Fork of Issaquah Creek gradually descends through the LIV from the Hobart Gap to Lake Sammamish, losing about 100 feet of elevation. From a hydraulics standpoint, it is expected that the steep sections of the North and East Forks of Issaquah Creek would provide coarser bedload (sands and gravels), and have a higher hydraulic conductance. When the stream enters the LIV, it's gradient decreases and finer sediments (sands and silts) are deposited, potentially reducing the hydraulic connection between the streambed and the underlying aquifer.

Stream gaging was performed in March 1992 on the North Fork and East Fork of Issaquah Creek. On the North Fork, three stations were gaged between the Mc Donald Well and 60th Street (approximately 1,000 feet apart). On the East Fork, two stations were gaged (approximately 1,000 feet apart) near the Sunset Overpass of I-90. The objective of the stream gaging was to determine whether significant stream/aquifer interaction was occurring at the edge of the upland areas surrounding the LIV. The accuracy of the survey is estimated at +/- 1 cfs, due to the shallow stream depth and low velocity of water flowing through the stream. On the North Fork, measured streamflow decreased from 3.3 cfs upstream of the McDonald well to 2.8 cfs downstream of the Mc Donald well, and then increased to 4.1 cfs below the 60th Street bridge farther downstream. These results do not indicate large streamflow losses or gains and are within the accuracy of the survey.

Therefore, at that streamflow, stream/aquifer interaction of less than 1 cfs per 1,000 feet of streambed is estimated along the North Fork at its confluence with the valley floor. Along the East Fork, a similar conclusion is reached. Streamflows measured upstream and downstream of the Sunset overpass were 9.8 and 9.3 cfs respectively. These values are within the accuracy of the survey and are consistent with streamflows used by King County SWM. Thus, stream/aquifer interaction along the East Fork between the Sunset overpass and confluence with the Lower Fork Issaquah Creek is estimated at less than 1 cfs per 1,000 feet of streambed. Because of the limited extent of steam gaging, these streamflow relationships may not be representative for all seasons or flow regimes. Additional stream gaging data are needed to fully characterize stream/aquifer interaction along the edge of the LIV.

Mini-piezometers were installed at six locations in the LIV (four on the Lower Fork and two on the North Fork) in June, 1991 (Appendix E). These piezometers were placed in or directly adjacent to the streambed to a depth of 5 to 8 feet. They measure the relative water-levels in the stream and underlying shallow groundwater. The results at four of the six locations indicated that stream water levels were "perched" 1 to 3 feet above the groundwater level, indicating little interaction between the stream and aquifer. At two of the stations, groundwater levels were equal to or higher than the stream water-level, suggesting continuity between the systems.

Monitoring of streamflow and shallow groundwater levels during the pumping test at SPWSD well 9 also indicated limited hydraulic continuity with the streams. The cone of depression created by the 9-day pumping test extended over nearly two square miles, and the drawdowns observed at the water-table (based on a hand-contoured drawdown map) can account for over 80% of the water pumped from the aquifer during the test assuming a bulk porosity of 20%. Appendix C contains a drawdown map and volume calculations for the well 9 test. If stream infiltration provided a significant contribution to the water pumped from the well, drawdowns in distant observation wells would be much less. Thus, infiltration from the stream to the aquifer is interpreted to be a minor component of the water drawn to the well when it is pumped. There is still a long-term impact to surface waters during pumping, but this impact occurs at the discharge areas (i.e. the wetlands directly adjacent to Lake Sammamish) of the groundwater system because there is less groundwater moving through the aquifer as a result of pumping.

For the purpose of wellhead protection delineation, it is concluded that within the central portion of the LIV, where the majority of urban development is occurring, streams are a minor source of water to the wells. In the wetland areas downstream of the production wells, pumping may influence surface waters, but this aspect of the hydrogeology is not a concern of the WHPP.

3.3.9 Water Balance

A water balance provides an overall assessment of the quantities of water entering and leaving the LIV aquifer. Water balances can be computed in a number of ways, using surface water information, water use information, and groundwater data. Water balance estimates of the LIV aquifer have been made by CH_2M HILL (1993), Parametrix (1993), and Golder Associates as part of this project. Table 6 summarizes the results of the various analyses.

Groundwater Recharge:

The aquifers within the LIV are recharged from precipitation occurring within the Lower Issaquah groundwater basin and from down-valley groundwater flow through the Hobart Gap in the Upper Issaquah valley. A significant finding of the GWMA report was that the down-valley flow through the Hobart Gap is a minor component of the overall groundwater flow to Lake Sammamish. The maximum likely groundwater flow through the gap is less than 2 cfs based on the aquifer thickness, and transmissivity at the Hobart Gap (Parametrix, 1993).

Additional groundwater recharge may occur from losing stream sections along the valley margins (e.g. East Fork and North Fork). However available limited stream gaging and mini-piezometer data do not indicate losing reaches of the Issaquah Creek system below the East Fork. The bedrock areas along the southern LIV contribute indirectly to recharge to the LIV aquifer. Shallow soil infiltration probably flows laterally along the bedrock surface until reaching the valley floor, where higher permeability sediments are present, and recharge occurs. As discussed in Section 3.2, an estimated 16 cfs of recharge may occur in the lower fork sub-basin of Issaquah Creek based on streamflow and climatic data.

Based on the current understanding of the groundwater system, the Plateau areas (Grand Ridge and Tradition Lake Plateau) are important recharge areas, because of the exposure of coarse-grained near-surface sediments which may be continuous with the valley aquifer via the deltaic landform. Infiltration of precipitation into the subsurface from these area is likely, but additional deep and shallow wells are needed to further characterize the Plateau areas. The glacial tills in the area may create locally perched zones and serve to buffer infiltration from the plateau to the LIV aquifer. This buffer may attenuate infiltration, but the overlying ground surface still represents a recharge area. In areas where the till is absent, such as the western portion of Grand Ridge, direct infiltration to the LIV aquifer is likely. In areas where the till is present, indirect infiltration may reach the LIV aquifer via more complex pathways. As discussed in Section 3.2, an estimated 6 cfs of recharge may occur from the eastern upland areas (North Fork and East Fork Sub-basins) based on streamflow and climatic data.

Groundwater Discharge:

Water balance calculations performed for the East King County Regional Aquifer assessment (CH_2M HILL, 1993) indicate an average groundwater discharge to Lake Sammamish at between 15 and 27 cfs, based on an analysis of the entire Issaquah Basin, including losses and transfers out of the basin.

Water balance calculations for the Issaquah GWMA (Parametrix, 1993) indicate a similar estimate of 25 cfs. The GWMA study further estimated that infiltration from the Lower Issaquah Valley is about 11 cfs, based on the relative size of the basin above and below the Issaquah Gap. The remaining 14 cfs would have to flow through the Issaquah gap area from the upper Issaquah Basin in order to discharge to Lake Sammamish. However, this amount of flow through the gap is not supported by drilling information. The maximum likely groundwater flow through the gap is less than 2 cfs based on the limited aquifer thickness, extent and transmissivity. Thus, an estimated 13 cfs recharge is contributed in the LIV study area. It is possible that the unaccounted 12 cfs from the upper Issaquah Basin may surface as baseflow to Issaquah Creek.

Based on hydrologic analysis of the North Fork, East Fork and Main Fork sub-basins of Issaquah Creek, recharge to the LIV aquifer, prior to groundwater withdrawals, is on the order of 22 cfs. Groundwater withdrawals are approximately 5 cfs, leaving a net discharge to Lake Sammamish of approximately 17 cfs.

Based on the similar results of the three estimates of discharge to Lake Sammamish, a groundwater discharge to Lake Sammamish of between 13 and 20 cfs is assumed.

Water Balance

Figure 13 is a conceptual sketch of water-balance components of the LIV. A water balance implies that groundwater recharge is balanced by groundwater discharge and withdrawals. Actual measurement of groundwater recharge is difficult, so it is commonly assumed that groundwater discharge equals groundwater recharge less groundwater withdrawals. Using this logic, groundwater recharge to the LIV is on the order of 20 to 25 cfs, with 5 cfs leaving via groundwater withdrawal and 15 to 20 cfs discharging to Lake Sammamish and the wetland area. Using the sub-basin streamflow analysis, up to 10 cfs may enter the LIV via the eastern Plateau areas, with the remaining 10 to 15 cfs entering along the western valley margin, through the Hobart Gap, or via stream infiltration along Issaquah Creek below the Issaquah Gap.

3.3.10 Hydrogeologic Conceptual Model

This section summarizes the hydrogeologic understanding of the LIV aquifer system, as discussed in previous sections:

- The stratigraphy within the LIV is highly complex, consisting of shallow Alluvium, Recessional Outwash, Delta, Till, Lacustrine, and Undifferentiated Glacial deposits. The Delta deposits are highly permeable and are the most important source of groundwater within the LIV. Recessional Outwash is also highly permeable, and occurs in the eastern higher elevations providing an important media for groundwater recharge. The shallow alluvial deposits vary in permeability, and may or may not be fully saturated. The other hydrogeologic units are less permeable, and may provide local aquitards within the LIV;

- The LIV hydrogeologic system is bounded at depth and along the border of the groundwater basin by low-permeability bedrock; on the south by Hobart gap, which allows only a limited quantity of groundwater to pass from the Upper Issaquah Valley; on the north by Lake Sammamish where the groundwater within the LIV discharges; and at the surface by streams, lakes, and permeable and impermeable areas;

- Groundwater elevations within the LIV vary from about 25 feet msl near Lake Sammamish to about 200 feet msl in the Issaquah Gap. In the central valley area groundwater elevations are generally between 50 and 70 feet. In the Grand Ridge area groundwater elevations vary from 400 to over 800 feet;

- Groundwater-levels fluctuate annually between 7 and 15 feet within the LIV. The timing and magnitude of the fluctuations is the same for shallow zones and deeper zones. Groundwater-levels respond rapidly to precipitation events;

- The direction of groundwater flow within the LIV is generally northwestward toward Lake Sammamish, but varies annually within the central valley area from a northwestern direction during periods of high groundwater-levels to a more northern direction during periods of low groundwater-levels;

- Within the central valley area the horizontal hydraulic gradient is relatively flat at between 0.001 and 0.002 ft/ft. Vertical hydraulic gradients are generally directed upwards except in the vicinity of the City's and District's production wells (COI 4/5, and Well 7/8). On Grand Ridge the horizontal hydraulic gradient is 0.067 ft/ft. A steep vertical hydraulic gradient exists between the Grand Ridge terrain and the valley floor;

- The LIV aquifer system is a series of discontinuous permeable zones and less permeable zones which, as a whole, behave as a single unconfined aquifer. Locally semi-confined lenses of aquifer exist, but are not representative of the aquifer as a whole. Pump tests show that water-levels are affected in shallow zones as well as deeper zones, demonstrating hydraulic communication throughout the aquifer system. Transmissivity is estimated at 67,000 to 70,000 ft^2/d, based on two long-term pumping tests. Average hydraulic conductivity is estimated at between 200 and 300 ft/day.

- Streams are a minor source of water to the wells in the central portion of the LIV; and

- Average annual recharge to the LIV aquifer is between 20 and 25 cfs. The eastern plateau areas (Grand Ridge and Lake Tradition) may provide up to

30% of the direct recharge to the LIV, with the remainder occurring within the main valley. Average annual discharge to Lake Sammamish and the adjacent wetland area is between 10 and 20 cfs.

4. LOWER ISSAQUAH VALLEY WELLHEAD PROTECTION AREA DELINEATION

This section presents the derivation of the proposed wellhead protection areas for the City's and District's wells.

4.1 WHPA Delineation Definitions

A wellhead protection area (WHPA) can be broadly defined as that area in the vicinity of a well or wellfield in which certain restrictions and/or plans have been enacted to protect the well or wellfield from groundwater contamination. The delineation of the WHPA is most commonly based on the time of travel (TOT) from a potential contaminant source to a well. An area around the well can be defined, termed a capture zone, which represents an area having a specified TOT to the well. For example, a 1-year capture zone represents an area around a well or wellfield in which contaminants could reach the well within one year. The common practice has been to define WHPA's based on 1-year, 5-year, and 10-year TOT's. The capture zone area for each of these TOT's is progressively larger for increasing TOT, since the groundwater would move farther over a longer time period. Management strategies are typically tailored to these TOT's, with more restrictive approaches within the shorter capture zone.

There are several assumptions in the TOT or capture zone approach that should be recognized. First, the time required for a contaminant to reach the well is based on the groundwater flow rate within the aquifer. In other words, the contaminant is assumed to be transported through the aquifer at the same rate as the groundwater. This is not always the case, and different contaminants move through the groundwater at different rates, dependent on their chemical behavior. However, from a planning standpoint, the TOT approach is conservative and appropriate for developing management strategies. Potential contaminant sources, specific in location and type of contaminant, should be evaluated on a case-by-case basis, using more sophisticated fate and transport models used in groundwater contamination studies. Section 6 discusses the behavior of various contaminants in more detail.

Secondly, the time required for a contaminant introduced at the ground surface to reach the underlying aquifer is not incorporated into the capture zone or TOT. It is assumed that a contaminant released in a WHPA capture zone would reach the water table instantaneously. Again, this is not always the case. Contaminants released at the ground surface can adhere to soil particles and become dispersed and diluted as they move to the water table through infiltration. There are possible direct pathways, such as a well with a poor surface seal, or an improperly abandoned well. The importance of the vertical, unsaturated transport component depends on the depth to the water table and the type of contaminant. Again, the conservative assumption for planning purposes requires a simplified approach that does not incorporate these processes. The shallow depths to groundwater in the Issaquah area support the conservative assumption of "instantaneous" transport to the water table. However, potential contaminant sources, specific in location and type of contaminant, should be evaluated on a case-by-case basis, using more sophisticated fate and transport models used in groundwater contamination studies. Section 6 discusses the behavior of various contaminants in more detail.

4.2 WHPA Delineation Methods

A number of methods of differing sophistication are used in the derivation of WHPAs. A summary of the methods and results is provided below. Appendix H contains the mathematical formulation and results of each of these analyses.

- **Calculated Fixed Radius method (CFR)**, is the simplest approach and is based on a simple water balance formula. This method does not require knowledge of the aquifer characteristics, except for porosity. The well capture zone derived from this method simply consists of a circular area surrounding the wellhead. No consideration is given to the regional hydraulic gradient, or aquifer boundaries. This method is inappropriate for the LIV system.

- **Analytical Calculations**, take into account the basic aquifer characteristics, such as transmissivity, aquifer thickness, and hydraulic gradient. The calculations assume steady state conditions and calculate capture zones to the boundary of the hydrogeologic system. This method is inappropriate for the LIV system.

- **Hydrogeologic Mapping** involves mapping the aquifer boundaries, particularly recharge areas, in relation to the wells of interest. A qualitative assessment of groundwater elevations and more quantitative flow net analyses can provide general information on the source of water to wells and it direction of flow. Hydrogeologic mapping is carried out to some extent for any WHPA analysis, and can generally determine the ultimate recharge areas of the aquifer. However, it cannot by itself be used to determine time-based (TOT) well capture zones, as these require consideration of groundwater flow rates and aquifer properties.

  Hydrogeologic mapping is based on the geology of the area and evaluation of recharge areas, as discussed in Section 3. Based on the analyses presented in Section 3, recharge areas are located along the margins of the Issaquah Valley and on the upland plateau areas of Grand Ridge and Lake Tradition. The extent of recharge areas in the Valley floor is less certain because recent alluvial deposits have covered the permeable glacial sediments.

  On Figure 5, showing the surface geology of the area, the areas representing coarse outwash and ice-contact deposits are interpreted as major recharge areas. These areas encompass approximately 2,850 acres. Specific TOT designations are not associated with the hydrogeologic mapping approach, and additional computations are needed to refine WHPA delineation.

- **Numerical groundwater flow models** are the most sophisticated methods of WHPA delineation and are required for complex systems composed of non-linear aquifer boundaries and multiple wells. A numerical model incorporates the hydraulic characteristics and boundary conditions of the aquifer and used a "particle tracker" to numerically simulate the rate and direction of "particles" of groundwater moving through the system. The accuracy of a WHPA derived from a numerical model is a function of the how well the numerical model can simulate observed conditions of the groundwater flow system. This, in turn, is a function of how much data are available to develop the model, and on the complexity of the groundwater flow system.

The proposed WHPA's for the LIV aquifer are based on a composite of well capture zones determined from the various methods outlined above. Because of the complexity of the aquifer, the proposed WHPA's are weighted toward the numerical modeling and hydrogeologic mapping results, rather than the simpler analytical results. The description and results of the groundwater model are presented in the following section.

4.3 Numerical Groundwater Modeling

Groundwater models are a useful tool to represent and understand groundwater flow and contaminant transport. It is important to understand that models are used in hydrogeology as tools. It is rare that a groundwater model can accurately simulate or predict groundwater conditions in all portions of the aquifer. This is particularly true of the LIV aquifer because of its complexity. However, groundwater models are more accurate than other available methods and represent the best available technology for describing aquifer responses. The primary objective of the numerical model is to accurately simulate the response of the aquifer and use the model as a predictive tool in land-use planning. Groundwater modeling technology has improved dramatically in recent years and is no longer restricted by complex data files or intensive computer requirements. Models now exist that have graphical interfaces and run easily on personal computers. Recognizing that new WHPA strategies, changes in the location and amount of groundwater withdrawal, and additional hydrogeologic data might require modification or re-evaluation of capture zone delineations in the future, a secondary objective of the modeling for the WHPP was to try and develop the model using a flexible, "user friendly" software that could be used in on-going wellhead protection planning activities.

