REPORT

METHOD TO EVALUATE AQUIFER VULNERABILITY THROUGH CONJUNCTIVE USE OF A GROUNDWATER FLOW MODEL AND A GEOGRAPHIC INFORMATION SYSTEM

Clark County Water Quality Division
Department of Community Development

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Completed under Washington Department of Ecology
Centennial Grant Water Fund Grant TAX 91016
in Cooperation with US Geological Survey-Water Resources Division,
the City of Vancouver and Clark Public Utilities

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Clark County, Washington

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SUMMARY REPORT

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INTRODUCTION

Many situations exist where land use and waste disposal practices are incompatible with groundwater quality protection. In Clark County, almost all drinking water is derived from relatively shallow aquifers. In many areas, the water quality of these aquifers appears to be affected by facilities or activities such as on-site waste disposal systems and improper disposal of industrial and commercial waste.

Often, insufficient water quality data exist to identify areas where groundwater contamination is occurring. Vulnerability mapping provides a means to identify areas where groundwater contamination is most likely to occur by evaluating land use and hydrogeologic information. Vulnerability mapping also provides a framework for assembling and collecting groundwater management information. Vulnerability mapping allows groundwater protection measures to be focused where contamination is most likely. It also allows delineation of areas where proposed land use or current zoning may be incompatible with long-term groundwater resource protection.

Groundwater vulnerability mapping or assessment is a term often used to describe a variety of methods designed to map areas where natural groundwater conditions (hydrogeologic factors) and human activities (contaminant loading potential) make groundwater contamination more likely. Vulnerability assessment methods are generally descriptive; they examine existing conditions and describe areas where conditions are most conducive to groundwater contamination.

Groundwater susceptibility mapping methods such as DRASTIC (Aller and others, 1987) were created and promoted to provide a simple means to identify areas where hydrogeologic conditions such as aquifer properties, depth to water, and recharge rates make groundwater more sensitive to contamination. However, susceptibility mapping is a weak predictor of actual groundwater contamination because the location and rate of contaminant loading are not considered.

When the potential or measured contaminant loading is combined with a hydrologic susceptibility assessment, the result is called a vulnerability assessment. Vulnerability, as defined here, is determined by evaluating both the hydrogeologic susceptibility and the potential for contaminants to enter the groundwater system. The simplest vulnerability assessments are performed by overlaying maps of known or suspected contamination sources, such as septic systems, land fills or underground storage tanks on a susceptibility map. This overlay is used to evaluate the relationship between the distribution of sources and groundwater susceptibility.

Groundwater vulnerability mapping is a developing management tool. Numerous different approaches to mapping groundwater vulnerability have been tried in many areas. The methods are generally either very simple, requiring little site specific data or are complex methodologies applied to specific sites or specific management objectives. In some cases, vulnerability assessments have focused on finding and evaluating potential contamination sources within wellhead protection areas.

This project was designed to produce a relatively simple to use, GIS based method to assess aquifer vulnerability. A computerized geographic information system (GIS) is a tool that facilitates compilation and analysis of large amounts of land use, contaminant source and groundwater information. Another important use for GIS is the ability to use results from groundwater flow models to graphically display groundwater flow patterns, potential contamination sources and important groundwater discharge points.

A computerized groundwater flow model with particle tracking is used to numerically simulate groundwater flow paths. GIS mapping of the particle tracking results gives the capability of linking recharge areas with high risk activities to the parts of the groundwater system they recharge.

The GIS is used to analyze and map groundwater particle tracking results and information describing potential contamination sources, land use and susceptibility. The method can be applied in a number of ways to protect groundwater quality and manage groundwater resources.

The method developed for this project was applied at a regional scale for Clark County and is most appropriate for analysis of groundwater flow and vulnerability at a regional scale. However, GIS data can be used for detailed analysis of potential contaminant sources in localized areas. Generic versions of this method can be applied to analysis at any scale that groundwater flow modeling permits. The method would be especially useful for wellhead protection area management.

PURPOSE

This is a pilot project intended to develop a vulnerability assessment method that incorporates simulation of groundwater flow paths and the use of a GIS to store, analyze and map groundwater flow and land use information. The method was to be used as a local management and planning tool. In addition to local use, the method and its development should serve as an example for management agencies considering a GIS based method to assess vulnerability and aid management and planning that protect groundwater quality.

Integrating a GIS into the vulnerability mapping process provides a tool for a multitude of applications including resource management analysis and education. A set of objectives for the project are:

- Use a geographic information system to map and analyze data.
- Incorporate susceptibility mapping into GIS based vulnerability mapping.
- Incorporate simulated rate and direction of groundwater flow into vulnerability mapping by using a regional groundwater flow model and particle tracking model with a GIS interface.

- Characterize the contaminant loading potential of areas contributing groundwater to important recharge areas.

- Map land use factors and potential contaminant sources of groundwater contamination.

- Use geochemical groundwater age dating to check the accuracy of modeled groundwater travel times.

- Evaluate the method as a planning tool.

SCOPE

This methodology is designed to address the conditions and groundwater issues associated primarily with urban development in Clark County. Moderate to low density urban development in the Vancouver metropolitan area and smaller cities is the primary source of contamination to groundwater. Larger areas of low density rural residential, agricultural and forest land uses dominate outlying areas. While agriculture is not a major land use in Clark County, individual farm areas can pose localized threat to water quality.