The general methodology of groundwater modeling is to numerically discretize the aquifer into blocks and assign aquifer properties to each block. At the edges of the model, boundary conditions are specified such as constant head, constant flux, and no-flow. The aquifer properties and boundary fluxes are then adjusted, based on supplemental direct hydrogeologic information, such as pumping tests and hydrogeologic mapping, in order to calibrate the model to existing conditions. The model is calibrated to measured water-levels throughout the aquifer. This is one reason that an entire year of detailed water-level monitoring was performed for the Wellhead Protection Program. When the model adequately re-creates the observed water-levels in the aquifer, using reasonable parameters consistent with direct hydrogeologic data, it is used as a predictive tool. In this case, it is used to predict the 1-year, 5-year, and 10-year capture zones for each of the LIV production wells. Capture zone delineations were performed for the City wells COI 1/2, COI 4/5, and SPWSD wells 7/8. The grouping of the wells into well-pairs was based on the proximity of the wells to each other.

The distribution of water-level measurements in the LIV is not uniform, so the focus of the calibration was to represent groundwater-levels in the central valley area near the COI and SPWSD wells as closely as possible. Modeled groundwater-levels in the northern and western valley area were more difficult to calibrate because there are very limited groundwater-level data in these areas. The dimensional characteristics of the valley, (aquifer thickness, and hydraulic conductivity) were represented within the model based on hydraulic testing and drill logs discussed in Sections 2 and 3. The total groundwater discharge to Lake Sammamish, based on the water balance calculations, was an important calibration parameter.

The groundwater flow system within the study area is complex and does not lend itself easily to numerical modeling. The main difficulties with modeling the system are:

- The overall thickness, extent and detailed stratigraphy of the deltaic/outwash aquifer in the LIV is not well known;

- Aquifer thickness, extent and groundwater-levels are not well known in the eastern plateau areas; and

- The transition from the recharge areas in the eastern plateau areas to the relatively horizontal two-dimensional groundwater flow system within the valley floor is difficult to simulate because of the large vertical head difference between these areas.

Consequently, an approach involving a three-dimensional "black-box" model and a simplified two-dimensional model was developed. The purpose of the more complex three dimensional model was to test assumptions and boundary conditions used in the two-dimensional model and evaluate the validity of the 2-D model. The three-dimensional model was developed using MODFLOW/MODPATH, as discussed in the following section.

4.3.1 MODFLOW/MODPATH Modeling

To evaluate the potentially-complex stratigraphy and uncertainty about conditions on the eastern plateau area, a three-dimensional simple box model was developed using MODFLOW. The aquifer was represented as a rectangular system consisting of ten layers with a stream traversing the uppermost layer of the aquifer (Appendix G). A simple rectangular-shaped model domain was chosen for this purpose, rather than attempting to represent the actual valley floor configuration. The modeled domain was 16,000 feet long by 8,000 feet wide, which represents the approximate length and width of the Lower Issaquah Valley. The domain of the model consisted of 10 permeable layers which were chosen to be 20-feet thick, separated by 5-foot thick aquitards, for an overall thickness of 275 feet. The 10-layer MODFLOW model of the Lower Issaquah Valley was developed to study the effects of anisotropy on well capture zones. Anisotropy is a measure of the preference for horizontal rather than vertical groundwater flow and is usually the result of stratigraphy. An anisotropy of 100:1 means that horizontal hydraulic conductivity is 100 times greater than vertical hydraulic conductivity. The hydraulic conductivity of the permeable layers was 100 to 300 feet/day, similar to observed conditions. The hydraulic conductivity of the aquitards was varied as part of the analysis of anisotropy. Constant head boundaries were assigned to the northern and southern boundaries to simulate the observed gradient of 0.001. The lateral boundaries were assumed to be impermeable. A single well pumping at a constant rate of 1,700 gpm was located 3,200 feet from the eastern border and 8,000 feet from the southern border.

The intent of the MODFLOW modeling exercise was to evaluate the effect of varying parameters on the minimum travel time to a pumping well screened in the lower portion of the aquifer and on the number of particles reaching the well from a hypothetical source located 2,000 feet from the well. This sensitivity analysis resulted in the following conclusions:

- The critical anisotropy of the aquifer as a whole was on the order of 1000:1. If, on the whole, horizontal hydraulic conductivity exceeds vertical hydraulic conductivity by less than 1000:1, then incorporating multiple layers and anisotropic conditions in the model did not significantly alter the number of particles captured from a source located 2,000 feet from the well;

- The continuity of a low-permeability confining layer (0.01 to 0.35 ft/day) was important to a lateral extent of about 1,000 feet for a 100/ft/day aquifer and to a lateral extent of 320 feet for a 350 ft/day aquifer. If such a low permeability layer could not be demonstrated, it's presence in the model did not significantly alter the number of particles captured from a source located 2,000 feet from the well;

- Stream infiltration within the central valley area of less than 1 cfs per mile of stream has a maximum of a 60-day effect on the minimum travel time from the location of the stream to the well. Thus, including a stream in the model would not dramatically change the results of the capture zone; and

- Recharge from the eastern plateau areas in excess of 20% of the down-valley flow will impact the shape and extent of the capture zones.

Based on the conclusions of the "black box" model, and supporting hydrogeologic evidence, a multi-layer groundwater model is not presently necessary to simulate the LIV aquifer system specifically:

- Geologic logs do not indicate that low-permeability layers are laterally extensive;
- Pumping test responses and long-term water-level responses do not suggest high anisotropy values or low-permeability leakage within the aquifer as a whole; and
- Stream gaging does not indicate more than 1 cfs per mile stream losses in the central valley area.

The sensitivity of the model to recharge from the eastern plateaus could easily be incorporated into a 1-layer, 2-dimensional model. Thus, a 1-layer, 2-dimensional modeling approach was taken for find delineation of capture zones.

4.3.2 FLOWPATH Model

The one-layer steady state model of the Lower Issaquah Valley area was developed using FLOWPATH, which is based on a block-centered finite difference formulation. The modeled area of approximately 6.7 square miles lies primarily within the valley floor area. Because of the difficulty in simulating the transition between the eastern plateau and the lower valley, the model does not directly include the eastern plateau area. Rather, the groundwater contribution of the eastern plateau area was incorporated into the valley floor model as a constant-flux boundary condition. The model configuration is shown on Figure 14. The following assumptions apply to the two-dimensional plan view model:

- The aquifer system behaves as a single confined isotropic aquifer with specified heterogeneities;
- The aquifer system is 200 feet thick, except extending from south of Issaquah to the Hobart Gap, where it thins from 200 to 50 feet;
- Lake Sammamish is represented as a constant head condition at 25 feet msl. The model was calibrated so that between 10 and 20 cfs discharges to the Lake boundary, based on water balance calculations.;
- The Issaquah Gap boundary has a constant head of 150 feet during the winter and spring, when water-levels are the highest; and 140 feet msl during the summer and fall, when water-levels are the lowest;
- Constant flux boundaries along the eastern perimeter of the Lower Valley are similar, with a total influx of between 5 and 10 cfs based on water budget calculations. The flux from the eastern boundary was adjusted within these ranges during the model calibration process;
- Constant flux boundary conditions of the southern and western perimeter of the Lower Valley were adjusted as part of model calibration;

- No-flow boundary conditions were assigned to portions of the valley margins where bedrock outcrops exist;

- The bedrock underlying the valley bottom is impermeable;

- The City's and District's wells are assumed to pump constantly at a combined rate of 4.2 cfs, based on usage data from 1990-1991. A future scenario was developed assuming appropriation of all SPWSD water rights applications and a possible re-distribution of groundwater withdrawals by the City of Issaquah as shown on Table 7.

The major model assumption is that of a single confined aquifer with no recharge or stream infiltration from the central valley area. The aquifer system within the Lower Issaquah Valley area, as a whole, appears to behave generally as unconfined to semi-confined. Small-scale heterogeneity in hydraulic conductivity, thickness and extent of water-bearing zones are present. After considering a number of different ways to represent the aquifer system numerically, the decision was made to assume it is fully confined. The assumption of fully confined conditions is conservative (and over-estimates capture zone extent), because all groundwater is assumed to enter the system from the boundaries. Additionally:

1) The contribution to the aquifer system from precipitation occurring within the valley floor area is much less than that entering along the margins of the valley. The likely maximum potential contribution assuming the basin average recharge of 4 inches per year over an area of 2,100 acres would be about 1 cfs. However, the vertical hydraulic gradient throughout much of the valley floor area is directed upwards, and as such, only the shallow unconfined sediments could receive recharge. Furthermore, the areal recharge distribution within the valley area is patchy due to urbanization and it would be difficult to assign recharge rates accurately;

2) The contribution of water from streams and creeks to the aquifer system in the valley floor area is not a sensitive parameter, based on the results of the 3-D MODFLOW simulations. Furthermore, the vertical hydraulic gradient is directed upward throughout much of the valley floor area, and, as such, leakage from the creeks could not enter the aquifer system. Leakage from streams to the aquifer at the margins of the LIV is incorporated via the constant flux boundary condition; and

3) Predicted capture zones will be the same from a confined and unconfined 1-layer model if both models have the same hydraulic head distribution and hydraulic properties.

As the understanding of the hydrogeologic system improves with the collection of additional data, complexities may be incorporated into the model, if deemed appropriate. For present planning purposes, we have opted to take a somewhat conservative approach to modeling the valley groundwater system. Potential contaminant sources within the

WHPA's, specific in location and type of contaminant, should be evaluated on a case-by-case basis, using more sophisticated fate and transport models used in groundwater contamination studies. This however, is beyond the scope of the Wellhead Program and is more the responsibility of those potentially responsible for groundwater contamination. Section 5 discusses the behavior of various contaminants in more detail.

4.3.3 FLOWPATH Calibration and Results

Calibration of the model to observed conditions proceeded as follows:

- Horizontal hydraulic gradients were approximately reproduced by varying the hydraulic conductivity of the aquifer;
- Flux entering the valley from the south and west and the flux entering the valley from the east was varied to match the groundwater-levels and directions of flow occurring in the central valley area. This was done for both the seasonal high and low groundwater-level conditions; and
- The change in direction of flow between the seasonal high and low groundwater-level periods was matched to observed conditions by changing the ratio between the flux entering from the south and west, and the flux entering from the east.

All modeling results are presented in Appendix H and summarized in Table 8. Two different cases are presented:

- Case 1 assumes a constant hydraulic conductivity (200 ft/day) within the model domain;
- Case 2 assumes that the aquifer along the eastern valley margin (deltaic materials) is more permeable (300 ft/day) than the sediments farther to the west and north; and
- Case 3 assumes the hydraulic properties of Case 2, but evaluates boundary fluxes in the model.

Each case included simulations under conditions of the "average" annual high groundwater-levels (case 1a and 2a) and the "average" annual low groundwater-levels (Case 1b and 2b). The results are as follows:

<u>Case 1-Constant Hydraulic Conductivity</u>

Table 8 summarizes the calibration results for Case 1. A uniform hydraulic conductivity is assumed for Case 1. Case 1a represents the annual high groundwater-level conditions, while Case 1b represents the annual low groundwater-level conditions. To calibrate the model, the annual high groundwater-levels measured in February 1992 were used for

Case 1a, while September 1992 water-levels were used for annual low groundwater levels (Case 1b).

The results indicate that a single constant hydraulic conductivity of the valley floor aquifer system can be used to accurately match the observed groundwater-levels and flow directions. Discrepancies between modeled and observed water-levels are less than 2 feet at all wells except in the area around SPWSD wells 7/8. The discrepancy observed in this area is caused by the surrounding pumping wells. The total groundwater flow to Lake Sammamish for this case is 16.7 cfs, which is within estimated ranges. Groundwater flow from the eastern boundary for Case 1a is 7.1 cfs, or approximately 34 percent of the total groundwater flow entering the valley floor area. This also is consistent with water balance estimates.

The annual low water-levels and flow directions occurring in September of 1992 in the central valley area can be a matched by reducing the groundwater flow entering from the valley margins, and reducing the Issaquah Gap boundary to 140 feet (2.5 cfs flux). Flux from the eastern boundary is reduced to 4.1 cfs, or about 23 percent of the total groundwater flow entering the valley floor. Groundwater flow from the south and west was not decreased. The total groundwater flow to Lake Sammamish in this case is 13.8 cfs, which is still within estimated annual ranges.

These results simulate the observed recharge, showing a variable distribution of recharge to the LIV during the course of a year. On the whole, of course, recharge is higher in the winter/spring and lower in the summer/fall. The relative contributions from the east and south/west boundaries of the aquifer change appreciably. Flux from the eastern model boundary must be reduced significantly to reproduce observed summer/fall groundwater levels. Recharge from the eastern plateau areas appears to occur as a transient "pulse" during winter/spring and illustrates the importance of the eastern Plateau area (both Grand Ridge and Lake Tradition Plateau) for restoring groundwater-levels after summer. The model supports the hypothesis that the eastern plateau area supplies between 20 and 35 percent of the total groundwater flow entering the LIV aquifer system.

Case 2-Variable Hydraulic Conductivity

Table 8 summarizes the calibration results for Case 2. For Case 2, the hydraulic conductivity in the vicinity of the wellfields is assumed to have a hydraulic conductivity 1.5 times higher (300 ft/day) than the materials located farther west and north. This scenario is more consistent with the conceptual model of the high-permeability delta deposits concentrated along the eastern valley area. For the high water-level case (Case 2a), the groundwater contribution from the east to 9.7 cfs (47 percent of the total inflow to the model). The higher inflows from the Plateau areas are necessary because, if the hydraulic conductivity is higher in the eastern and central valley area, the total groundwater flow through the area must be greater to match the observed hydraulic gradient. The total groundwater flow to Lake Sammamish for this case is 16.5 cfs.

For the annual low groundwater-level case (Case 2b), the Plateau recharge was reduced to 6.1 cfs (36 percent of the total) to match observed groundwater-levels and flow directions. The groundwater contribution along the southern and western borders was not decreased. The Hobart gap area boundary head was reduced from 150 to 140 feet, consistent with Case 1c. The total groundwater contribution to Lake Sammamish for this case is 12.9 cfs.

Similar to Case 1, Case 2 indicates a proportionally higher contribution of recharge from the eastern plateau during winter/spring recharge compared with the south and west. Further, Case 2 suggests that the total groundwater contribution from Grand Ridge and Lake Tradition may be as much as 45 percent of the total recharge to the aquifer.

Case 3 - Boundary Fluxes

Table 8 summarizes the calibration results for Case 3. Identical hydraulic properties to Case 2 were used. The purpose of the simulation was to determine the minimum flux necessary from the south and western margins of the LIV that would reproduce observed groundwater levels and flow directions. The surface geology of the western LIV is not indicative of high recharge, and lower fluxes are possible. The results indicate that at least 2.7 cfs cumulative inflow from the west and southwest boundaries is necessary to calibrate the model. This necessitates a proportional increased flux from the east of between 8.6 and 13.9 cfs. Total groundwater flow to Lake Sammamish is between 11.5 and 15.6 cfs consistent with water balance estimates. The modeled inflow of between 8.6 and 13.7 cfs from Grand Ridge and Lake Tradition Plateau is higher than the estimates based on hydrologic data. For Case 3, between 75% and 89% of the recharge to the LIV originates from the eastern plateau areas.

4.4 Well Capture Zones/WHPA Delineation - Current Conditions

Well capture zones for 1-, 5- and 10-year capture zones were developed from the model groundwater-levels for Cases 1, 2 and 3. The modeled capture zones for each case are presented in Appendix H, and summarized on Table 9.

1-year Capture Zones

The composite 1-year capture zones for all cases are shown on Figure 15. Appendix H contains the individual capture zone delineations. Because groundwater-levels and flow directions fluctuate annually, the actual capture zones will encompass a portion of both the annual high water-level capture zone and the annual low water-level capture zone. In order to provide a reasonable estimate of the overall 1-year capture zone, superposition of all cases should be considered to represent the 1-year capture zone and WHPA.

5-year Capture Zones

The composite 5-year capture zones for all cases are shown on Figure 16. Appendix H contains the individual capture zone delineations. Because groundwater-levels and flow directions fluctuate annually, the actual capture zones will encompass a portion of both the annual high water-level capture zone and the annual low water-level capture zone. In order to provide a reasonable estimate of the overall 5-year capture zone, superposition of all cases should be considered to represent the 5-year capture zone. Capture zones for SPWSD 7/8 and COI 1/2 extend to the constant flux boundary of the model.

The 5-year capture zone extends to the eastern content flux boundary of the model. The model cannot be used to predict the extent of capture zones east of the model boundary. Capture zones within the domain of the model are still accurate. The approach to travel time analysis outside of the model domain is described below.