For the most part, existing data was used for this vulnerability method. Previous data collection and analysis for the Clark County Ground Water Management Program produced the groundwater flow model and most of the GIS maps used in this investigation. Additional information was collected by the US Geological Survey to develop a particle tracking model for the Portland Basin groundwater flow model and to age date groundwater. New maps were created by Clark County for a septic system inventory and animal waste application sites.

REPORT STRUCTURE

This report is structured to accommodate results from project components and a summary report describing the methodology as a planning and resource management tool. General results and evaluation of the method are presented in this summary report. A more complete description of method development and applications is presented in a set of appendicized reports. The summary report and each appendix are stand alone reports.

The summary report describes methodology development and the use of the method as a planning tool. It documents the steps used to produce the Clark County vulnerability methodology, evaluates the methodology, and describes steps to assess if this methodology is appropriate for an area. A bibliographic listing of the project related reports and documents is included at the end of the summary report.

The appendix reports are the basis for the summary report and are important to evaluating the methodology. Appendix A is a US Geological Survey Open File Report describing the development of the particle tracking model and use of the particle tracking model for vulnerability evaluation. The remaining appendices are reports by Clark County. Appendix report titles are:

APPENDIX A.	Use of a Groundwater Flow Model with Particle Tracking to Evaluate Ground-Water Vulnerability, Clark County, Washington.
APPENDIX B.	Growth Management Act Critical Recharge Area Designation For Clark County, Washington.
APPENDIX C.	Method to Estimate Groundwater Contaminant Loading Potential Ratings.
APPENDIX D.	Volatile Organic Compound Detections Compared to Hydrogeologic and Land Use Characteristics.
APPENDIX E.	Comparison of Nitrate Data to Hydrogeologic Susceptibility, Land Use and Population Density.
APPENDIX F.	Wellhead Protection Area Inventory Using a Geographic Information System.

PROJECT APPROACH

This project was completed under a cooperative agreement with the Oregon District Office US Geological Survey Water Resources Division. A general vulnerability model and methodology was developed by the US Geological Survey in Portland, Oregon. The US Geological Survey report describing model development and several applications of the vulnerability methodology to Clark County vulnerability assessment is included in Appendix A.

Additional analysis was performed by the former Intergovernmental Resource Center and Clark County Water Quality Division to augment the model developed at the US Geological Survey. Local work tested the US Geological Survey methodology by transferring the model results to county computers and applying the methodology to local planning and groundwater management issues. Groundwater quality data were also examined and compared to land use and hydrogeologic factors by the Clark County Water Quality Division and the former Intergovernmental Resource Center. Appendix B is a report describing the use of a GIS and modeling to define recharge areas and critical groundwater resource areas for Growth Management Act planning. Appendix C describes the method to establish the contaminant loading potential ratings used in Appendix B. Appendix D and Appendix E are reports that summarize comparison of local water quality data with land use and susceptibility factors. These reports, along with water quality and land use analysis from areas outside Clark County form the basis for the contaminant loading potential ratings in Appendix C. Appendix F describes the use of a GIS to perform inventory of wellhead protection areas.

ACKNOWLEDGMENTS

This project was completed under Washington Department of Ecology Centennial Grant TAX 91016. A cooperative agreement with the US Geological Survey Water Resources Division Oregon District resulted in development of the particle-tracking model and development of the basic vulnerability method. Local funding for this project was provided by the City of Vancouver and Clark Public Utilities. Members of the state-wide advisory task force assisted with final review of the methodology. The task force included: Nancy Winters, formerly of Washington Department of Ecology; Tim Tayne, Thurston County Environmental Health Division; Kirk Sinclair, Washington Department of Ecology, Southwest Region; Stan Miller, Spokane County Water Quality Management Program; Kathy Killian, US Soil Conservation Service; Scott Downey, US EPA Region 10; Ginny Stern, Washington Department of Health; Kirk Cook, Washington Department of Ecology; and Allen Moore, Washington Department of Ecology.

Information was provided by Olympic Pipeline, the Soil Conservation Service Clark County Conservation District, Clark Public Utilities, Pacific Groundwater Group, the City of Vancouver, the Southwest Washington Health District and the University of Washington Extension.

Geographic Information System analysis was performed by Clifton McCarley at the Clark County Department of Assessment and GIS, and Jeanne Keyes, Gar Clarke and Karl Peterson at the former Intergovernmental Resource Center.

USE OF THE METHODOLOGY AS A PLANNING TOOL

This section provides background describing use of the methodology as a planning tool and provides guidance on the limitations and resources required to use the method. Parts of this section describe the general model methodology, suitable applications, limitations, data and support requirements, and steps to assess whether to use the methodology.

DESCRIPTION OF THE GENERAL VULNERABILITY METHOD

This methodology uses a GIS to provide a link between three dimensional groundwater flow simulation and maps of potential contamination sources and water supply sources. Mapping groundwater flow paths allows the user to make an assessment of the likely path between important groundwater discharge areas such as public supply wells and known or potential sources of contamination. Susceptibility analysis helps determine which sites are in areas where contaminants are most readily moved from land surface into groundwater. Appendix A provides a complete description of the method developed by the US Geological Survey.