10-year Capture Zones

The composite 10-year capture zones for all cases are shown on Figure 17. Appendix H contains the individual capture zone delineations. Because groundwater-levels and flow directions fluctuate annually, the actual capture zones will encompass a portion of both the annual high water-level capture zone and the annual low water-level capture zone. In order to provide a reasonable estimate of the overall 10-year capture zone, superposition of all cases should be considered to represent the 10-year capture zone.

The 10-year capture zones extend to the eastern constant flux boundary of model for all wells except COI 4/5. The model cannot be used to predict the extent of capture zones east of the model boundary. Capture zones within the domain of the model are still accurate. The approach to travel time analysis outside of the model domain is described below.

Capture Zones Outside Model Domain

As discussed previously, difficulties in modeling the transition from the eastern plateau areas to the valley floor necessitated a simplification of the model that prevents predicting the extent of capture zones on the eastern plateau areas. It would be extremely difficult, without substantial additional data on groundwater conditions at all depths on the Plateau to propose discrete, spatially variable capture zones on Grand Ridge and Lake Tradition Plateau. However, it is possible to calculate equivalent vertical travel times from the plateau areas to the valley floor. The calculation of the vertical hydraulic conductivity can be made based on Darcy's equation using the boundary fluxes from the model and the head differences between the Plateau area and the valley floor. Darcy's equation is expressed as:

$$Kv = \frac{q}{iA}$$

where

Kv = vertical hydraulic conductivity (ft/day)
q = flux from eastern model boundary (ft^3/day)
i = vertical gradient based on head differences
A = recharge area outside model domain (ft^2)

Appendix H, Table H-2 summarizes these calculations. Vertical hydraulic conductivities of between 0.8 and 2.7 feet/day are calculated. Using these conductivities and an effective porosity of 25%, a vertical groundwater velocity of between 0.2 and 0.6 feet/day is calculated. Translating this velocity into a travel time from the Plateau (elevation 460 feet) to the Valley floor (elevation 50 feet), a travel time of between 2 and 6 years is estimated from the upland areas to the LIV aquifer and model boundary. The capture zones for LIV wells COI 1/2 and SPWSD 7/8 reach the model boundary of about 4 years. Thus travel time from Grand Ridge and Lake Tradition Plateau is estimated to be between 6 and 10 years.

Figure 18 shows a composite overlay of all capture zones and recharge areas for the LIV aquifer.

4.5 Well Capture\Zone WHPA Delineation - Future Conditions

A final case was considered using projected water-rights as pumping rates for the area production wells, including SPWSD Well 9. Table 7 summarizes the projected withdrawals based on water rights applications. Withdrawal from SPWSD wells 7/8 is increased three-fold, and SPWSD 9 is assumed to be on-line at a rate of 3,225 acre-feet/year. Issaquah wells COI 1/2 are increased through a possible transfer of water rights from the City's Gun Club wells (Lynne, 1993). The purpose of this simulation was not to evaluate water-rights or groundwater availability, but to evaluate the possible increase in capture zone area resulting from increased groundwater usage in the LIV. The actual increases in groundwater usage, if any, cannot be determined at this time but the simulation is based on all known applications and existing rights.

The results of the simulation indicate that the capture zones of the wells increase substantially, essentially encompassing the entire LIV at the 10-year TOT, and a substantial portion of the LIV at the 5-year TOT. Figure 19 shows the 5-year capture zone using projected withdrawals. Appendix H, Figures H-16 to H-20, show the modeled water-table configuration and capture zones. Of particular interest is the skew of the capture zones to the west. Whereas under present conditions the capture zones extend roughly southeast from the wells, under projected conditions the capture zones extend much farther west, towards Tibbets Creek. One reason for this is the inclusion of SPWSD well 9. The position of the well is such that it intercepts a large proportion of the flux from the eastern upland areas, forcing wells SPWSD 7/8 and COI 4/5 to draw water from further to the west.

Although this projected simulation is a hypothetical scenario, it is clear that increased groundwater usage in the LIV will enlarge the capture zones and WHPA's in the Valley, on the eastern recharge areas, and possibly out to the western portion of Issaquah. This may influence WHPA strategies, particularly with respect to re-location or permitting of hazardous materials facilities west of the present capture zones for the wells.

5. SUMMARY AND CONCLUSIONS: HYDROGEOLOGY

The significant findings and conclusions from the hydrogeologic analysis and capture zone delineations are summarized as follows:

Geology

- The pre-glacial bedrock structure of the LIV forms a deep bowl up to 600 feet deep between the East Fork Issaquah Creek and Lake Sammamish. Between the East Fork and Hobart Gap, bedrock depths are shallower and more uniform;

- Complex depositional environments during the last glacial retreat formed large deltas that extend from near ground-surface on the eastern Plateau areas (Grand Ridge and Lake Tradition), to well below sea-level in the valley floor. These deltas may extend as much as 3,000 feet into the LIV;

- The sediments within the delta are typically heterogeneous and there is no evidence of stratigraphic continuity of individual sediment types (e.g. clays). The deltaic materials contain discontinuous layers and lenses of sand, gravel, and silt;

- On the western edge of Grand Ridge, the deltaic deposits are exposed at ground surface. East of this exposure of deltaic deposits is a coarse sandy till. This till may represent an ablation till, rather than a basal till;

- There are no data regarding the sediments deeper than 100 feet in the Grand Ridge and Lake Tradition area. Older glacial deposits, possibly containing coarse sands and gravels may underlie the more recent glacial deposits. Bedrock is greater than 250 feet deep in places on Grand Ridge based on a geophysical survey.

- Fluvio-lacustrine depositional processes dominated the later stages of glacial retreat. These sediments overlie the deltaic deposits and interfinger with the delta at its margin. The lacustrine sediments are finer than the deltaic deposits, consisting of sands, silts and clays; and

- Recent alluvial process have deposited a variety of sands, gravels and silts over the LIV.

Hydrology

- Hydrologic analysis of precipitation run-off and streamflow in sub-basins of the LIV indicates total groundwater recharge to the LIV of 22 cfs, which is consistent with previous estimates;

- Hydrologic data indicate that about 27% of the recharge to the LIV aquifer occurs within the East Fork and North Fork sub-basins; and
- Increased run-off due to urbanization will reduce groundwater infiltration in direct proportions.

Hydrogeology

- The deltaic deposits underlying the eastern portion of the LIV are highly permeable and the most important source of groundwater in the area;
- Aquifer transmissivity is estimated at approximately 67,000 ft^2/day, with a storativity of between 10^{-4} and 0.2 depending on the method of analysis. Hydraulic conductivity is estimated at between 100 and 300 feet per day. Aquifer porosity is estimated at 0.25. Average hydraulic gradient is between 0.001 and 0.002. Groundwater velocity is between 0.4 and 2.4 feet per day;
- Groundwater levels fluctuate 7 and 15 feet annually at all depths monitored;
- Groundwater flow directions vary seasonally from a northwesterly direction in the winter/spring to a northerly direction in the summer/fall;
- Groundwater recharge occurs primarily on the Eastern Plateau areas (Grand Ridge and Lake Tradition) and along both margins of the Issaquah Valley between the East Fork and Issaquah Gap;
- Groundwater discharge is concentrated between Lake Sammamish and the adjacent wetland area. Average annual groundwater discharge is estimated at 15 cfs.
- There appears to be little stream/aquifer interaction in the central LIV area.. Stream gaging, mini-piezometer installations and pumping test results suggest limited hydraulic continuity between surface and groundwater within the central valley area. Additional stream gaging data are needed to further assess hydraulic continuity with the central LIV;
- Analysis of pumping tests and long-term water-level fluctuations indicates that groundwater withdrawals in the LIV affect shallow groundwater levels and cause downward vertical gradients from the water-table toward the completion zones of the wells; and
- The LIV aquifer system behaves as an unconfined to locally semi-confined aquifer. Analyses of pumping tests, water-levels, and hydraulic gradients do not suggest that significant regional confining layers are present within the aquifer system. As such, the aquifer is highly vulnerable to contamination from surface sources.

Wellhead Protection Delineations

- The typical WHPA delineation approach, using time of travel (TOT) as a basis, incorporates simplifying assumptions which conservatively over-estimate the potential impact of a contaminant release at the ground surface;

- Hydrogeologic mapping of recharge areas and numerical modeling are the most appropriate methods for WHPA delineations in the LIV aquifer system;

- Hydrogeologic mapping indicates that approximately 2,850 acres along the Eastern plateau area may provide recharge to the LIV aquifer.

- The modeling approach for the LIV aquifer system accurately reproduces observed hydrogeologic conditions and the model can be used as a predictive tool. The approach also satisfied a secondary objective, which was to develop the model using readily accessible software that could be easily modified to incorporate possible revisions in the future;

- The 3-dimensional modeling indicated that a low permeability confining layer had to be continuous over at least 1,000 feet to have a significant impact on the capture zone of a well. Geologic logs do not indicate that low-permeability layers are laterally extensive;

- The 3-dimensional modeling indicated that horizontal hydraulic conductivity had to exceed vertical hydraulic conductivity by at least 1000:1 in order to have a significant impact on the capture zone of a well. Water-level and pumping test responses do not indicate high anisotropy or low vertical leakage;

- The 3-dimensional modeling indicates that steam infiltration of 1 cfs per mile of stream had a minimal effect on the capture zone of the well. Stream gaging and mini-piezometer installations do not indicate stream losses in excess of 1 cfs per mile;

- The 2-dimensional model accurately reproduces observed water-levels for both high-flow and low-flow conditions to within 2 feet in most wells. Predictive simulations of capture zones for both high-flow and low-flow conditions incorporate the change in seasonal groundwater flow direction;

- The 2-dimensional model accurately reproduces observed water-levels for both a uniform hydraulic conductivity and for a variable hydraulic conductivity aquifer, where more permeable sediments are concentrated along the eastern margin of the LIV (similar to the distribution of deltaic sediments);

- The 2-dimensional model indicates that increased influx of groundwater from the eastern plateau area during the winter and spring is the primary reason for the change in groundwater flow direction.

- The 2-dimensional model indicates that flux from the eastern plateau areas may account for between 22% and 47% of recharge to the aquifer. An adequate calibration to observed water-levels can also be obtained with up to 89% of total recharge to the aquifer originating from the eastern plateau areas;

- Composite WHPA capture zones, based on superposition of model results for different cases incorporate the variable groundwater flow direction and range of hydraulic conductivity within the LIV aquifer;

- Composite 1-year WHPA capture zones encompasses approximately 85 acres, distributed as three non-coalescing circular areas around each well pair;

- Composite 5-year WHPA capture zones encompasses approximately 450 acres. Capture zones for COI 1/2 and SPWSD 7/8 coalesce and reach the boundary of the model. The capture zone for COI 4/5 remain distinct;

- Composite 10-year WHPA capture zones encompass an area of at least 800 acres. Capture zones for COI 1/2 and SPWSD 7/8 coalesce and reach the boundary of the model. The capture zone for COI 4/5 coalesces with the other capture zones but does not reach the model boundary;

- It is not possible to delineate spatially distributed capture zones on the eastern plateau areas. The additional travel time from the Plateau area to the boundary of the model is between 2 and 6 years. The capture zones for COI 1/2 and SPWSD 7/8 reach the model boundary in 4 years. Thus, the Plateau areas lie in a 6- to 10-year capture zone; and

- Future groundwater withdrawals in the LIV will enlarge the capture zones of wells in the LIV, possibly including a large portion of the southern LIV to the Issaquah Gap, and western portion of the LIV to Tibbets Creek.

6. WATER QUALITY EVALUATION

This section presents a general discussion of groundwater contamination issues and processes, followed by an evaluation of current groundwater and surface water quality of the Lower Issaquah Valley (LIV).

6.1 Overview of Contaminant Hydrogeology

Groundwater contamination can be defined as artificially induced degradation of natural groundwater quality, which may impair the use of the water, and create a human health hazard. Contaminant types can be broadly classified into inorganic chemicals, organic chemicals, microbiological contaminants, and radionuclides. Inorganic chemicals include metals and nitrate. Organic chemicals include petroleum products, pesticides and herbicides, chlorinated solvents, and other miscellaneous organic compounds. Microbiological contaminants include bacteria, particularly coliform bacteria, viruses, and giardia. Table 10 presents a general breakdown of contaminant categories and characteristics of typical contaminants.

There are a large number of potential sources of groundwater contamination, which are broadly grouped into point sources and non-point sources based on the areal extent of the contaminant source. Point sources include underground storage tanks (UST's), landfills, construction activities, mining activities, and agricultural activities (animal feed lots, dairy). Non-point sources include agricultural use of fertilizers, pesticides and herbicides, septic systems, and urban runoff. The division between point and non-point sources is gradational. For example, depending on the number and areal extent of septic drainfields, septic systems could be classified as either a point or a non-point source.

The transport of a contaminant from the ground surface to an aquifer is a highly complex subject, dependent on a number of hydrogeologic and chemical parameters. It is beyond the scope of the WHPP to evaluate specific transport pathways for all contaminants of concern. Rather, the objective of the WHPP is to provide a general technical framework for planning purposes and for more detailed future analyses as required. The following summary of general contaminant behavior is included to briefly discuss significant transport parameters associated with the various contaminant categories.

In general, there are two important properties to recognize in contaminant transport from the ground surface to groundwater:

- Sorption reactions with soil particles (particularly organic matter) are important in controlling the migration rate and concentration of contaminants in both the unsaturated and saturated portions of the sub-surface. In some cases, these processes significantly retard the rate of contaminant migration, and may significantly attenuate the concentration. As such, the plume for a retarded contaminant may expand more slowly and the concentration may be less than for a non-reactive contaminant; and

- The solubility of the contaminant is important in the concentration of the contaminant since it determines how easily the contaminant dissolves in water. A given volume of contaminant with a high solubility is more likely to attain a high concentration in groundwater than a similar quantity of a low-solubility compound.

Table 11 contains a list of several contaminants and their respective travel times across a 1,000-foot pathline in a granular aquifer similar to the LIV aquifer. Appendix I contains additional contaminants and the assumptions used in developing the travel times. Table 11 shows that travel times range over orders of magnitude depending on the type of contaminant.

The concentration of a contaminant is usually referenced to a Maximum Contaminant Level (MCL) established by state or federal agencies based on toxicity and risk to human health. These MCL's are the standards by which the severity of contamination are assessed, and are in many, but not all, cases the established criteria for clean-up actions at contaminated sites. For groundwater protection studies, protection of the aquifer is often based on a level lower than the MCL as a target water quality which the community strives to maintain. Table 12 summarizes current primary drinking water standards (MCL's) for inorganic and organic contaminants.

Major Cations/Anions

In general, the major cations and anions do not pose a threat to human health and are not generally considered contaminants. At high concentrations, some compounds, such as chloride, sulfate and sodium, may cause a health risk. A secondary MCL for chloride (250 mg/L), and sulfate (250 mg/L) exists, and a MCL for sodium is expected in the future.

Metals

Elevated metals may cause a variety of health problems associated with accumulation of metals in body tissue. The transport and fate of trace metals is complex, due to their tendency to form complexes with inorganic and organic anions, which changes their potential solubility and transport characteristics accordingly, and due to their sensitivity to the specific conditions of the subsurface (pH, pE, and redox environment). Adsorption processes may also strongly influence the mobility of trace metals. For example, in some groundwater, many of the trace metals are strongly adsorbed, which reduces the dissolved concentrations significantly.

Nitrate

Nitrate contamination has been attributed to agricultural practices, septic systems, nitrogen fertilizers and urban run-off. Elevated nitrate concentrations pose a health risk, particularly to infants and small children, from a condition known as methemoglobinemia. A primary MCL of 10 mg/L exists of nitrate. In some cases nitrate in groundwater originates as nitrate-containing wastes or fertilizers applied to the ground surface. Nitrate may also originate from organic nitrogen which occurs naturally or is incorporated into the soil by human activities. A process called denitrification often occurs in the soil zone (and groundwater system) when organic matter is abundant and reducing conditions exist. Denitrification in the soil zone can remove large amounts of nitrate under certain conditions. Once nitrate reaches the water table, however, it is highly mobile (does not react or absorb to soil particles) and does not transform or break down readily unless denitrification occurs in the absence of dissolved oxygen.

Organic Chemicals

Organic chemicals are becoming an increasingly problematic contaminant in groundwater. They include petroleum products (gasoline, diesel oil), solvents, pesticides and herbicides. The health risk of organic contaminants range considerably. Many are toxic to the nervous system or vital organs and others are carcinogens. One of the common behaviors of most organic chemicals is their occurrence in multiple phases. During migration from a surface source to the water table, organic chemicals can partition into three distinct phases, occurring in:

- Soil pores and soil solids as a residual;
- Soil gas as a vapor; and
- Pore water and groundwater as a dissolved phase.

Thus, a given quantity of contaminant released to the subsurface has a very complex pathway from its source to groundwater. Many organic contaminants are volatile and a portion of a spill on the ground surface will volatilize into the atmosphere or soil pore space. A spill may migrate downwards in a liquid phase and mix with groundwater at the water table. However, water infiltrating through the soil may "pick up" contaminants present in soil vapors and residuals. A fluctuating water table may also pick up contaminants in this manner.

Organic contaminants can be broadly classified according to their non-aqueous behavior into Light Non-Aqueous Phase Liquids (LNAPL) and Dense Non-Aqueous Phase Liquids (DNAPL). These distinctions are important to the fate and transport of organic contaminants in groundwater.

As the name implies, LNAPL is lighter than water, and, when present in groundwater, often floats at the water table. LNAPL contaminants include gasoline, oils, and greases. The most prevalent potential LNAPL contaminant in the LIV is gasoline. Gasoline is a complex mixture of over 200 different hydrocarbon compounds. Of these compounds, soluble aromatics typically comprise more than 95 percent of the dissolved constituents. As a result, the dissolved components typically associated with gasoline contamination are normally dominated by the aromatics benzene, toluene, ethylbenzene, and xylene (BTEX).

As the name implies, DNAPL is denser than water, and, when present in groundwater, often sinks below the water-table. Below the water table, DNAPL in large quantities may migrate to the bottom of the aquifer or perch on stratigraphic heterogeneities within the aquifer. If present as a free-product liquid phase below the water table, DNAPL can be a continuing source of dissolved groundwater contamination lasting many decades. DNAPL contaminants include solvents used for cleaning and degreasing of metal parts. Common components of solvents include trichloroethylene and trichloroethane. Tetrachloroethylene (PCE) is commonly used in dry cleaning processes.

6.2 Groundwater Quality in the LIV

As part of this study, three rounds of water quality samples were taken from wells located throughout the LIV between May 1992 and April 1993, as summarized on Table 4. The samples were analyzed for various constituents, including the major anions and cations, priority pollutant metals, iron and manganese, nitrate, turbidity, volatile organics, pesticides, herbicides, and PCB's. Appendix E contains the groundwater quality database prepared for this study. Additionally, water quality sampling was performed between 1990 and 1992 (Geraghty and Miller, 1992) in 18 monitoring wells around the ARCO Station at the corner of Gilman Blvd. and Front Street after a leak in one of the underground storage tanks was detected. These data were provided to the WHPP and are summarized in this section. The WDOE also performed sampling at six sites in Issaquah and analyzed for lead and organic compounds, (WDOE, 1992). The groundwater quality is summarized by category below.

6.2.1 Major Cations and Anions

The major cations and anions were analyzed to determine the general character of the groundwater occurring within the LIV. These constituents are generally of only minor concern with regard to human health. Secondary contaminant levels, however, have been assigned to chloride and sulfate. Also, high sodium concentrations pose a possible health risk for people with heart disease, and a MCL of 40 mg/L is expected to be established for sodium in the future.

The groundwater occurring within the LIV is a calcium bicarbonate type of water. The groundwater contains relatively low concentrations of dissolved solids, indicating that the groundwater is relatively young. Most of the groundwater sampled throughout the LIV is "soft", with a hardness of less than 75 mg/L as calcium carbonate ($CaCO_3$), calculated from calcium and magnesium concentrations. Only one production well (Bell) falls into the moderately hard category of between 75 and 150 mg/L as $CaCO_3$.

The chloride and sulfate concentrations in groundwater are well below the secondary MCL's. In addition, sodium concentrations are well below the expected MCL of 40 mg/L.

6.2.2 Priority Pollutant Metals

All priority pollutant metal concentrations from wells sampled as part of the WHPP were below detection limits within the LIV.

A number of shallow monitoring wells not sampled as part of the WHPP have reported elevated levels of lead. The drinking water standard for lead is 50 parts per billion (ppb), or 5 ug/L. Elevated lead levels in groundwater are often associated with gasoline contamination, stormwater run-off, and possibly aerosol lead from vehicle emissions. Samples submitted to WDOE between January 1990 and July 1991 showed lead concentrations varying from 6 to 70 ppb. The highest lead concentrations were reported near the Texaco Station at the corner of Sunset and Front Street in Issaquah. Wells at the proposed Virginia Mason facility on Gilman Blvd also showed elevated lead concentrations (19 to 5 ppb).

Lead concentrations in monitoring wells at and around the ARCO station ranged from below detection to 124 ppb. The highest concentrations were observed in wells MW-8, MW-10, and MW-12 during August of 1991. These wells are all completed at the water-table at depths of less than 20 feet below ground. Deeper completions near these wells showed concentrations of less than 3 ppb. The most recent sampling analysis for lead at the ARCO site was in February 1992. At that time, the highest lead concentration was 22 ppb in MW-8, and less than 5 ppb in all other wells sampled.

Elevated lead concentrations have not been observed in deep production wells in the LIV.

6.2.3 Iron and Manganese

Secondary contaminant standards exist for iron and manganese, due to aesthetic and taste considerations.

Within the LIV, the iron and manganese concentrations are generally low, with the exception of 5 wells with iron concentrations above the current SMCL of 0.3 mg/L (SPVT1-1, WH3-1, SPVT3, WH2-1, and SPVT2-2), and 3 wells with manganese concentrations above the SMCL of 0.05 mg/L (SPVT3, WH2-2, and SPVT2-2). For each of these samples which exceeded the SMCL, turbidity was greater than 4 NTU's, and in one case, (the SPVT2-2 sample) had an extremely high turbidity of 160 NTU. The high turbidity of these samples was likely responsible for the reported high iron and manganese concentrations, because iron and manganese attached to the suspended particles may have been dissolved into the groundwater sample during sample preparation (acidification). Therefore, these samples are not believed to represent the true groundwater quality, and the iron and manganese concentrations throughout the LIV are believed to be below their respective SMCL's.

6.2.4 Nitrate

Nitrate concentrations in all wells sampled as part of the WHPP were less than 1.5 mg/L. Nitrate concentrations of greater than 1 mg/L were detected in 9 wells (Lakeside-new, SP7-2, DAROUT, SPVT1-1, SPVT5-1, Caldwell, WH2-1, SPVT3, and WH3-2). These nitrate concentrations imply slight groundwater quality degradation, possibly due to lawn fertilizers, septic systems, or pastured farm animals. Present nitrate concentrations within the LIV are typical of urbanized areas. Continued monitoring of nitrate concentrations is advisable to establish trends in nitrate concentrations. At present there are no trends in the nitrate data with respect to time or well completion depth.

6.2.5 Turbidity

Elevated turbidity may result in aesthetic and industrial-use problems. In addition, high turbidity is often associated with coliform bacteria.

Within the LIV, turbidity of greater than 1 NTU was detected in 15 wells. All but one of these were monitoring wells, in which the high turbidity can be attributed to insufficient development, a common occurrence for monitoring wells. The Bell Telephone well was the only production well with elevated turbidity.

6.2.6 Volatile Organic Compounds (VOCs)

Volatile organics include many of the contaminants associated with petroleum products and industrial solvents. Volatile organics were detected in two monitoring wells (SPVT5-1, and SPVT8-4) sampled as part of the WHPP:

- In SPVT5-1, 1,1,1-Trichloroethane was detected in all sampling rounds at concentrations of up to 1.3 µg/L. The present MCL for 1,1,1-Trichloroethane is 200 µg/L. This constituent is a solvent used in metal cleaning products. The contaminant was first detected in May 1992 at a concentration of 0.7 µg/L, and was sampled again November 1992 with a detected concentration of 1.2 ug/L, and then recently sampled again (April, 1993) with a detected concentration of 1.3 µg/L. This may suggest a trend of increasing concentration.

- Five volatile organic compounds were detected in monitoring well SPVT8-4 during the October, 1992 sampling round. However, organic volatile compounds were not detected when the well was re-sampled, suggesting that the reported results were likely due to contamination of the sample at the laboratory or during transport to the laboratory.

Volatile organic compounds have been detected in shallow monitoring wells installed as a result of releases of hydrocarbon from gasoline stations in the LIV. Common VOC's associated with gasoline include benzene (MCL=5 µg/L), ethylbenzene (MCL=70 µg/L), toluene (MCL=100 µg/L), and total xylenes (MCL= 1000 µg/L). At the ARCO site, water quality can be summarized as follows:

- Benzene concentrations exceeded 3,000 µg/L in onsite wells MW-1, MW-2, and MW-14 in 1991, but were below 2 µg/L or undetected in downgradient monitoring wells. The last reported sampling in August 1992 showed benzene concentrations of 1,000 µg/L in on-site well MW-1 and 32 µg/L in on-site well MW-14. Concentrations in downgradient off-site monitoring wells were less than 2 µg/L or below detection.

- Ethylbenzene concentrations exceeded 700 µg/L in onsite wells MW-1, MW-2, and MW-14 in 1991. Concentrations in downgradient monitoring wells were below 2 µg/L or undetected. The last reported sampling in August 1992 showed ethylbenzene concentrations of 385 µg/L in on-site well MW-1, 7 µg/L in MW-2, and 34 µg/L in on-site well MW-14. Concentrations in downgradient off-site monitoring wells were less than 2 µg/L or below detection.

- Toluene concentrations exceeded 1,400 µg/L in onsite wells MW-1, MW-2 and MW-14 in 1991, but were below 2 µg/L in downgradient monitoring wells. The last reported sampling in August 1992 showed ethylbenzene concentrations of 385 µg/L in on-site well MW-1, 7 µg/L in MW-2, and 34 µg/L in on-site well MW-14. Concentrations in downgradient off-site monitoring wells were less than 2 µg/L, or below detection.

- Total xylene concentrations exceeded 2,000 µg/L in onsite wells MW-1 and MW-2 in 1991. Concentrations in downgradient off-site wells MW-6, MW-7 MW-9 and MW-11 ranged from 3 to 10 µg/L. These wells are completed above 40 feet below ground. The last reported sampling in August 1992 showed total xylene concentrations of 300 µg/L in on-site well MW-1, 2 µg/L in MW-2, and 81 µg/L in on-site well MW-14. Concentrations in downgradient off-site monitoring wells were less than 2 µg/L, or below detection.

6.2.7 Pesticides and Herbicides

Pesticide chemicals have a wide range of health effects, and many are carcinogenic. Wells in the LIV were analyzed for pesticides and herbicides using EPA method 8080 and 8150, respectively (see Appendix E). Concentrations of all pesticides and herbicides analyzed in wells sampled for the WHPP were below detection limits.

6.2.8 Summary

The groundwater within the LIV generally contains few dissolved solids, and is classified as a calcium bicarbonate type of water. In general, the groundwater quality from production wells within the LIV is excellent, with only slightly elevated iron and manganese concentrations. Herbicides, pesticides or PCB's were not detected within the LIV, and priority pollutant metals are below regulated limits. Shallow groundwater contamination from volatile organic compounds associated with underground gasoline storage tanks has been documented above drinking water standards in shallow monitoring wells the LIV. One organic compound (1,1,1-Trichloroethane,) has been detected and confirmed in monitoring well SPVT5-1 at concentrations of up to 1.3 ug/L. Other organic compounds (benzene, toluene, ethylbenzene, and xylene) have been detected in other monitoring wells not monitored as part of the WHPP.

6.3 Surface Water Quality in the LIV

Surface water quality is important with regard to groundwater quality since it is often indicative of the quality of stormwater run-off, which may reach groundwater through direct infiltration. Stream water quality is summarized briefly below, with an emphasis on drinking water constituents rather than toxicity to fish or riparian habitat.

METRO monitors several sites within the watershed on a monthly basis during baseflow conditions, as part of its annual quality of local lakes and streams program, including three sites on Issaquah Creek and one site on Tibbetts Creek. In addition, Metro has collected grab samples during high flows and storms since 1987 from one site on Issaquah Creek. Metro further collected five samples from five sites within the Issaquah basin during 1989 and 1990 as part of a storm water quality sampling program.

Between 1989 and 1990 dry season fecal coliform geometric means of four of the five stream locations exceeded state water-quality standards. The East Fork Issaquah Creek location did not exceed the standard. Yearly geometric means exceeded state standards in three of the five sites, while the wet-season state standard was exceeded in only Tibbetts Creek. An evaluation of baseflow metal concentrations, indicated that copper, chromium, iron, nickel, and zinc concentrations were below their respective aquatic standards, and cadmium, mercury, and lead concentrations were below detection limits.

Two fish kills occurred on the North Fork Issaquah Creek in March and April, 1990. Water and tissue samples indicated the fish kill was due to a combination of elevated metal, ammonia, sulfides, 1,2 Benzenedicarboxylic Acid, and Diisonyl Ester along with low hardness.

6.4 Urban Run-off/Stormwater Quality

Water quality evaluations of stormwater/urban runoff for various land uses are available from several water quality studies, including Golder Associates, 1992; the National Urban Run-off Program (US EPA, 1983), and a study for the City of Portland (Woodward-Clyde, 1992). These studies appear to be the most relevant stormwater quality assessments with regard to potential groundwater contaminants and land uses. Stormwater contaminant concentration data has also been collected within the Issaquah valley by METRO to evaluate potential groundwater quality impacts.

Table 13 summarizes representative median concentrations in stormwater run-off. In general, concentrations are similar for all land-uses, with slightly higher nitrate concentrations in residential areas, and higher zinc concentrations in commercial areas. Lead concentrations are similar for all land-uses at the NURP sites, while lead is higher in commercial/industrial areas in the Portland study. Total petroleum hydrocarbons (TPH) is similar for all land-uses, based on the Portland study.

7. LAND USE AND CONTAMINANT INVENTORY

This section present the results of a land-use and contaminant inventory of the LIV area.

The land-use and contaminant source inventory for the LIV developed from the following data:

- Land-use maps provided by the City of Issaquah;
- Land-use maps for King County (King County SWM, 1990; King County SWM, 1992);
- WDOE Underground Storage Tank Investigation List, March 1992;
- City of Issaquah listing of business licenses issued, 1991;
- Telephone survey/interview of 65 potentially hazardous materials businesses, March, 1993;
- City of Issaquah Fire Department inventory of hazardous chemicals;
- State of Washington RCRA filers, Issaquah area;
- SPWSD and City of Issaquah sewer service map; and
- Aerial photograph review of Issaquah area for 1936, 1968, 1974, and 1990.

Land-use and contaminant source information were input to a Geographic Information System (GIS) database, which also contained geologic and capture zone information from the WHPA delineation portion of this study. This allowed graphical overlays of land-use with WHPA's for analysis.

7.1 Past Land-use

Aerial photographs of the Issaquah area from 1936 and 1968 show that land-use prior to construction of Interstate-90 was predominantly rural and that little noticeable change in land-use occurred during that time. The two major developments in the LIV prior to 1974 were the construction of Interstate-90 and the Lakeside sand and gravel pit. Equipment fueling, solvents and excavations during construction may have caused contaminant releases, but quantities are not known. The former Issaquah Airport located west of the LIV production wells operated until about 1987, handling light aircraft traffic. Fueling docks and solvents may have been used at the airport, but quantities are unknown.

There is no evidence from the aerial photos to indicate severe contamination that has since been built-over or excavated. There are no large ground stains or facilities present on any of the aerial photos that would suggest the use or discharge of hazardous materials.

7.2 Current Land-use

The City of Issaquah has twelve land-use designations. For the purposes of wellhead protection, these land-uses were combined into five separate groups as summarized on Table 14. A separate land-use designation was established for transportation corridors in Issaquah, which includes I-90, and major arterials within the City. King County zoning codes, with the exception of the western portion of Grand Ridge and Lake Sammamish area, are rural 5-acre (RA-5) for all county areas of interest outside the jurisdiction of the City. Figure 20 shows the present land-use in the LIV.

Land-use within the delineated wellhead protection areas is summarized on Table 14:

- Land-use in the 1-year TOT's is predominantly vacant/undeveloped or residential for all wells. The future activities in these vacant/undeveloped areas are therefore important to groundwater quality in the LIV. A significant proportion of land-use in the 1-year WHPA's is transportation. Vehicular accidents, street run-off, and construction activities are therefore potential contaminant sources of concern for groundwater.

- Land-use in the 5-year TOT's is predominantly vacant/undeveloped (40%), followed by residential (26%) and commercial (16%) land-uses. Future activities in vacant/undeveloped areas are therefore important to groundwater quality in the LIV. Specific activities permitted in residential and commercial land-uses are also important to groundwater quality in the LIV. Permitting of on-site use or storage of hazardous materials in commercial zoned areas may represent a threat to groundwater quality. About 12% (53 acres) of the 5-year WHPA is a transportation. Vehicular accidents, street run-off, and construction activities are therefore potential contaminant sources of concern for groundwater.

- Land-use in the 10-year TOT's is predominantly vacant/undeveloped (45%), a slightly higher percentage of the TOT compared to the 5-year TOT. Future activities in vacant/undeveloped areas are therefore important to groundwater supplies in the LIV. Residential land-use occupies about 26% of the TOT, similar to the 5-year TOT. The land-use acreage shown on Table 14 do not include acreage outside of the City of Issaquah. Commercial land-use occupies about 12% of the 10-year TOT (proportionally less than the 5-year TOT). Permitting of on-site use or storage of hazardous materials in commercial zoned areas may represent a long-term threat to groundwater quality. Only about 8% (61 acres) of the 10-year WHPA is a transportation arterial, not including the proposed Sunset By-pass. Vehicular accidents, street run-off, and construction activities are still potential contaminant sources in the 10-year TOT.