The components of the analysis are the GIS, the groundwater flow model, the particle tracking model, an interface between groundwater models and the GIS and GIS resource maps. The GIS used for this project is ARC/INFO by Environmental Systems Research Institute, Inc. ARC/INFO is a widely used software package that can be operated on many types of computers including IBM compatible PCs. Almost all of the work for this project was done on UNIX work stations by professional GIS analysts or technical staff trained and experienced in using a GIS.

Two groundwater simulation models are used. The Portland Basin Groundwater flow model (Morgan and McFarland, in press), constructed using the US Geological Survey MODFLOW programs (McDonald and Harbaugh, 1988), simulates the groundwater flow system. Particle tracking simulation is done by the US Geological Survey particle tracking model MODPATH (Pollock, 1989). MODPATH uses MODFLOW simulation results and additional information describing unit porosity to simulate groundwater flow paths. Groundwater flow paths can be simulated in forward or backward directions. Reverse particle tracking determines recharge points to parts of aquifers. Due to the logistics of mapping recharge points and obtaining uniform particle densities within the model, only reverse tracking was used.

A method was developed to allow GIS analysts or planners using GIS to apply particle tracking model results without actually using the groundwater flow model or the particle tracking model. A GIS map, referred to as an endpoint coverage, is used to describe model particle paths as recharge points to each flow model cell. The recharge points are mapped and contain information describing the location of the origin of each particle tracked back to its recharge point, the hydrogeologic unit of the particle and the time of travel from the particle origin backwards to its recharge point. The endpoint coverage uses the results of a model simulation of the average conditions for the year 1987 to 1988 (Morgan and McFarland, in press).

The endpoint coverage is used to match recharge areas to the parts of aquifers where the recharge will travel. An example of an application for the endpoint coverage is selecting areas of concern such as high risk land use or an existing groundwater contamination site, then identifying the model cells and aquifers where the recharge endpoints originated. According to the model this is the area of the groundwater flow system that will be affected by contaminated recharge from the selected areas. The time of travel between origin and recharge points can be used to screen particles according to age. For instance, a time window of 50 years might be used to simulate the main period of development in Clark County.

In addition to vulnerability mapping using potential contaminant source and flow path mapping, several other uses were developed for the GIS data sets. These include mapping water quality data, analysis comparing water quality data to hydrogeologic and land use characteristics, and presenting data maps such as estimated recharge or susceptibility.

SUITABLE APPLICATIONS

The methodology described in this project is appropriate for general regional planning processes such as identifying areas where groundwater protection is critical and where groundwater is likely to be contaminated. The method is applicable to wellhead protection area delineation if the model scale is suitable and to management as a GIS tool. The methodology provides a framework for data collection and management for groundwater protection and management programs and identifies areas where data is lacking. Graphics and maps produced by the method are useful for educating policy makers and the public. Maps are also being used to proceed with management activities such as municipal wellhead protection programs. A major component of the program has been assembling and updating databases. Availability of detailed data describing tax parcel land use and distribution of potential contamination sources such as septic systems can provide a tool for assessing management options.

The methodology has been applied to several groundwater and resource management programs:

- Growth Management Act Critical Area Designation
- Wellhead Protection Area Delineation
- Wellhead Protection Area Land Use Inventory

Specific applications include:

- Aquifer recharge area mapping
- Mapping susceptibility using simulated groundwater age
- Compiling wellhead protection area delineations
- Contaminant loading potential mapping
- Groundwater vulnerability mapping
- Critical drinking water aquifer mapping
- Comparison of water quality with contaminant and hydrogeologic factors
- Mapping aquifer areas receiving large amounts of recharge from dry wells
- Mapping aquifer areas receiving significant amounts of recharge from septic systems

Growth Management Act Critical Area Designation

Results from analysis using the methodology were compiled to map critical recharge areas (Appendix B). Critical areas analysis is intended to provide a picture of the areas where it is most important to protect groundwater for local growth management planners and policy makers. A GIS was used for both analysis and presentation of water resource data. Data presentation maps include the distribution of private wells, public supply wells, the water table aquifer, estimated recharge rates, and groundwater quality data. Groundwater particle tracking mapped the recharge areas for principal aquifers. Contaminant loading potential was mapped by land use using simple ratings presented in Appendix D. Separate vulnerability maps were made for countywide water table aquifers and two individual aquifers. The ARC/INFO grid module was used to sum numerical ratings for susceptibility and contaminant loading factors. Critical aquifers were mapped using urban area boundaries and wellhead protection area boundaries.

Wellhead Protection Area Delineation

As a part of a separate project (Centennial Cleanwater Fund Grant TAX 91075), particle-tracking analysis using the Portland Basin groundwater flow model was used to define wellhead protection areas for City of Vancouver public supply wells. Particle tracking defines areas that contribute water to high-yield public supply wells (Orzol and Truini, in press). The contributing areas were transferred from the model grid to the county GIS parcel base and incorporated into county critical area and wellhead protection area mapping. The City of Vancouver uses these wellhead protection areas for their wellhead protection program.