7.3 Contaminant Source Inventory for the LIV

This section summarizes the present potential contaminant sources in the LIV and specifically within the 1-, 5-, and 10-yr WHPA's delineated in Section 4.

As part of this study, a database of the past and present UST's and chemical handlers has been developed. The database is presented in Appendix J, and graphical output from the GIS is presented on Figures 21 through 27. Potential groundwater contaminant sources within the LIV include UST's, spills at chemical handling facilities, stormwater/urban runoff, and transportation spill hazards. In addition, future zoning/density changes could impact groundwater quality, by increasing urban runoff, increasing the number of septic systems, and possibly increasing the number of UST's or chemical handlers.

Underground Storage Tanks

Based on WDOE UST data from 1992, there are 39 UST site facilities in the LIV which are currently operational, being investigated, or were recently operational. These facilities have one or more tanks, with total facility capacities ranging from 1,100 gallons to over 160,000 gallons. The storage tanks contain primarily gasoline, diesel, fuel oil, and propane. Priority pollutant metals such as lead or chromium are sometimes associated with UST facilities. Some of these facilities have been taken out of service and the tanks removed. Some tanks have also been removed and replaced with new and safer tanks. Appendix J summarizes the UST database, including the known history of each facility and the present and past potential release quantities. Currently there are about 32 operating facilities remaining within the Issaquah area. Figure 21 shows the location of the 39 UST facilities on file with WDOE. Figure 22 shows the locations of UST facilities where leaks have been reported, suspected, or under assessment. Fourteen facilities in the LIV have reported UST releases of contaminants.

Within the WHPA's, there are 16 UST facilities. Table 15 summarizes the number of tanks and the total volume of product within each WHPA. For the purposes of WHPA planning, no distinction is made between facilities with double-walled tanks or release detection systems. It is highly unlikely that the total volume contained in the UST's within each WHPA would be released to the aquifer instantaneously. Figures 23 and 24 show the locations of UST's relative to modeled capture zones.

Chemical Handlers

Based on review of the RCRA filers listing and telephone interviews with area businesses, there are 16 businesses within the LIV area that handle chemicals that could potentially contaminate groundwater. Figure 25 shows the location of chemical handlers in the LIV. Most of these businesses handle only small quantities of chemicals. However, some of these chemicals, particularly the solvents (DNAPL), are of concern with respect to groundwater contamination. Seven dry cleaning facilities exist within the Issaquah area which reportedly use the solvent tetrachloroethylene (PCE). The quantities of PCE used for dry cleaning are generally small, less than 55 gallons on-site at a given time. Three businesses (Grange Supply, Lakeside Gravel Pit, and Gilman Autobody) use solvents for cleaning and degreasing purposes. The contaminants present in solvents vary, but may include a variety of regulated VOC drinking water contaminants. All businesses reportedly have no more than 55 gallons of solvent on site at any given time. Six businesses reportedly have other petroleum oil products, including waste oil, on site. Quantities range from less than 100 to 2,500 gallons (Lakeside Industries). One business (Circuit Partner) handles about 80 different chemicals in both dry and liquid form. Most of the chemicals are acids and metal complexes. Solvents or regulated VOC compounds are not reportedly on-site. The hazard to groundwater posed by each chemical was not evaluated, since this business is presently outside of the WHPA's. The chemical handler database is presented in Appendix J.

Within the WHPA's, there are six chemical handlers. Table 15 summarizes the facilities within each WHPA. For the purposes of WHPA planning, it is assumed that the maximum reported amount is on-site as a potential spill release. It is highly unlikely that the total volume contained within each WHPA would be released to the aquifer instantaneously. Figures 26 and 27 show the locations of chemical handlers relative to modeled capture zones.

Urban Runoff

Urban runoff can potentially contaminate groundwater, and is a relatively constant source. Run-off can be evaluated in terms of a contaminant load to groundwater. A contaminant load is a mass of contaminant entering the system over a period of time. This mass can be determined from the concentration (mass per unit volume) and the infiltration rate (volume per unit time). If storm sewers are present, only a small portion of stormwater is likely to infiltrate to groundwater. In developing possible contaminant loads (see Section 8) it is conservatively assumed that present contaminant loads are a function of the median stormwater run-off concentrations shown on Table 13 and an infiltration rate, expressed as a percentage of mean annual precipitation.

The City of Issaquah has a stormwater collection system, but discharges storm water run-off into surface waters primarily in the downstream reaches of Issaquah Creek near Lake Sammamish. The stormwater collection system reduces the amount of direct infiltration of stormwater from urban areas. However, some areas, such as East Sunset Way, do not have stormwater collection. Interstate-90 is potentially a significant source of direct infiltration of untreated stormwater run-off. The present design of the Interstate does not include a stormwater collection system, and all road run-off is allowed to discharge directly to the ground via outfalls. There are approximately 50 outfalls along the 4.5 mile stretch of I-90 along the East Fork of Issaquah Creek. Available monitoring data are insufficient to determine the magnitude of water quality impacts from I-90. However, it is estimated that up to 215 acre/feet per year, or 70 million gallons per year, of stormwater run-off are generated by Interstate 90 adjacent to the East Fork of Issaquah Creek (SWM, 1992).

Transportation Spills

A significant percentage of land-use within the 1, 5, and 10-year TOTs to LIV production wells are associated with transportation. As such, contamination from spills of hazardous chemicals caused by vehicular accidents are a significant concern. Various chemicals may be transported via the interstate on tanker trucks or other transport vehicles or personal vehicles. There are no data regarding type or quantities of hazardous materials transported on interstate or local highways in the Issaquah area. A tanker truck can carry as much as 10,000 gallons, while other tankers may transport tens of 55 gallon drums. Accident statistics for Interstate 90 between SR-900 and the Sunset interchange are summarized on Table 16. The table shows that, in general, there has been an increase in total number of accidents and the accident rate (per million vehicle miles) along this portion Interstate-90. There have been four documented fuel spillages, but no reported hazardous spills along this section of I-90 since 1980. Since 1988, the accident rate is approximately one accident per 167,500 vehicles, with an estimated average daily traffic volume of 33,050 vehicles over that period. Using these figures, there are approximately 73 accidents per year along I-90. The probability that one of these accidents will involve a loaded tanker truck, or other vehicle transporting hazardous materials is difficult to determine. However, given that the interstate presently has no stormwater or spill containment structures, it is likely that a major spill along the interstate would result in discharge of hazardous materials to the ground surface.

There are no data concerning accident rates or spillage along City arterials. Accidents along City arterials are likely to be contained by the City's stormwater collection system, but some areas, such as East Sunset Way, do not have stormwater collection.

Future Land-Use

Presently, groundwater quality in LIV production wells is excellent, and existing land-uses have not resulted in groundwater contamination above drinking water standards. Therefore, control and prediction of the impact of future land-uses is a significant objective for wellhead protection. The recent growth of the LIV area has resulted in some ambiguity regarding future land-use developments. As such, it is not possible to document or inventory projected land-use changes and predict the impact on groundwater quality in the LIV. Possible land-use changes that may affect groundwater quality in the LIV include:

- *Grand Ridge MPD.* The largest potential land-use change in the LIV is the proposed Grand Ridge MPD. A rural zoning designation for the eastern portion of Grand Ridge has recently been approved by the King County council, and it is unlikely that high-density development will occur in this area. This portion of Grand Ridge was not incorporated into the WHPA modeling and capture zone delineation because it appears to be at the boundary of the aquifer system. However, further investigations are needed to determine hydrogeologic conditions at depth.

- *Lakeside/West Grand Ridge Urban Zone.* The western portion of Grand Ridge is presently zoned urban. This portion of Grand Ridge is important to wellhead protection planning because it provides direct recharge to the LIV aquifer. This has two implications. First, land-use protection on Grand ridge must strive to minimize potential surface contamination from point sources and stormwater. Secondly, as discussed in Section 3, urban development in this area which results in increased annual run-off to surface water will proportionally decrease the recharge to the aquifer from the Grand Ridge area. Changes in the recharge patterns may also alter the shape of capture zones for the LIV production wells. Attempts to maintain recharge through re-infiltration of stormwater must pay strict attention to water quality and contaminant loads. The urban zoned portion of Grand Ridge, particularly adjacent to I-90, is located within a 7 to 10 year WHPA under present groundwater withdrawals. Under future increased groundwater withdrawals, a proportionally larger area of the presently urban-zoned portion of Grand Ridge will lie in a 7 to 10-year WHPA. Future land-use decisions for this area should consider impacts to groundwater quantity and quality.

- *The proposed Sunset By-pass.* This transportation project would result in a multi-lane highway from the Sunset I-90 interchange to the Issaquah-Hobart Road south of the central business district. The proposed route has not been finalized, but it would traverse both the 5-year and 10-year WHPA's. Minimizing groundwater quality impacts, both during construction and afterwards, will be necessary for this project;

- *Expansion of commercial and light industrial land-uses.* This may be recommended as growth in Issaquah continues. The central business district of Issaquah lies in a 5-year and 10-year WHPA, and possible groundwater quality impacts must be evaluated prior to re-zoning or permitting of potentially hazardous activities.

- *Increased development on the Lake Tradition Plateau.* Similar to Grand Ridge, the Lake Tradition area is an important recharge area and lies in a 7 to 10 year capture zone under present conditions. Increased development may increase run-off and reduce groundwater recharge to the Lower Fork sub-basin, which provides up to 16 cfs to the LIV aquifer. Changes in the recharge patterns to the LIV aquifer may alter the shape and extent of capture zones for LIV production wells.

- *State of Washington anti-degradation policy (WAC 173-200-030).* This legislation may affect all projected changes in land-use within the LIV. The policy states that existing water quality shall be protected, and contaminants that will reduce the existing quality thereof shall not be allowed to enter such waters, except in those instances where it can be demonstrated to the department's [WDOE] satisfaction that:

(i) An overriding consideration of the public interest will be served; and

(ii) All contaminants proposed for entry into said ground waters shall be provided with all known, available, and reasonable methods of prevention, control, and treatment prior to entry.

Appendix I contains the WAC-173-200 concerning groundwater quality.

8. CURRENT AND FUTURE GROUNDWATER CONTAMINATION POTENTIAL

A quantitative assessment of contamination potential is desirable to develop a ranking of contaminant types and contaminant sources. The concentration of a contaminant is usually referenced to a Maximum Contaminant Level (MCL) established by state or federal agencies based on toxicity and risk to human health. These MCL's are the standards by which the severity of contamination are assessed, and are in many, but not all cases, the established criteria for clean-up actions at contaminated sites. For groundwater protection studies, protection of the aquifer is often based on a level lower than the MCL as a target water quality which the community strives to maintain. Quantifying contamination potential or risk to public health is difficult from both a technical standpoint and from a public communication/ acceptance standpoint. Two approaches were used in developing a ranking of groundwater contamination potential in the LIV:

- One approach was to compute, for various contaminant types, a critical load of a given contaminant and compare this "critical" load to the estimated or observed actual loads of contaminants within the LIV capture zones. This approach worked well for non-point sources of inorganic contamination, but was less useful for point sources of organic contaminants;

- The second approach was to utilize a ranking strategy worksheet developed by the US EPA. While a thorough evaluation of assumptions and methodology could not be carried out on the EPA method, the results showed similar trends and conclusions to the more specific approach used in the loading calculations. The EPA ranking provided a more broadly defined means of ranking contaminant sources.

Groundwater contaminant sources are commonly divided into two categories: point and non-point sources. The approach to predicting possible contaminant concentrations from these sources differs for each source category. Non-point sources are those sources which are aerially extensive and relatively continuous over time. Urban run-off, fertilizer applications, and multiple septic systems can all be treated as non-point sources. Point sources are those sources which have a specific location and extent, and which occur over a distinct period of time. Underground storage tanks, chemical handling facilities, landfills, and individual septic tanks can be treated as point sources.

The results of the contaminant ranking approaches are summarized in the following sections.

8.1 Contaminant Loading Approach

The contaminant loading approach begins with the question; "how much contaminant is theoretically necessary to cause an undesirable concentration in a production well?". The undesirable concentration has been conservatively assumed to be one-half the MCL for a given contaminant. This level is termed an "action level". The concentration of a contaminant in a well is dependent on the amount of mixing with "clean" groundwater flowing through the aquifer. One gallon of one contaminant mixed with 5,000 gallons of clean water may not result in a concentration that exceeds drinking water standards, while one gallon of a different contaminant may result in serious groundwater contamination. It is beyond the scope of the WHPP to quantitatively assess all possible contaminants with respect to their travel time to production wells and potential concentration. For the purposes of wellhead protection planning, four "indicator" contaminants have been selected which are commonly associated with specific land-uses or activities, and which have established primary drinking water MCL's. For non-point sources, the indicator contaminants are:

- Lead: Commonly associated with urban run-off.
  MCL = 0.05 mg/L. Action Level: 0.025 mg/L.

- Nitrate: Commonly associated with urban run-off, septic tanks, and fertilizers. MCL = 10 mg/l. Action Level: 5 mg/L.

For point sources, the indicator contaminants are:

- Benzene: Commonly associated with USTs.
  MCL = 0.005 mg/L. Action Level: 0.0025 mg/L.

- Tetrachloroethylene: Commonly associated with on-site dry cleaning.
  MCL = 0.005 mg/L. Action Level: 0.005 mg/L.

Contaminant loads are expressed as a mass (e.g. kilograms per year). The critical loads are calculated based on the action-level concentration of the contaminant (mg/L) and the quantity of water pumped from a single well or multiple wells in a wellfield.

Critical loads are calculated by as follows:

$$Lcrit_i = (Ccrit_{i,j} * Q)$$

Where

$Lcrit_i$ = Critical load of contaminant i (milligrams/year)
$Ccrit_{i,j}$ = Action-Level concentration of contaminant i (milligrams/Liter)
Q = Total pumping rate from production wells (Liters/year)

Calculation of present loads is similar to calculation of the critical load, being:

$$L_i = (C_{i,j} * I)$$

Where,

L_i = Load of contaminant i (milligrams/year)

$C_{i,j}$ = Concentration of contaminant i for land-use/source j (milligrams/Liter)
I = Infiltration rate to the aquifer (Liters/year)

The calculation of actual contaminant loads are dependent on a number of parameters, many of which are not well known. For example, the amount of benzene which would be necessary to exceed the critical load is dependent on the distance of the source to a well, the quantity of the spill, the area over which the spill occurs, and various contaminant transport parameters such as sorption coefficient, retardation factor and biodegradation. It is beyond the scope of the WHPP to provide detailed data or analyses regarding specific processes or parameters controlling contaminant transport and behavior in the LIV. However, in order to accommodate the uncertainty and range of potential parameter values, a risk-based approach has been developed using simple calculations and transport models using the spreadsheet @RISK. This approach enables a range of values (minimum, maximum, and expected) to be utilized in calculations. In the @RISK worksheet, these calculations are repeated many times (typically 1,000 or more), randomly selecting parameter values from the specified ranges. Thus, a calculated result for a contaminant load is expressed as a distribution of values, showing minimum, maximum and expected values. The expected value occurs most frequently, while the less frequent results are out on "the tails" of the distribution. The results of the non-point and point source analyses are presented in the following sections.

8.1.1 Non-Point Sources

Non-point sources of contamination have been grouped into three categories: urban/storm runoff, fertilizer application, and septic systems. Nitrate loads associated with these activities have been estimated based on data from urban run-off studies (US EPA, 1983, Golder 1991, METRO, 1982), and from USGS studies (Frimpter, 1992). Lead loads associated with various land-uses have also been estimated from urban run-off studies (NURP, 1983, Woodward-Clyde, 1992). Six land-use categories were used, as outlined in Section 7. Application rates, contaminant concentrations, or groundwater infiltration rates under each category were estimated based on these data.

The results of the nitrate analyses are detailed in Appendix K, containing the worksheet calculations based on parameter ranges. The following discussion is based on expected values only. Table 17 summarizes the predicted nitrate loads (expected values only) to the LIV aquifer under present conditions, and two possible future development scenarios. For all cases, the contribution from urban run-off is low. Under present conditions, the majority of nitrate load is likely due to fertilizer applications. The predicted load of 2,650 kg/yr nitrate is based on an assumed fertilized area of 33 acres within the 10-yr WHPA, or 290 lawns of 5,000 ft^2 area (100 ft x 50 ft). The predicted groundwater concentration is similar to observed conditions at 0.8 mg/L. The two future load analyses include possible development of 1,180 acres on Grand Ridge and Lake Tradition Plateau. Development at 1-acre density and 5-acre density was evaluated. Fertilizer applications could be as high 10,300 kg/yr for the 1-acre development scenario (1,095 new lawns contributing 3 lbs of nitrate per 1,000 ft^2). A nitrate load of 6,500 kg/yr is estimated for the 5-acre development scenario (273 new 10,000 ft^2 lawns with similar application rates). For both scenarios, septic application rates were based on 2.5 persons per unit, with 1,180 new units for the 1-acre scenario and 273 new units for the 5-acre scenario.

The results of the nitrate analysis show that:

- Under present conditions, nitrate loads appear acceptable and the predicted concentration of less than 1 mg/L is within observed ranges of nitrate levels in the LIV aquifer;

- Fertilizer applications in future residential areas on the recharge areas of Grand Ridge and Lake Tradition Plateau could cause some degradation in water quality, particularly at 1-acre density;

- Future development utilizing septic systems at 5-acre density may increase nitrate loads with some degradation of groundwater quality, though below critical loads; and

- Future development utilizing septic systems at 1-acre density may increase nitrate loads to unacceptable levels, approaching state drinking water standards.

The results of the lead analyses are detailed in Appendix K, containing worksheet calculations based on parameter ranges. The following discussion is based on expected values only. Table 18 summarizes the predicted lead loads to the LIV aquifer under present conditions, and one possible future development scenarios. Under present conditions, the majority of lead load is from residential land-use, because it has a proportionally higher total area than other land-uses. The predicted load of 42 kg/yr is based on assumed infiltration rates for various land-uses. The predicted groundwater concentration is on the order of 10 ppb, which is similar to observations in several shallow wells in the LIV. Future development of 1,180 acres on Grand Ridge and Lake Tradition Plateau, the addition of the Sunset by-pass, and added commercial development increases the predicted load to 75 kg/yr. The predicted groundwater concentration is on the order of 20 ppb, which is also similar to observations in several shallow wells in the LIV.

The results of the lead analysis are somewhat inconclusive, given the complex transport behavior of lead. However:

- Under present conditions, lead loads in urban run-off may have some impact on water quality and the predicted concentration of about 0.01 mg/L is within observed ranges of lead levels in the LIV aquifer; and

- Future development may increase lead loads due to increased residential land-use and associated transportation. Lead loads could approach an action level of 0.025 mg/L without water quality protection measures.

8.1.2 Point Sources

Point sources containing organic compounds are more difficult to evaluate because of the complex behavior of organic compounds in groundwater. Specifically, retardation and biodegradation processes are very significant transport parameters and influence the calculated contaminant concentration as a function of both time and distance from a contaminant source. In general, the effect of degradation and retardation processes is that, to achieve a specified concentration (e.g. an action level of one-half the MCL) at a well, larger contaminant loads are required at greater distances from the well. In other words it may take 10 gallons of gasoline at a distance of 400 feet to exceed the action level, while it could require 1,000 gallons at a distance of 1,000 feet to achieve the same concentration.

A simplified assessment of organic contaminant transport was carried out to evaluate the possible range of loads necessary to cause degradation in groundwater quality above the action level of one-half the MCL for benzene. Utilizing a probabilistic approach similar to that for non-point sources, a range of aquifer and transport parameters were used to calculate critical contaminant loads at various travel times from well SPWSD 7/8. Appendix K contains details of the parameters used. The results are summarized as follows:

- For benzene, the critical load of gasoline is on the order of 200 gallons per day released to the aquifer at the 1-year time of travel assuming an action-level of 2.5 µg/L. This equivalent to 73,000 gallons of gasoline released in a one-year time frame. The critical load of gasoline is on the order of 500-times higher at the 5-year time of travel due to the buffering effects of biodegradation and retardation of benzene.

- Critical loads for DNAPL contaminants such as PCE are much lower than for benzene. Simple loading calculations suggest that as little as one-gallon of PCE released in the 1-year WHPA could cause contamination above the action level.

These load calculations do not imply that the calculated contaminant loads are acceptable levels for groundwater management. The complexity of transport of organic contaminants requires a site-specific analysis. However, the calculations do illustrate the "order-of-magnitude" volumes theoretically necessary to cause severe groundwater contamination. A spill of organic contaminant (e.g., gasoline), unless it is directly adjacent to a well, may not cause a health risk, and management of these types of sources should reflect an understanding of the behavior of these compounds. The critical load approach for point-source organic contaminants was not implemented in a detailed LIV-specific risk assessment because of difficulties in determining:

- The likelihood of contamination;

- Appropriate ranges of initial concentrations and spill volumes;

- The effect of multiple source-types and locations (transportation, USTs, chemical handlers); and

- Exposure and toxicity parameters necessary to "normalize" the risk associated with point sources (benzene, PCE) versus non-point sources (e.g. nitrate), as well as the risk between specific point sources (e.g. UST site 1 versus UST site 3).

It is beyond the scope of the WHPP to develop a comprehensive, site-specific assessment of contaminant risks in the LIV. However, existing methodology developed by EPA was used to rank point sources as a screening process. The results of the ranking are discussed in the following section.

8.2 EPA Ranking Methodology

The EPA ranking methodology for contamination risks is based on the likelihood and severity of well contamination. The likelihood of well contamination is a function of the likelihood of release at the source and the likelihood of reaching the well. The severity of well contamination is a function of release quantity, contaminant attenuation, and toxicity. This approach is a simplified form of risk assessment that uses limited data to develop the relative risk of various potential contaminants. This method requires some knowledge of the hydrogeology, but can be implemented by competent non-hydrogeologists for planning purposes. The basic methodology assumptions, and limitations of the method are presented in Appendix L, which is taken directly from the US EPA document.

The ranking methodology was used independently of the contaminant load analysis to provide a preliminary ranking of point source hazards associated with UST's, chemical handlers, and transportation hazards (spills of hazardous substances). Through the use of the EPA risk approach, the overall contamination potential of sources are ranked in order to provide a framework for establishing priorities with regard to wellhead protection efforts.

The following general hydrogeologic properties were used in the EPA methodology:

Parameter	Range in EPA Screening
Depth to Aquifer	12-50 feet
Hydraulic conductivity	10^{-3} to 10^{-1} cm/sec
Groundwater Velocity	33 to 330 ft/yr

The hydraulic properties used in the screening are fixed ranges in the risk assessment and are considered accurate and not subject to change.

Each potential point source determined from the contaminant source inventory was evaluated using the EPA methodology, including all USTs and chemical handlers identified within the 5-year and 10-year capture zones. An important parameter in the EPA methodology is the distance of a source from the well. In several cases, a number of point sources were lumped into the same ranking assessment based on their similar distance from a well. Similarly, for transportation spills, all of the production wells in the LIV are less than 1,000 feet from a major arterial or Interstate and, in terms of a screening level risk assessment, the distance to a transportation hazard is similar for all wells.

The second important parameter is the type of contaminant, which affects the toxicity, persistence, and degradation scores used in the risk assessment. For UST sources, benzene is the contaminant used for scoring; for chemical handling facilities, tetrachloroethylene (PCE) was used. For transportation spills, five contaminants were evaluated: sulfuric acid, benzene, carbon tetrachloride, chromium, and a mix of volatile organic compounds (VOC Mix).

The resultant score of a given contaminant source for a given well is ranked numerically from negative 200 to positive 10. Scores greater than zero are high risk sources. Scores between zero and -4 are considered moderate risk sources, and scores less than -4 are considered low risk sources. The relative ranking of sources is valid regardless of its actual score, which provides a means of ranking among low or moderate risk sources.

The results of the screening are summarized on Table 19. There are no high risk (score greater than 0) sources in the LIV. There are two moderate risk sources (score between 0 and -4) in the LIV. All other sources are considered low risk according to the EPA method. The highest ranking risk (score of -2.6) in the LIV is a transportation spill of sulfuric acid, which applies to all wells in the LIV. The second highest ranking risk are the UST's and chemicals handled at the Grange Supply (score of -3.9), applying only to COI wells 1 and 2. The higher scoring "low risk" sources (scores between -20 and -4) include primarily chemical handlers and all other transportation spill hazards (chromium, benzene, carbon tetrachloride, and VOC mix). All of the gasoline stations in the LIV have very low scores (less than -100).

8.3 Discussion

The results of the contaminant load analyses and the EPA screening process are similar in many ways. Both approaches suggest a relatively low overall risk of groundwater contamination to LIV production wells under present conditions. This is supported by the observed water quality in the LIV aquifer. Both approaches indicate relatively low risks from present point sources of benzene (e.g. gas station USTs). The contaminant load analysis suggests that a relatively small release of PCE could exceed action levels. However, using the EPA approach, the risk is actually quite low, due possibly to the toxicity and persistence factors incorporated in the risk-screening methodology.

Based on the results of the two contaminant evaluations, a relative ranking of groundwater contamination hazards to the LIV aquifer has been developed as shown on Table 20. This ranking includes relative hazards under present land-use conditions, and under possible future land-use conditions. Under present land-use, the highest hazard is posed by a chemical spill along any of the major thoroughfares in the LIV, followed by chemical handling facilities. Non-point sources of urban/residential contamination have the lowest ranking under present land-uses.

Future changes in land-use will affect the relative ranking of contaminant sources. However, land-use changes must be evaluated on a site-by-site basis, particularly for point sources, such as service stations or chemical handling facilities. Table 20 shows a continued low ranking for these categories, but assumes that no additional facilities are sited within the WHPA's for present production wells. Transportation spills will likely remain a high-ranking hazard under any development scenario. However, increased spill response and spill containment readiness could reduce the risk from transportation. Future urban/residential development, particularly on the recharge areas of the LIV, is potentially a high ranking ground water quality hazard. As shown in the nitrate analysis, 1-acre lot development using septic on the recharge areas of Grand Ridge and Lake Tradition Plateau would pose a high risk to groundwater quality (possibly approaching the MCL for nitrate). Development at 5-acre density using septic tanks reduces the risk, but will still result in groundwater quality degradation. Development with urban services (sanitary sewer) and open space to maintain recharge would likely further reduce risks from nitrate.

9. GROUNDWATER QUALITY MANAGEMENT

9.1 Summary of Key Technical Issues

To summarize the key technical issues identified in previous sections:

Hydrogeology

- The LIV aquifer is a heavily used, complex stratified system that is difficult to simulate using simple models;
- Significant seasonal fluctuations in groundwater levels, groundwater flow directions and hydraulic gradients are present. Superposition of multiple well capture zones is the only way to delineate WHPA capture zones using a time-of-travel approach;
- Present groundwater withdrawals intercept down-valley flow and influence water-levels in virtually all surrounding wells within a 2 mile radius. Strong downward gradients are produced from the pumping wells which draws water from the shallow water-table towards the deeper portions of the aquifer. Thus, the aquifer is very vulnerable to contamination at the water table;
- Recharge from Grand Ridge and Lake Tradition Plateau areas is significant, especially during the winter/spring. The estimated travel time from Grand Ridge/Tradition Plateau to the LIV production wells is between 6 and 10 years;
- One-year capture zones for wells SPWSD 7/8, COI 1/2 and COI 4/5 underlie 82 acres, primarily within the City of Issaquah;
- Five-year capture zones for wells SPWSD 7/8, COI 1/2 and COI 4/5 underlie 450 acres, primarily within the City of Issaquah, but including some County land near Lakeside, Grand Ridge, and the Sunset Interchange area;
- Ten-year capture zones for wells SPWSD 7/8, COI 1/2 and COI 4/5 underlie at least 710 acres within the City of Issaquah, and unincorporated King County along Grand Ridge and Lake Tradition Plateau; and
- Future increases in groundwater usage by SPWSD and the City of Issaquah may increase the 5- and 10-year capture zones to production wells and encompass nearly all of the LIV area.

Groundwater Quality and Contamination

- Present groundwater quality is excellent for all parameters in all potable water-supply wells in the LIV. A number of shallow monitoring wells have shown elevated levels of regulated contaminants including benzene, trichloroethane, xylenes, and lead;

- Seven documented hydrocarbon releases within the LIV since 1988 have not been detected in deeper production wells in the LIV. These releases have occurred within the modeled 5-year capture zones of production wells;

- Bio-degradation of light hydrocarbons (LNAPLs) associated with gasoline products may provide some measure of natural protection from sub-surface gasoline contamination;

- Contamination of the aquifer from dense hydrocarbons (DNAPL's) would be very serious and difficult to characterize;

- Contamination of the aquifer from stormwater and residential applications is not apparent at present levels of development. Increased development, resulting in greater run-off and less recharge to the aquifer increase the potential for groundwater contamination from stormwater and residential contaminants, such as nitrate;

- The overall risk of groundwater contamination from current point sources is relatively low using the EPA methodology for ranking contamination potential. Groundwater contamination risks from present non-point sources, based on estimated contaminant loads from specified land-uses, is also low.

- Accident statistics along the Interstate-90 are insufficient to determine the probability of a serious tanker spill. However, transportation ranks highly in comparison with other sources in the EPA screening. The consequences of a spill along transportation corridors (e.g. I-90) are serious and should be addressed;

- The risk of groundwater contamination from future point sources could be high, depending on the location and type of contaminant, using the EPA methodology for ranking contamination potential. The risk of future groundwater contamination from future non-point sources, based on estimated contaminant loads and specified land-uses, could also be high.

9.2 Recommended Wellhead Protection Strategies

A number of strategies for groundwater quality protection have been developed in recent years as awareness of groundwater contamination has increased. There are several important considerations in evaluating appropriate wellhead protection strategies:

- Other environmental programs, ordinances, and policies provide, in many cases, substantial overlap with possible local responses for groundwater protection. The intent of the WHPP is to provide a technical framework for implementing workable strategies, not to re-develop management structures or responses that may already exist at other level of government;

- The nature of present land-use and contaminant sources in the LIV is such that future conditions pose an equal or greater risk to groundwater supplies as compared to present activities. Thus, water quality protection strategies should emphasize management of future land-use;

- Public education and involvement is key to any implementation effort. An informed and participatory public will greatly enhance the ability of the local jurisdiction to implement strategies and funding for programs; and

- Implementation of strategies will require varying levels of short-term and long-term expenditures by the governing jurisdictions. The trade-off between expenditure and the level of protection must be considered. The present dependence on the LIV aquifer as a sole source of drinking water suggests that protection at any cost is needed because additional new groundwater supplies have not yet been identified in the LIV; allocation of new water rights is presently curtailed by hydraulic continuity issues; and a tie-in to a regional water source is many years away.

With these considerations in mind, a number of wellhead protection strategies can be addressed. Wellhead Protection Programs across the country have typically relied on strategies focusing on administrative approaches such as zoning changes and permitting procedures. Alternative strategies such as engineering solutions and contingency sources are also considered in conjunction with regulatory approaches. Typical WHPA strategies are summarized on Table 21. The planning objective, legal considerations, and general administrative requirements for each strategy is shown. Many of these strategies are applicable to the Lower Issaquah Valley including:

- Aquifer Management Zones;

- Land Use Zoning and Control;

- Special Permitting;

- Hazardous Materials Handling Regulations;

- Public Education;
- Engineering;
- Spill Response Planning;
- Water Supply Contingency Planning; and
- Monitoring and further technical studies

Each of these strategies are discussed in the following sections. These sections summarize possible components of each strategy, but do not make specific recommendations regarding policy or structuring of an ordinance.

9.2.1 Aquifer Management Areas

Rationale

Establishing Aquifer Management Areas is the first step towards groundwater quality management. It provides a focus for all subsequent management strategies and is a declaration of commitment on the part of jurisdictional bodies to groundwater protection. The term aquifer management area (AMA) is consistent with existing terminology used by the City of Renton, and is recommended to provide consistency in WHPA terminology in the State.

This is a high priority element of Wellhead Protection, and must be established prior to implementing other recommended strategies.

Specific Requirements/Recommendations

- A wellhead protection committee (WHPC) should be established to address wellhead protection issues. The WHPC should be able to develop policy and resolve issues affecting local wellhead protection areas. Issues involving regional groundwater management should continue to be addressed by the Groundwater Advisory Committee (GWAC) established for the Issaquah Basin Groundwater Management Area.
- Three specific AMA's should be designated in the LIV corresponding to the capture zones delineated from the hydrogeologic analysis. AMA-1 should correspond to a TOT less than 1-year, AMA-2 to between 1 and 5 years, and AMA-3 to all TOT's greater than 5 years. The Grand Ridge/Lake Tradition upland areas should receive an intermediate (AMA-2) designation, which is more appropriate to its importance as an aquifer recharge area, and the likelihood of being within a 5-year TOT under increased groundwater usage. It is presently estimated that these areas lie in a 6- to 10-year capture zone.

- General policy statements regarding management directives should be adopted for each AMA. The language used in these policy statements should be developed by the jurisdictional entities, and reflect high (AMA-1), moderate (AMA-2), and baseline (AMA-3) levels of management policy. For example, AMA-1 policy may emphasize zoning and land-use control, while policy for AMA-2 may emphasize permitting requirements or design standards. AMA-1 designations may result in restrictive controls on land-use. AMA-2 designations are more actively "managed" and may require protective policies and goals, in conjunction with flexible management and permitting.

Special Considerations

A legal description of the AMA's will be required for developing any ordinances within these areas. The parabolic shape of the modeled capture zones is not amenable to legal descriptions consistent with survey markers or roads. Therefore, modified AMA designations, specific to jurisdictional boundaries should be developed. These modifications should be made by the governing jurisdiction, since the approach to the modification will be subjective in nature.

Development of management policy for each AMA designation should focus on long-term strategies. Given that dependence on locally withdrawn groundwater supplies is likely to continue for at least 10-years, and possibly more, even an AMA-3 designation should receive sufficient protection policy to minimize groundwater quality degradation. Similarly, an AMA-2 designation based on possible future withdrawals rather than current withdrawals may be more appropriate and suitably conservative.