Wellhead Protection Area Land Use Inventory

Wellhead protection areas were inventoried for several land use and waste management practices using GIS data compiled by the county. Two paper maps were produced for each wellhead area showing the results of the inventory. Examples of the inventory maps are included in Appendix F. One set of maps shows existing land use for each parcel, whether or not each parcel had a septic system, sanitary sewer lines and the wellhead protection area boundaries. Another set of maps shows current zoning for each parcel, regulated underground storage tank locations, water well locations, sites with groundwater or soil contamination, land fills and dumps. The GIS and a spread sheet program were used to make a summary table for each wellhead protection area, totaling the inventoried features for 1 year, 5 year and 10 year zones of contribution. Appendix F includes an example of a summary table for one wellhead area.

The inventory maps and summary tables were distributed to the public water systems for use with their wellhead protection programs. The inventories appear to be adequate for use by utilities to meet requirements of the State Wellhead Protection Program. Computerized inventory maps have been transferred to Clark Public Utilities and the City of Vancouver for use in their wellhead programs who are using it to implement wellhead protection programs. These computerized maps will be a basis for field inspections by the City of Vancouver and Clark Public Utilities.

Several uses have been found for the inventory maps. The City of Vancouver has routed copies to all city departments with activities that can influence wellhead protection. For instance, the public works department views septic system inventories in wellhead protection areas as a means to prioritize septic system elimination program activities. The inventory maps have also been used by county planners for evaluating permit applications under the county interim wellhead protection ordinance. Managers at the county have used the maps as a tool to show the potential impacts of land use activities on water quality.

Database Compilation and Sharing

Databases compiled for the project are used by several agencies and municipalities. Septic system inventories were compiled and matched to computerized parcel mapping. This data was shared with the local health district to help facilitate a septic system maintenance program. The project also coordinated with the Clark County Citizens Hazardous Waste Task Force to map sites of groundwater and soil contamination. Data sharing is yet to reach a level where GIS information can be directly transferred from one organization to another. At this point, the county is the only local government that has significant GIS facilities. GIS data is usually transferred as paper maps, databases or spread sheets and AutoCAD compatible maps. Hopefully, data sharing will become more common and easier as PC-based GIS utilities become more sophisticated and widely used.

LIMITATIONS

The accuracy and assumptions of the groundwater flow simulation, susceptibility and contaminant loading potential models result in limitations to the use of this method. The scale and accuracy of GIS data sets also place limitations on method use. Because the method is descriptive, no numerical or statistical measure of contamination risk is made.

While the methodology has limitations as a technical predictive tool, these limitations are not critical when the preventive philosophy of most groundwater protection programs is considered. The emphasis is often on identification, containment or removal of contamination sources to minimize contaminant release to groundwater.

All models make simplifying assumptions to produce a manageable simulation of real world conditions. Numerical models used for this method, MODFLOW (McDonald and Harbaugh, 1989) and MODPATH (Pollock, 1989), are deterministic models producing a single outcome using a predetermined set of conditions. Descriptive models include DRASTIC (Aller and others, 1987) and computer overlays of land use and sites that have the potential to release contaminants into groundwater.

Contaminant loading potential ratings are intended for general regional analysis. They are based on analysis of the relationship of regional water quality to individual land use and hydrogeologic characteristics or factors. Ratings are not rigorously defined and include a high degree of subjectivity. Care should be used when transferring contaminant loading potential ratings from Clark County to other areas. The ratings used in this project were based in part on conditions in Clark County.

Groundwater Flow Model Limitations

Model users must consider both the limitations of the MODFLOW code and the Portland Basin flow model. Description of limitations to the use of the MODFLOW code is provided by McDonald and Harbaugh (1988). Morgan and McFarland (in press) describe the development and limitations of the Portland Basin model.

Morgan and McFarland (in press) describe the simplifying assumptions used to make the Portland Basin groundwater flow model. The principal simplifying assumptions are: 1) It is a steady-state simulation of time averaged conditions for 1987-1988; 2) transmissivities are fixed for all aquifer units regardless of changes in saturated thickness; and 3) simplification of some model boundaries as no-flow conditions.

The Portland Basin model is a steady state model simulating an equilibrium condition. The steady state model cannot simulate the dynamics of changing rates of recharge, stream flow and groundwater consumption. Steady state modeling was done because inadequate water level and water use information exists to create and calibrate a transient model capable of simulating changes with time due to a change in pumping or recharge rates. The use of a steady state flow model in conjunction with particle tracking is not a major limitation because the US Geological Survey MODPATH particle-tracking program is limited to steady state calculations.

The Portland Basin groundwater flow model was designed as a regional model. Model discretization scale, or model cell size, limits the usefulness of the method to relatively small scale analysis of regional or larger local areas. Each Portland Basin model cell represents the hydrologic and hydrogeologic characteristics of an area of about 200 acres (3,000 feet by 3,000 feet). Significant limitations due to scale include: 1) The inability to simulate groundwater discharge at individual features such as pumping wells and streams other than as a flow rate distributed throughout an entire cell, and 2) Generalizations made to describe the hydraulic and hydrogeologic properties within each cell.

The model was constructed using data compiled at a scale at least as detailed as the model discretization scale. Of necessity, model hydrogeologic properties, recharge rates, pumping and stream flow are estimates based on as much field data as possible. Iterative model calibration to the best known parameters, aquifer water levels and stream flow rates was used to adjust less well known aquifer hydraulic parameters.