Designation of AMA's will overlap with the following programs:

- King County Sensitive Areas designation - Critical Aquifer Recharge Areas (CARA's);

- Issaquah Groundwater Management Program; and

- City of Issaquah interim Critical Areas Ordinance.

Administrative Support

Management of the AMA's will require administrative oversight. The City of Issaquah, King County, and SPWSD should cooperatively fund a position for management of the AMA's. Responsibilities may include:

- Coordinate and implement Spill Response and Water Supply Contingency Plan;

- Coordinate public education activities;

- Coordinate with planning and public works personnel regarding development plans, environmental reviews, construction projects, and water-supply planning;

- Oversee monitoring programs and further technical studies; and

- Integrate surface water, and non-point pollution programs into Wellhead Protection activities, possibly in conjunction with the proposed Basin Steward position recommended in the draft Basin and Non-Point Action Plan (King County SWM, 1993).

Estimated Cost

The cost of administering the WHPA program should include annual salary for the administrator and a budget for staffing and program support. A senior-level administrator is recommended. Annual budgets could range from $10,000 to $300,000 depending on the program objectives for a given year.

9.2.3 Land Use Zoning and Control

Rationale

Prohibiting certain land uses or activities is an accepted purvey of government and in many cases is the most cost-effective means of managing water quality since administrative costs associated with permit reviews or site inspections are not necessary. There are difficulties in restricting or prohibiting land-uses or re-zoning. It may be easier to control future land-uses through permitting and design review than to re-zone or prohibit existing and future land-uses. Based on the present groundwater quality conditions and presently low risk to groundwater quality, strategies other than zoning and land-use prohibition may be appropriate.

Possible Specific Requirements

The following land-use zoning and control options may be appropriate for the LIV:

- Re-zoning of the western portion of Grand Ridge. Re-zoning of this area may be necessary to maintain adequate high quality groundwater recharge to the LIV aquifer. Any land-use changes to the Western portion of Grand Ridge must address groundwater recharge and groundwater quality. An emphasis must be placed on land-use that maintains open-space and limits or prohibits potential contaminant sources.

- Set minimum open-space requirements for Grand Ridge and Lake Tradition Plateau that will maintain current levels of groundwater recharge from these areas. A similar recommendation was proposed by King County SWM (Recommendation BW 3 from the Draft Basin and Non-Point Action Plan) and is consistent with the goals of Wellhead Protection. The King County recommendation could be proposed without modification as a wellhead protection strategy;

- Prohibit businesses handling DNAPL contaminants within WHPA's. Commercial activities generating DNAPL contaminants, such as trichloroethylene, or tetrachloroethylene could be prohibited or relocated. Six dry cleaners, two automotive business and the Lakeside Gravel facility are within the 5-year WHPA would be impacted by this strategy. These businesses may not be entirely dependent on the on-site hazardous materials and a possible compromise would be to re-locate only the hazardous materials;

- Prohibit businesses handling any organic contaminants within WHPA's. Gasoline service stations or other commercial activities generating organic compounds, such as benzene and toluene could be prohibited or relocated. This strategy was used in Renton to eliminate UST's within AMA's in the City. The City offered incentive payments to business to re-locate within a specified period of time. There may be legal challenges to this strategy since there has been no documented contamination of LIV production wells, and the results of this study actually suggest a relatively low risk from the present distribution of service stations.

Special Considerations

Zoning issues in the LIV are complex, as the recent Grand Ridge issue demonstrated. It is beyond the scope of the WHPP to propose more detailed zoning or land-use restriction strategies since there are so many other factors influencing these issues. From a groundwater quality protection standpoint, maintaining present zoning and permitting processes, may not offer the level of protection that meets the standards of the community, particularly as the area continues to develop. Enforcement of the state anti-degradation policy offers some additional protection, but action on the local level is important. However, a "zero-risk" approach, which eliminates all present and future possible sources of groundwater contamination through land-use control, may not be in the best economic/development interests of the community either. The trade-off between initial expenditure, long-term cost and the level of protection must be considered. From a groundwater quality standpoint, the present zoning configuration and likely development scenario is not in the best interests of long-term water quality protection. Urban zoning should be located away from recharge areas, and, at a minimum, should set minimum open space requirements and require compliance with the state anti-degradation policy (WAC 173-200). Development on recharge areas should meet the above requirements and require re-infiltration of treated stormwater runoff.

Administrative Requirements

Initial preparation, review and adoption of zoning changes or land-use restrictions will require some administrative support. Little oversight will be required after the changes have been adopted, but inspections and enforcement may be necessary to insure compliance.

Estimated Cost

Adoption of zoning or land-use prohibition is a low-cost option to develop. The ultimate cost of such a strategy may be higher if legal challenges result; if the City's tax base is eroded.

9.2.4 Special Permitting

Rationale

Special permitting is an effective means of dealing with proposed land-uses on a case-by-case basis. It provides the City or County with a method for obtaining more detailed analysis and/or design specifications prior to permitting certain land uses. As discussed in Section 6, many groundwater contamination problems must be dealt with on a case-by-case basis since the transport and behavior of contaminants varies. Special permitting may be a better alternative to land-use control since it provides a site-by-site assessment of land-uses rather than a comprehensive ban on land-uses which could result in legal action by businesses wanting to locate facilities in WHPA's. A permitting process can provide added flexibility by using existing design standards and guidelines as a baseline (e.g. King County or WDOE documents) for planning review with additional "line-item" requirements by the local jurisdiction as necessary for groundwater protection. The responsibility for plan review and acceptance would fall to the Wellhead Protection Administrator, in conjunction with SEPA review, public works, and planning departments. The "trigger" for considering special permit requirements should be any location within an AMA.

Specific Requirements/Recommendations

There are a number of possible land-uses or activities that could require special permitting for groundwater quality protection. These include:

- Drainage plans for construction projects and new facility siting within WHPA's, including plans for conveyance, ditching, wet ponds, and biofiltration.

  Suggested reference guideline documents:

  King County Surface Water Design Manual

Biofiltration Swale Performance, Recommendations, and Design Considerations. WDOE Publication 657, October, 1992.

- Drainage plans in compliance with the Puget Sound Highway Run-off Program (WAC 173-270) for existing and new highway projects;

  Suggested reference guideline documents:

  King County Surface Water Design Manual

  Stormwater Program Guidance Manual for Puget Sound Basin. WDOE publication 92-32 and 92-33, July 1992;

- Stormwater detention and/or re-infiltration plans for new developments;

  Suggested reference guideline documents:

  Stormwater Program Guidance Manual for Puget Sound Basin. WDOE publication 92-32 and 92-33, July 1992;

  Biofiltration Swale Performance, Recommendations, and Design Considerations WDOE. Publication 657, October, 1992.

  WDOE publication 83-8, Guidelines to Prevent, Control and Contain Spills from the Bulk Storage of Petroleum Products, August 1983.

  WDOE publication 82-1, Design Criteria for Gravity Oil/Water Separators, January, 1982

- Design plans for facilities handling hazardous materials.

  Suggested reference guideline documents:

  WDOE publication 83-8, Guidelines to Prevent, Control and Contain Spills from the Bulk Storage of Petroleum Products, August 1983.

  WDOE publication 82-1, Design Criteria for Gravity Oil/Water Separators, January, 1982

Special Considerations

Permitting procedures must be specifically outlined including:

- An ordinance specifying types of facilities requiring design permits;
- Accessible guidance documentation for permittees; and

- A comprehensive list of regulated chemicals.

In addition, coordination with on-going WDOE programs and databases pertaining to hazardous materials permitting is necessary.

Administrative Requirements

Oversight and review of special permits necessary for water-quality protection should be the responsibility of the Wellhead Protection administrator, in conjunction with SEPA, public works and building/design code reviews.

Estimated Cost

The cost of permit reviews would be incorporated in the annual salary and budget of the Wellhead Protection Program administrator.

9.2.5 Hazardous Materials Handling Regulations

Rationale

There are a number of existing state and federal regulations controlling the use, storage and transport of hazardous materials. The requirements, penalties, and justification of these regulations are well established and there is no basis for proposing substantial regulatory oversight and control at the local level, once a facility is sited. Permitting provides the local jurisdiction sufficient input into the location and type of facility. However, it is important to maintain an accurate inventory and history of hazardous materials used in the jurisdiction, both within WHPA's and elsewhere. Any regulatory efforts at the local level should focus on inventory and site history. This will provide documentation that could be used if additional wells are sited in other areas of the LIV, or if a contaminant release occurs.

Specific Requirements/Recommendations

The goal of a regulation/ordinance requiring inventory and history at hazardous materials facilities is to provide the local jurisdiction (e.g. the City of Issaquah) with in-house capabilities to monitor the use of hazardous chemicals. Specific components include:

- An ordinance requiring chemical handling facilities to comply with documentation requirements;
- An effective and accessible computer database to store and retrieve information pertaining to type, quantity, and transport of hazardous chemicals;
- A comprehensive list of regulated chemicals;

- A schedule of compliance specifying reporting frequency and format; and
- Coordination with on-going WDOE programs and databases pertaining to hazardous materials handling.

Special Considerations

An inventory program needs to be simple and flexible in order to allow easy input from the affected businesses and to provide useful output for planning and oversight by the WHPA program. Businesses should not feel they are subject to another level of regulation, but rather are contributing information to a working database. Increasing public awareness of Wellhead Protection and continuing public outreach will enhance the effectiveness of this type of program.

There may be overlap with existing state and county programs aimed at waste reduction and monitoring. Inventory data from these programs may also be useful at the local level for monitoring potential groundwater contamination in the area.

Administrative Requirements

Oversight and review of an inventory program would be a primary responsibility of a Wellhead Protection administrator.

Estimated Cost

The cost of developing a hazardous material inventory would be incorporated in the annual salary and budget of the Wellhead Protection Program administrator. Computer software and hardware would be necessary to properly develop and maintain the inventory data. The GIS system utilized in the WHPP study would be an excellent platform for the continued storage, retrieval and presentation of a contaminant source inventory.

9.2.6 Public Education

Rationale

Successful implementation of a WHPP requires public awareness of the issues, the proposed measures and the opportunities for productive involvement. A mix of technical information, mapping of jurisdictional commitment and motivational cues is necessary to allow the public to support relevant governmental, financial and regulatory initiatives; to acquire new attitudes and skills; and to modify personal behaviors with the aim of protecting and enhancing groundwater quality in the LIV aquifer system.

The recommended program would encompass present and future educational needs, from the perspectives of general awareness of the WHP and water supply/water quality issues, as well as the specific information requirements of commercial/industrial interests, homeowners, UST owners, citizen and environmental activists/volunteers/voters. Extensive educational materials have already been created and distributed by related agencies and jurisdictions. These materials are referenced in Appendix M.

Without this level of effort and input, the possibility of achieving the desired end result of protecting the LIV aquifer is haphazard at best.

Specific Recommendations

Education for increased general awareness of the WHP and water quality/water supply issues should begin now and include the following main messages:

- The LIV Aquifer System is a limited resource and a treasure which must be preserved, enhanced and used intelligently.
- Actions of individuals, corporate and governmental members of the public can either destroy, sustain or improve the quality of the groundwater/drinking water supply.
- Pollution prevention is less expensive than replacing wells and treating contamination.
- Wellhead protection requires specific pro-active measures which are identified in the WHP plan. It does not happen by itself. Wellhead protection requires citizen support of new ordinances, permit procedures, funding and personnel requirements. It also requires the support of commercial and industrial interests, and the staff and elected officials of overlapping jurisdictions.

The recommended tools or activities for relating these messages include:

- Publication of a small "WHP Educational Magazine" which summarizes and illustrates the key recommendations of the WHP and where people fit in. For distribution in schools, public meetings, Chamber, and to Public Information officers of related agencies.
- Public meeting to announce release of the plan, provide a basic briefing and outline a proposed schedule of implementation.
- Press and media articles (including City newsletter) announcing the release of the plan and its key components as well as the main messages listed above. Also announcing the availability of the "WHP educational magazine", and offering to speak at meetings of special interest groups. Ongoing and regular media coverage of the Main Messages above and the implementation process lays the groundwork for approval of financial and institutional measures supporting aquifer protection; helps to influence the knowledge and attitudes of the community; and affects the coverage of specific

potentially "sensational" events such as hazardous material spills. Thus, the press is more likely to support specific behavioral and institutional changes rather than reacting and portraying local government negatively.

- Piggyback at any related existing activities such as Hazardous Waste Collection to distribute the "WHP educational magazine" and announce any upcoming actions.

- Workshop for local government staff and elected officials who will be involved in implementation of WHP via permit review, land use decisions, inspection and monitoring. Collaboration is critical to create a regulatory framework which is logically consistent, fair and enforceable. Increasing competition for funding requires efficiency and dovetailing rather than duplication. Public education efforts should help to educate the constituent interests and create support for less tangible projects such as maintenance, risk-prevention and monitoring.

Specific information requirements of existing and potentially contaminating sources as identified in Section 7.3 should also be addressed. These include UST owners, dry cleaners, gas stations and other chemical handlers. Activities include:

- Direct mail the "WHP educational magazine" to these identified businesses.

- Direct mail a packet identifying current regulations, request for inventory, and specialized education about handling and spill response. These materials have been compiled by other communities (see Appendix) and can be reissued by the WHP Administrator.

- Direct mail notice of specialized trainings areawide (by King County, DOE, DOH, Cities of Bellevue, Olympia, etc.) to relevant businesses.

Public education measures should be implemented in support of the Recommended Wellhead Protection Strategies as detailed in Section 9.2. Specifically:

- Aquifer Management Areas - Encourage public support by local press article describing why AMA's are needed and how they will be managed. Outline pros and cons and ramifications to the homeowner, the local business owner, the children of the future. Include calendar or diagram of process of designation of AMA's with opportunities for public input clearly noted.

- Land Use Zoning and Control - Specific measures dependent on nature of options employed, whether new ordinances, rezoning, conditional use restrictions or new project review. Any of these options should involve public notification via the press, and direct mail to any specifically involved businesses or landowners. The "WHP educational magazine" should be made available to the Chamber and other business groups so that the baseline information about WHP is already assimilated, including the location of the WHP/AMA Areas. Permit applicants should also be given a packet containing the WHP summary, mapping and planning considerations.

- Special Permitting - Support new regulations by increasing public awareness of WHP and the need for more detailed analysis and design specifications prior to permitting certain land uses. The health of the area's economic climate and preservation of jobs and profits must be linked with the need to protect the aquifer. The use of local press is key. When in the implementation phase, provide a library of resource materials and guidance documentation for permittees and citizens.

- Hazardous Materials Handling Regulations - Use local press for the initial support to establish new regulations. Create and distribute specialized materials for hazardous materials handlers detailing regulated chemicals, compliance schedules for reporting, agency and regulatory overlapping, and the underlying rationale for compliance. Provide ongoing notification of all chemical handlers about relevant trainings in surrounding jurisdictions. Encourage compliance via publicity and awards, such as the City of Bellevue program. (See Appendix M for details.)

- Spill Response Planning - Use local press for support of the need for Spill Response Planning and appropriate funding to establish and implement a program. Provide ongoing interaction with related agencies and jurisdictions. Provide press coverage of examples of agency cooperation, case histories. Provide recognition of emergency response personnel and records.

- Monitoring - This is one of the areas where the use of citizen volunteers can increase the amount and frequency of monitoring for water level and water quality in local surface water. The use of volunteers can reduce monitoring funding requirements while providing hands-on education about the realities of WHP and also generating newsworthy coverage of water quality issues. The Puget Sound Water Quality Authority has funded multiple demonstration projects in this area.

Special Considerations

The public is the key to approval or disapproval of the political, regulatory and financial measures required to actually implement the Wellhead Protection recommendations. Access to the community through the audience of its school children should not be underestimated. Where children are concerned, people are more open to consideration of the need to pay now to protect the future. Educating children to educate their parents about specific behavioral practices has been demonstrated to be highly effective, especially in areas such as recycling, and hazardous waste disposal. This has been shown in many of the model PIE programs of the Puget Sound Water Quality Authority. In the City of Issaquah, the Boy Scouts have carried on a successful program of storm-drain stencilling.

Kitsap County in cooperation with multiple state and local agencies, created an Environmental Education Resource Guide for educators which is applicable to the LIV.

Other special interest groups provide a unique opportunity for networking support for WHP throughout the community. Because of the extensive planning work associated with the GMA, and the East Sammamish Community Plan, there is already a select body of citizens with technical background. They are a naturally receptive audience trained to be able to understand the immediate need for wellhead protection measures. They have already pre-selected themselves as citizen activists and demonstrated their commitment to the community. Direct mailing of the "WHP educational magazine" and periodic updates of the process of implementation would help to maintain this strong constituency. A commitment by the WHP Administrator to speak at local service groups like Chamber and League of Women Voters is worthwhile in terms of educating about WHP and the need for political support and endorsement of various regulatory measures. Other natural community allies are the environmental groups such as the Audubon Society and Garden Clubs. Their members would be naturally compatible with the goals of the WHP and would be open to learning of specific protection measures and volunteer activities.