The model can only simulate saturated flow and cannot address the unsaturated parts of flow systems. Unsaturated materials between land surface and the model water table are not simulated. Also any shallow flow systems vertically separated from the regional flow system are not simulated.

The Portland Basin groundwater flow model makes a three dimensional simulation of a very complex system. The model simulation will not exactly match real world conditions. Examples of hydrologic characteristics simulated by the model that may not match real world conditions are aquifer water levels, the water table aquifer, groundwater discharge rates to streams, rivers and springs and groundwater flow rates through the modeled aquifer system.

Differences between simulated and observed water levels can influence particle tracker results. Any difference between modeled characteristics and the real world or observed conditions can cause some discrepancy between simulated particle paths and real world groundwater flow paths. Generally, horizontal groundwater flow directions from the model match directions mapped from observed water levels.

Particle-Tracking Model Limitations

Particle tracking modeling is subject to the limitations of the groundwater flow model as well as the limitations of the particle-tracking model. The US Geological Survey particle-tracking model author (Pollock, 1989) describes model limitations as being due to assumptions of the method, discretization effects and uncertainty in parameters and boundary conditions. The important limitations for this application to the Portland Basin are due to discretization and uncertainty in parameters and boundary conditions.

Pollock (1989) states that discretization effects influence the level of detail at which the hydrogeologic system is represented in the simulation, the accuracy of particle velocity calculations and the ability to accurately represent internal sinks such as pumping wells and discharge to streams. Pollock describes the effect of discretization and particle-tracking analysis on cells that have weak sinks. Weak sinks are cells that have features such as wells that do not discharge at a rate large enough to consume all of the water entering the cell. The net result is that some of the water that enters the cell passes through the cell. It is difficult to interpret results of particle-tracking in systems with weak sinks because: 1) there is no way to know if a specific particle should discharge to the sink or pass through the cell, and 2) path lines through weak cells may not accurately represent the path of any water in the system if the cells contain point sinks that cannot be accurately represented as being uniformly distributed throughout cells. The small scale discretization of the Portland Basin groundwater flow model results in many weak sink cells due to well pumping or leakage to streams and springs.

Pollock (1989) suggests that the most important limitation of any groundwater simulation is the uncertainty in boundary conditions and the hydrogeologic parameters used to define the system. The degree to which the model simulates the real system places additional constraints on interpreting particle-tracking analysis. Snyder and others (in press; Appendix A) identify the no-flow boundary along the eastern edge of the model as being a significant limitation to particle-tracking simulation. Here, the no-flow boundary simulates the contact between modeled basin filling sediments and older rocks that bound the basin. At this boundary, all particles are constrained to flow along the east boundary of the model producing results that probably do not accurately represent the real world where flow across the boundary would occur. Simulation of this no-flow boundary in the Portland Basin model does not appear to be a significant limitation outside the cells immediately adjacent to the boundary. But because of this boundary, particle tracking is not used in the cells that are adjacent to the model boundary.

Another important limitation of the MODPATH particle-tracking model is that it is an advective transport model. In an advective transport model, any contaminant is assumed to be attached to a particle of water moving through porous media. Any MODPATH simulation of contaminant transport must assume that the contaminant has the mobility of water and is not influenced by physical processes such as dispersion and diffusion or chemical interactions between contaminants and rock or water.

Susceptibility Mapping Limitations

As is the case with groundwater flow modeling and particle tracking, susceptibility mapping has significant limitations that can be characterized as limiting assumptions of the model and limitations due to data accuracy.

DRASTIC Mapping

A DRASTIC map provides the user with a simple means to characterize relative groundwater susceptibility to pollution for areas of 100 acres or greater (Aller and others, 1987). The degree of susceptibility depends upon a combination of hydrogeologic properties such as depth to water, geology, soil and recharge rates. The relative DRASTIC susceptibility index can be used to help identify areas where groundwater protection is critical, allowing resources to be directed toward the most significant potential problem areas.

At best, susceptibility maps can identify areas where there is a significantly higher or lower ease of contaminant-bearing recharge movement to groundwater. Site specific or contaminant specific susceptibility assessment would require detailed analysis of soil and rock characteristics, recharge characteristics, and physical and chemical characteristics of the modeled contaminant.

DRASTIC is a simple model that utilizes normally available information about groundwater characteristics to map susceptibility of areas. These hydrogeologic characteristics, when mapped at the scale of a DRASTIC map, do not replace site specific investigations. Nor does DRASTIC, by itself, determine the suitability of a specific site for a particular use such as solid waste disposal.

DRASTIC mapping only allows evaluation of one aquifer at each point on a single map. In Clark County, this is the water table aquifer based on water well data. DRASTIC does not consider the direction or rate of groundwater movement. While recharge rates and topography are incorporated, the direction of groundwater movement is not considered. Areas where groundwater discharges to rivers, lakes and wetlands are not specifically identified. DRASTIC assumes that contaminants are discharged to land surface and are flushed into groundwater by rainfall or other water, such as irrigation applied to land surface. Another important assumption is that the contaminant has the mobility of water and is carried with water.

The data used to create the Clark County DRASTIC map are generally as accurate as the data used to create the groundwater flow model. Some generalization was done to simplify mapping of complex features such as the variability of hydraulic conductivity within aquifers. A complete description of the process to make the Clark County DRASTIC map is in Swanson (December, 1991).