Overlap with Existing Programs

There is considerable overlap with existing plans and regulations. Of primary note are the East Sammamish Community Plan, the Draft Basin & Nonpoint Action Plan for the Issaquah Creek Basin and the Issaquah Groundwater Management Area Plan. The WHP Administrator should work to support appropriate basinwide recommendations, and to become familiar with related agency programs in King County and Washington, as well as programs in neighboring cities of Olympia, Renton, Bellevue and Bremerton. See Appendix M for further information on these programs. Many of the existing materials could be customized and adopted for use in the LIV.

Estimated Cost

Coordination and oversight of the program would be the responsibility of the WHP Administrator. The cost of creating the "WHP Education Magazine" would be approximately $10,000. For the first year, it is recommended that a consultant collaborate with the WHP Administrator in the creation of strategies for public education. The cost of this contract would be approximately $ 25,000, assuming that implementation were performed by the WHP Administrator and local government staff.

9.2.7 Engineering and Design Standards

Rationale

Engineering solutions to contaminant source control are often overlooked in favor of regulatory or administrative approaches to controlling the use of potential groundwater contaminants. Engineering issues are "built-in" to the permitting process in that design guidance and specifications are often available for permittees to base their designs upon. It is difficult, and possibly inadvisable, to force compliance to specific engineering design standards. Substantial costs would be incurred by the City and/or county in developing standards that are specific enough for engineering design. The subsequent costs of reviewing, approving, or offering variances are also high. New or existing businesses should bear the responsibility for design and maintenance of systems. However, rather than designate specific standards, flexibility and cooperation in the permitting process may provide better results. The additional cost of providing guidance documents and working individually with permittees may be substantially less than protracted negotiations and/or conflicts over set design standards. New and innovative approaches to water quality protection may also be overlooked by permittees in favor of "the county or city requirements".

Specific Requirements/Recommendations

Engineered solutions to groundwater quality protection should be encouraged for the following:

- Stormwater (detention, treatment and re-infiltration);
- UST Leak Detection Systems; and
- Engineered barriers or containment structures for spill containment.

Special Considerations

Ordinances requiring compliance to strict new standards may not result in more or better engineered solutions to water quality protection, particularly if there is inadequate enforcement. A commitment by the City and/or county to apply and enforce existing guidelines and to explore alternatives presented by permittees may be the most effective approach to engineering solutions.

Administrative Requirements

Oversight and review would be a joint responsibility of the Wellhead Protection administrator and Public Works Departments.

Estimated Cost

The ultimate cost of engineering approaches would be paid by the permittees, including the City for its public works projects. The additional costs incurred by the City for plan reviews could be incorporated in the annual salary and budget of the WHPA administrator. Partial funding by the City, County or State for innovative designs could be explored by the WHPA administrator and proposed on a case-by-case basis. The costs of permitting review may require additional review by public works or building departments for engineering design.

9.2.8 Spill Response Planning

Rationale

A comprehensive but informal response procedure is presently applied to incidents on Interstate-90. The Washington State Patrol, Washington Department of Transportation, Washington Department of Ecology and Issaquah Fire Department have established roles in dealing with accidents and spills of hazardous materials. The IFD and State Patrol are normally first responders to accidents, followed by Department of Transportation. If a hazardous spill is present, Ecology is notified who then direct a local clean-up contractor to mobilize equipment to the site for clean-up. The main deficiency in the present system is the time required for a spill containment contractor to arrive on-site. There is no established response procedure for dealing with spills on City or County roads.

Guidelines for developing a response plan are available from WDOE. However, a specific Spill Response Plan for the LIV has not been developed for the WHPP. Instead, general objectives and recommendations regarding spill response have been outlined. The reason for not providing a detailed spill response plan at this time is because many of the response plan elements suggested in the WDOE guidelines are beyond the scope of the Wellhead Protection Plan, and would be more effectively addressed after some measure of Wellhead Protection Planning and response has been initiated. In addition, a comprehensive spill response plan will also address impacts to surface waters and should include input from the Basin Planning activities in the LIV. Preliminary steps towards wellhead protection should be taken prior to developing the Spill Response Plan, including:

- Adoption of WHPA's;
- Establishment of a WHPA administrator; and
- Preliminary spill response plan activities, as discussed below.

Once these measures are taken, a more effective and comprehensive Plan can be developed which serves the needs of Wellhead Protection, provides additional regulatory impetus for formal adoption of a spill response plan, provides administrative support from conception to implementation through the WHPA administrator, and provides baseline commitment and training of local personnel on spill response.

Specific Requirements/Recommendations

The ultimate content of a spill response plan is detailed in the WDOE guidance, but includes:

- Promulgation of the plan by the Local Emergency Planning Committee;
- Endorsements by participating facilities or departments in all jurisdictions;

- Hazard analysis, including hydrologic and geographic analysis, and incident occurrence scenarios;
- Limitations of mitigation, response and recovery actions;
- Coordination with State Comprehensive Emergency Management Plan;
- Detailed operations plans designating responsibilities, levels of incident severity, notification processes, emergency response centers and coordinators, interactive hazards; and
- Detailed notification procedures during and after spill occurrences.

Development of the spill response plan will be most useful and consistent with other WHPA strategies if it is developed after some preliminary actions have taken place including designation of AMA's, appointment of a WHPA administrator, and development of a hazardous materials list. Additionally, a commitment to Spill Response would be established by:

- Training City of Issaquah Fire Department personnel in Spill Response. The minimum level of training for off-site emergency responders is defined in WAC 296.62.300-3112. Training can be arranged through Sgt. Glass at (206) 753-0347.
- Purchasing spill containment materials (absorbent, lights, polyethylene, etc.) by IFD or Public Works; and
- Establishing a contract with a clean-up contractor for spills within City limits.

Administrative Requirements

Development of the spill response plan would be a joint responsibility of the Wellhead Protection administrator, Issaquah Fire Department, and Public Works Departments.

Estimated Cost

The cost of training for Spill Response is minimal for Fire Department personnel. An in-house training program can be developed using state matching funds for continued in-house training and refreshers. Purchase of spill response equipment will probably be between $5,000 and $15,000 initially. The cost of developing the Plan could be incorporated in the annual salary and budget of the WHPA administrator.

9.2.9 Groundwater Supply Contingency Planning;

Rationale

Contingency planning for SPWSD was carried out in 1990 in response to pending water rights and possible aquifer contamination. No formal contingency planning has been carried out for the City of Issaquah.

A major obstacle to contingency planning in the LIV is the present inability to obtain water rights in the Issaquah Basin due to hydraulic continuity issues. Although not a specific objective of the WHPP, the data and modeling carried out for the WHPP suggests that the focus of long-term steady-state hydraulic continuity issues in the LIV should be the impact of groundwater withdrawals on the wetland area near Lake Sammamish and reduced groundwater discharge to Lake Sammamish, not on the impact to specific upstream reaches of the Issaquah Creek system.

Contingency planning and management of the LIV aquifer can be greatly enhanced by joint management the aquifer and operation of the major production wells by the City of Issaquah and SPWSD. The SPWSD and City of Issaquah have constructed an inter-tie between the two water systems, which enables water from all wells in the LIV to be distributed to either the City of Issaquah or the Sammamish Plateau. Both hydraulically and geographically, the wells in the LIV can and should be operated as a single wellfield. This, in itself, is an effective contingency since it provides multiple redundancy in groundwater sources for the area.

Specific Requirements/Recommendations

The following options have been recommended to SPWSD in a water supply contingency plan (Kennedy Jenks Chilton, 1991):

- *Purchase or Transfer of METRO's water rights from Lake Sammamish.* Obtaining surface water rights may provide a means for proposing mitigation strategies to impacts at the Sammamish Wetland and Lake Sammamish from increased groundwater withdrawals;

- *Maximize Development of the Sammamish Plateau Aquifer.* Additional development of the Plateau Aquifer would provide further source redundancy for SPWSD and could potentially allow for proportionally more use of the LIV aquifer by the City of Issaquah on an interim or emergency basis;

- *Develop groundwater from Evans Creek area.* Additional development of the Evans Creek area would provide further source redundancy for SPWSD and could potentially allow for proportionally more use of the LIV aquifer by the City of Issaquah on an interim or emergency basis.

- *Purchase or transfer of Darigold Creamery Water Rights.* If the Darigold well were used as a potable source, the WHPA for the well would not be any more or less susceptible to contamination than existing wells in the LIV. However, the Central Business district of Issaquah, between Sunset and Dogwood Streets would become part of a 1-year WHPA, which may restrict future land-use by potential hazardous materials handlers.

Additional recommendations, based on the assessment of the hydrogeology of the LIV includes:

- *Exploration of Grand Ridge, Lake Tradition Plateau for groundwater sources.* Additional development of the Grand Ridge and Lake Tradition Areas would provide further source redundancy for SPWSD or City of Issaquah. The hydrogeologic analysis from the WHPP suggests that an appreciable thickness of sediments may underlie western Grand Ridge and Lake Tradition. The location of these areas would minimize aquifer contamination concerns since they are within rural or undeveloped areas of the LIV. A deep test well is necessary to assess the groundwater potential in these areas, as well as a feasibility study of conveyance to respective distribution systems.

- *Exploration of Tibbetts Creek, Lake Sammamish Lowlands for groundwater sources.* Additional development of the LIV Aquifer would provide further source redundancy for SPWSD or City of Issaquah. The hydrogeologic analysis from the WHPP is inconclusive regarding groundwater development potential in these areas. The location of these areas may be inappropriate if commercial/industrial development associated with hazardous materials is shifted from the Central Issaquah area towards the Newport/SR-900 area. Additional Wellhead Protection Delineations beyond the scope of this WHPP would also be required. A test well is necessary to assess the groundwater potential in these areas, as well as a feasibility study of conveyance to respective distribution systems.

- *Continued participation in EKCRWA exploration of regional eastside groundwater sources.* Development of a regional water source for eastside communities may provide a long-term contingency for COI and SPWSD by decreasing the dependency on local production wells.

- *Evaluation of optimization strategies for combined COI and SPWSD use of production wells in the LIV.* The present intertie between SPWSD and COI allows for coordinated operation of the wellfield. Development of coordinated wellfield operation strategies for all wells could minimize vulnerability to contamination by optimizing the present redundancy of sources between COI 1/2, COI 4/5, SPWSD 7, 8, and 9.

- *Evaluation of the feasibility artificial aquifer recharge and recovery.* Artificial recharge and recovery of the LIV aquifer could be an effective contingency response for several reasons. From a supply standpoint, use of the aquifer as a storage reservoir may provide added capacity during critical usage periods, and reduce surface water impacts (possibly permitting additional withdrawals from the aquifer). From a water quality standpoint, artificial recharge may provide sufficient control of the hydraulic gradient to essentially direct the flow of groundwater and establish flowpaths that avoid potential contaminant sources.

- *Continue to work with WDOE regarding water rights and hydraulic continuity issues in LIV.* Further analysis of hydraulic continuity and mitigation strategies is needed in the LIV to evaluate the impact of additional groundwater withdrawals and increased urbanization on surface water and groundwater availability. Complex hydraulic continuity issues must be resolved and innovative mitigation, allocation, and water-rights strategies might be considered. There is presently no flexibility in contingency planning based on additional groundwater sources in the LIV until water rights issues are resolved.

Special Considerations

All contingency alternatives may be best approached as a conjunctive endeavor between the City of Issaquah and SPWSD. Water rights and hydraulic continuity issues need continued support if an agreement on water rights with WDOE is to be reached. A joint effort by the City of Issaquah and SPWSD demonstrating commitment to effective management of the resource and with specific recommendations for exploration, mitigation wellfield optimization, and water-rights may provide public and regulatory support for developing groundwater in the LIV.

Estimated Cost

The most effective approach to funding contingency planning projects would be to establish a joint budget between SPWSD and City of Issaquah and work together to develop scopes of work for specific items. Exploration elements will obviously be the most expensive elements, and could be phased over several budgeting periods. Water rights and hydraulic continuity issues need continued funding and support if an agreement from the WDOE is to be reached.

9.2.10 Monitoring

Rationale

Continued monitoring of groundwater quality and water-levels is essential to establish trends and detect problems before they reach the wellhead. In conjunction with continued inventory of contaminant sources, monitoring of water-levels and water quality in the LIV should continue.

In conjunction with monitoring, individual focused hydrogeologic studies are recommended to further develop the understanding of the aquifer, facilitate implementation of contingency planning alternatives, and increase the monitoring efficiency of the present monitoring network.

Specific Requirements/Recommendations

The following wells should continue to be monitored for water-levels on a monthly basis: WH-1, WH-2, WH-3, VT-1, Foothills Baptist, Egghead.

The following monitoring wells should continue to be monitored for water quality, including benzene, toluene, xylene, ethylbenzene, trichloroethylene, trichloroethane, and tetrachloroethylene on a yearly basis: WH-2, WH-3, VT-1.1, VT-5.1, VT-1.1.

Additional shallow monitoring wells are recommended at the following locations:

- Adjacent to I-90 on the north side of the Front Street interchange. A special permit from WDOT may be required which could take up to 6 months to grant. This well will provide added water quality monitoring directly upgradient of SPWSD 7/8;

- Along Newport Way in the Issaquah Creek sub-basin. This will provide water-level data along the western margin of the LIV; and

- On the western edge of the Grand Ridge upland. This will provide water-level and water quality monitoring along the eastern margin of the LIV aquifer.

A study of the dissolved oxygen characteristics of the aquifer would be useful to evaluate the ability of the aquifer to degrade and transform organic compounds. A similar study was initially considered at the ARCO facility, but was not initiated. Two phases could be considered. The first phase would involve field sampling of area wells. A second phase might be to simulate the transformation of a hypothetical spill of contaminant using a model. An integrated study utilizing all of the LIV wells would be most useful. Funding for the study could be provided from multiple sources including the City, County, State and local businesses handling organic compounds.

Estimated Cost

The cost of the monitoring programs are estimated as follows:

- Water-level monitoring: Incorporated into personnel budget of WHPA Program.

- Water quality monitoring: Sample analyses at $250 per sample. Sample collection included in personnel budget of WHPA program.

- Monitoring Wells: $12,000-$15,000 per well.
- Organic Contamination: $10,000 to $15,000 for sampling and analysis. $20,000 to $50,000 for modeling depending on complexity.

Coordination and oversight of the programs would be the responsibility of the WHPA administrator.

10. SUMMARY AND CONCLUSIONS - GROUNDWATER QUALITY PROTECTION

- Threats to groundwater quality are highly varied and dependent on the type of contaminant and hydrogeology. Generalizations and assumptions must be incorporated into any broad discussion of groundwater quality and contamination potential. Specific contaminants and locations must be addressed on a site-by-site basis;

- Groundwater from deep production wells is presently excellent, while some contamination from organic compounds and lead has been observed in the upper portions of the aquifer;

- Present land-use is predominantly residential or undeveloped, with lower proportions of commercial or transportation-related uses. Land-use in the 1-, 5- and 10-year capture zones reflects this general trend;

- The present inventory of potential contaminants within the LIV includes 39 UST facilities, sixteen chemical handling facilities, urban/residential run-off and potential transportation spills;

- Future land-uses that may impact groundwater quality include development of the West Grand Ridge Urban zone, the Sunset By-pass project, expansion of commercial/light industrial land-use, and development on the Lake Tradition Plateau;

- Based on estimated loads of nitrate under present conditions and possible future development scenarios, development of the Grand Ridge/Lake Tradition Plateau area may increase nitrate levels to the aquifer because of septic fields fertilizer applications and stormwater infiltration. Development at 1-acre density using septic fields may cause unacceptable nitrate levels in the LIV aquifer;

- Based on estimated loads of lead under present conditions and possible future development scenarios, further urban/residential development may increase lead levels in the shallow portions of the aquifer;

- Based on an EPA method of screening point sources, there are no "high risk" contaminant sources in the LIV. All potential contamination sources fell in a low to moderate risk according to the EPA methodology;

- Based on an EPA method of screening point sources and more detailed point source loading analyses, the risk of groundwater contamination in existing production wells from present distribution of service stations is actually quite low. This is due to the chemical behavior of gasoline and its ability to degrade naturally in the sub-surface;

- Based on an EPA method of screening point sources, the highest risk of groundwater contamination is posed by transportation spills along the I-90 corridor. Although ranked as a moderate risk to groundwater, a spill of sulfuric acid ranked highest in the EPA method;

- Wellhead protection strategies should build on existing programs, ordinances and policies and avoid overlap with other levels of government;

- The focus of wellhead protection should be on management of future land-use rather than control or re-direction of existing land-use. The exception to this is the urban-zoned western portion of Grand Ridge. Land-use and development in this sensitive recharge area should receive particular attention to wellhead protection issues.

- All wellhead protection strategies must begin with a commitment to address the issues. This is best accomplished by designating aquifer management zones, creating an administrative position for WHPA issues, and establishing public awareness of WHPA issues. Once these tasks are accomplished, more detailed WHPA strategies such as zoning policy, special permitting and review, and hazardous materials ordinances, can proceed;

- Spill response planning, establishment of special permitting procedures, and contingency planning are considered the most effective and high priority elements of wellhead protection in the LIV aquifer. Once initial WHPA policies are adopted, these issues should receive first attention.

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