Particle-Tracking Age Dating

Susceptibility mapping using simulated groundwater ages are subject to the limitations of the groundwater flow model and particle tracker. The simulated vertical and horizontal groundwater flow rates can greatly influence minimum groundwater age. Groundwater flow rates depend largely on head differences, hydraulic conductivity and porosity. Vertical hydraulic conductivities are known only approximately for units and are also estimated as aggregate values for each unit. Horizontal hydraulic conductivities are estimated from a few points. Porosity was estimated using an empirical relation between hydraulic conductivity and porosity.

The groundwater ages determined using particle tracking do not consider any effects of migration through soil or the unsaturated geologic material overlying the simulated flow system. Increasing or decreasing the number of particles in a simulation can change the results by producing a different number of solutions.

GIS Data Limitations

The successful use of a GIS for resource management depends upon high quality digital data. Each map or data set has some limitation due to the accuracy of location mapping or the quality of information mapped for each feature. Generally, all of the GIS maps used in this project are accurate to at least a level compatible with the scale of the groundwater flow model. In some cases the reliability and completeness of the data set are significant issues.

Map locations of specific sites are accurate to at least the scale of US Geological Survey 1:24,000 scale topographic maps in almost all cases. In some cases, such as the land fill and dump map, locations are not known well enough to be mapped at 1:24,000 scale and sites are mapped as points on a 1:48,000 scale county road map.

The newly completed Clark County Department of Assessment and GIS tax parcel mapping is the most accurate and inclusive database now available. The parcel database includes parcel boundaries, a centroid point for each parcel and tax assessment information for each tax parcel. Tax parcel boundaries were digitized from quarter section maps. This database provides an excellent format for compiling and analyzing data. With time, an increasing amount of information is being collected at parcel scale or transferred to parcel scale from other less accurate maps.

The accuracy of information describing mapped features can vary greatly. Generally, there is sufficient information to identify the feature. Data sources range from anecdotal accounts for undocumented dump sites to lengthy descriptions of permitted land fills. Many data sets come from sources outside the county such as the Department of Ecology underground storage tank program. These data can require significant effort to verify site addresses and then map and digitize site locations.

Data completeness is a significant limitation of the water well data base compiled for this project. Almost no records exist for wells constructed between 1950, when the US Geological inventoried a fraction of the wells in Clark County, and the mid 1970s, when the Department of Ecology water well construction reports began to be completed for most of the new well construction. The septic system inventory also lacks complete data outside the Vancouver urban area.

The accuracy and quality of the GIS mapping is summarized in the following section.

Water well location map - This set is probably about 60 percent complete with approximately 10,000 wells. Location accuracy is at 1:24,000 scale mapping for about 4,000 wells and at quarter of a quarter section for most of the rest.

Water well data tables - Most of the driller report data is compiled for 7,000 wells inventoried by the US Geological Survey in 1988. Data for the other wells is less complete.

Public supply wells - Wells with 25 or more hookups were compiled by the US Geological Survey from available well records and field inventory. Most of these wells are located at a scale of 1:24,000.

Water quality data for public supply wells - Some of the monitoring results reported to the Department of Health are compiled.

Water quality data for private wells - Data describing field parameters and nitrate, iron, manganese and coliform bacteria are compiled for 4,210 wells inventoried by Clark Public Utilities (Pacific Groundwater Group, March 1991).

Spring locations - Major springs and 1988 flows are mapped at 1:24,000 scale by the US Geological Survey.

Septic systems - Parcel level data that is field verified exists for much of the Vancouver urban area. Outside of this area data is less complete, using digital Southwest Washington Health District permit records dating to 1985.

Drywells - Current digital drywell mapping is compiled by quarter section from an inventory made by the Department of Ecology in 1988. The inventory is incomplete but covers most of the county.

1990 population census - Population counts are mapped at the census block level.

1974 general land use - Land use compiled by the US Geological Survey at 1:250,000 scale. The map is usable but dated because of encroachment of residential use into rural and forest areas. However, the map shows areas of urban and industrial development. Accuracy is good for the scale of the map.

Existing land use - Compiled by Clark County Department of Assessment and GIS, this detailed land use map includes parcel land use data and air photo interpretation of parcels over five acres. Map accuracy is at parcel scale. Land use accuracy is appropriate for detailed analysis.

Zoning - Created by Clark County Department of Assessment and GIS, this map shows current zoning using the parcel boundary map.

Functional road class - All roads in Clark County with classification by Washington Department of Transportation.

Rail lines - Compiled by the Clark County Department of Assessment and GIS.

Solid waste disposal sites - The map and database were compiled by the Clark County Groundwater Management Program in 1990 and includes permitted and abandoned landfills and dumps, as well as uncontrolled dump sites. The landfill sites are digitized from point locations at 1:48,000 scale. The location accuracy is considered poor. Landfill data is compiled in a table and ranges from good for permitted land fills to very poor for abandoned dumps and uncontrolled dumps.

Underground storage tank locations - Washington Department of Ecology inventory of underground storage tanks that are not exempt from federal underground storage tank regulations. The Department of Ecology data base is updated periodically and is available to the public. The GIS map was created by the Intergovernmental Resource Center using the Department of Ecology inventory. Tank sites were mapped on 1:24,000 scale maps using the site address. The most recent update was by the Intergovernmental Resource Center in March 1991.

Known sites of contamination - The Intergovernmental Resource Center compiled from Toxics Cleanup Program Affected Media and Contaminants reports by the Department of Ecology and site records from the EPA Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) into a GIS map of known and suspected contamination sites. The data tables and map were periodically updated, with the last update in September 1991. Sites were digitized from locations placed on 1:24,000 scale maps using addresses. This map and database are currently being updated and field verified by the Clark County Hazardous Waste Citizen Task Force.

Livestock waste application sites - Sites were identified using records from Soil Conservation Service Clark County Conservation District, University of Washington Extension, and Lacamas Lake Restoration, and mapped on parcel boundaries. The map includes some municipal sludge application sites and is not field checked.

Wellhead protection Areas - Compiled from work by Clark County Water Quality Division, the US Geological Survey, Clark Public Utilities (Pacific Groundwater Group), and the Intergovernmental Resource Center. This map has 1, 5, and 10 year zones of contribution for the principal wells of Clark County water utilities. Accuracy is good, maps are compiled on 1:24,000 scale parcel base.

DATA REQUIREMENTS

A large amount of information is required to develop and use this method. The principal types of information are hydrogeologic data to create the groundwater flow model and the GIS mapping describing land use and potential contaminant sources.

Groundwater Flow Model

The Portland Basin groundwater flow model is a complex finite-difference numerical model. About three years was spent to compile the data and construct and calibrate the final model. The total cost of model development, including data acquisition was about $1.2 million. The Portland Basin model uses information describing the geologic framework of the flow system (Swanson and others, 1993), aquifer and confining unit hydraulic properties (McFarland and Morgan, in press), a separate modeling effort to estimate the amount and distribution of recharge (Snyder and others, in press), the amount of groundwater withdrawn by pumping wells (Collins and Broad, in press), and stream discharges, groundwater seepage to and from streams, spring flow, stream and river altitudes, and groundwater elevations for each hydrogeologic unit (McFarland and Morgan, in press).

Any model used for three dimensional groundwater flow simulation and particle tracking should contain the basic design elements of the Portland Basin model. This includes description of the aquifer geometry and hydraulic properties, stream flow, leakage between groundwater and streams, spring locations and flow rates, recharge rates, water consumption for each aquifer by model cell and aquifer water levels. A model applied to a smaller area or designed to meet objectives focused on localized management issues would probably require much less total data than the Portland Basin model. A flow model developed for a specific area where groundwater management is occurring can concentrate on a localized aquifer or geographic area, hopefully reducing the complexity due to hydrogeologic and geographic diversity. This could help keep costs down by decreasing the amount of data that is collected.

Particle-Tracking Model

Particle-tracking modeling requires porosity values for each model cell. Porosity was estimated for each cell using an empirical relation between hydraulic conductivity and porosity (Snyder and others, 1994b). The model-calibrated horizontal hydraulic conductivity was used for porosity calculation. Porosity is usually not well characterized and generally falls within ranges specified in published tables. Because of this, it is not uncommon for models to use a single estimated porosity value for an entire aquifer or confining unit.

Susceptibility Mapping

Susceptibility assessment can be nearly completed using data compiled for development of the groundwater flow model. Soil mapping is normally a component of susceptibility mapping but is not necessarily collected for groundwater flow model construction.

Potential Contaminant Sources and Land Use Mapping

Vulnerability mapping requires data describing contaminant sources and important groundwater discharge points such as public supply wells. Potential and known contamination sources information includes mapped distribution of each feature and in some cases tabular data describing characteristics and contaminant loading potential. These are listed in the section GIS data limitations. A good summary of data bases describing actual and potential contaminant sources is Washington Department of Ecology (February 1992).

TECHNICAL SUPPORT REQUIREMENTS

This methodology has computer, data management, and technical staff support requirements that are commensurate with the resources available to an ongoing resource management program. Any plan to use a GIS should involve a long-term commitment to data acquisition and management that is generally beyond the scope of a single project. Consequently, use of a GIS intensive method should be part of an ongoing management program.

Computer Requirements

The Portland Basin model was developed by the US Geological Survey on a Prime mainframe computer. Later, the US Geological Survey moved the models to Sun and Data General UNIX work stations. The standard US Geological Survey groundwater flow model MODFLOW (McDonald and Harbough, 1988) and particle-tracking model MODPATH (Pollock, 1989) are public domain software and are available from the US Geological Survey or commercial vendors. Special software was written by the US Geological Survey, Oregon District, to facilitate the use of GIS data as input and output from the US Geological Survey models. These software packages, MODFLOWARC (Orzol and McGrath, 1992) and MODPATHARC (Orzol, in press) are public domain software available from the US Geological Survey.

Graphics and GIS software used by the US Geological Survey are largely licensed proprietary programs. ARC/INFO is the GIS used by the US Geological Survey and is available from ESRI (Environmental Systems Research Institute) of Redlands, California.

ARC/INFO Version 5 or newer is required to operate MODFLOWARC. In addition, MODFLOWARC source code includes ARC macro language code that must be compiled for the host computer operating system. Compiling the source code requires access to the ARC/INFO source code library. The MODPATHARC source code is in FORTRAN language and can be compiled using a FORTRAN compiler. MODPATHARC does include ARC/INFO commands in its programming. MODPATHARC can produce particle tracker output as ARC/INFO coverages using standard flow budget output from any MODFLOW model suitable for particle tracking analysis.

At Clark County, GIS ARC/INFO analysis is performed primarily on Hewlett Packard UNIX work stations by specialized GIS analysts in the Department of Assessment and GIS. IBM-PC compatibles are used by Water Quality Division staff to perform analysis of tabular data, some simple GIS analysis, and groundwater flow modeling. MODFLOW and MODPATH are used to run the Portland Basin groundwater flow model on IBM-PC compatibles at the county. Both programs are commercial versions of the US Geological Survey code compiled for PCs. MODPATH results can be plotted to monitor or graphics formats dependent on the version of MODPATH. Special, commercially available preproccessing and postproccessing programs are used to display and print MODFLOW output such as heads and flow budgets.

Staff Requirements

Technical staff are required to evaluate existing data and groundwater conditions to assess the appropriateness of the methodology for local use. Individuals with a strong background in groundwater hydrology, geology and resource management analysis will be needed to compile and evaluate existing hydrogeologic data and contaminant loading potential information. Creation of a groundwater flow model and particle-tracking model requires staff with groundwater flow modeling and GIS experience. It is likely that this aspect of the project will require an outside consultant. Susceptibility mapping requires a professional hydrogeologist with knowledge of the local hydrogeologic setting. Compilation and management of GIS data sets requires individuals with experience designing, using and maintaining GIS systems and databases.

Utilization of a vulnerability model requires an understanding of all the assumptions and limitations of the model components and data sets. These include use of the groundwater flow model and particle tracking modeling, assumptions and limitations of vulnerability mapping methods, and some understanding of contaminant transport.

The endpoint coverage method can be used for evaluating groundwater flow patterns and surface features by staff trained in the use of GIS. MODPATH is also relatively easy to use because it draws on previously calculated MODFLOW flow model results using an interactive program.

STEPS TO ASSESS WHETHER OR NOT TO USE THIS METHOD

This section contains a description of steps to assess whether the model should be used in an area. The methodology requires a very large investment in data collection and groundwater flow system characterization. Because of this, it probably would be impractical to use this method solely for vulnerability assessment. Collection of much of the groundwater flow system and land use information required for this method is likely to have been completed as part of a larger groundwater management program.

Define Program Objectives

The first and most important step is establishing the purpose and objectives of the program using the methodology. Objectives will help define the type of groundwater modeling and land use data that are required. Another important step is planning data collection and management programs that will fit with ongoing programs such as tax parcel mapping, utility system mapping, GMA planning, local health department programs, hazardous materials inventory by fire departments and wellhead protection programs. These programs may collect and maintain much of the information describing potential sources of contamination.

As part of the larger groundwater management program, vulnerability assessment costs would be chiefly for compiling existing data, data analysis, report preparation and incorporating the results into local management activities.

Availability of a GIS

Implementation of this method requires a GIS system that can accept groundwater flow model output, particle-tracking model output and a variety of maps and tables describing land use and potential sources of contamination.

Groundwater Flow Model Capable of Producing Particle-Tracking Analysis

A groundwater flow model capable of simulating particle tracking is required to implement the methodology. Any model and graphics or mapping processors used with this system need to be capable of outputting particle tracking results in a format compatible with the GIS.

The model should also be designed to meet management objectives. Critical considerations are whether the model cell size is appropriate for the model objectives, whether the model has sufficient vertical discretization to model the aquifers in question, whether transient simulations are needed for evaluating management options, and whether adequate data are available to create a model. A model should be calibrated to observed real world conditions such as aquifer water levels, stream flows and aquifer pump test analysis.

Computer model development cost depends on several factors. The complexity and size of the flow system has a great influence on model complexity and cost. The degree to which existing hydrologic and hydrogeologic data is compiled can also greatly influence model cost. If a large amount of original information needs to be collected for the model, many months or even years of data collection and analysis may be required. As an example, the Portland Basin groundwater flow model cost about $1.2 million to develop. This is a large three dimensional model for a hydrogeologically complex multiple aquifer flow system. All of the data for the model was collected and compiled by the US Geological Survey at the time the model was constructed. Use of a GIS to compile and analyze data may have increased the model development cost. However, there was an increased efficiency for data management and model calibration. The GIS gave enhanced ability to display and analyze model output. The use of a GIS also increases the ability of agencies to exchange and utilize data.

In areas with simple, single aquifer flow systems, a simpler two or three dimensional model could be constructed and calibrated at a much smaller cost. In cases where groundwater conditions are simple, the area is small and resources are limited, two dimensional analytical models may be appropriate. Two dimensional analytical models may not be appropriate for regional analysis but can be interfaced with GIS systems for analysis of groundwater flow near individual or small groups of pumping wells.

Susceptibility Mapping

Susceptibility mapping is not completed for many areas. If a map exists, it needs to be assessed to determine if it accurately represents the susceptibility of the aquifer or aquifers of interest. The assessment is critical because susceptibility maps such as DRASTIC only map one aquifer unit, usually the water table aquifer or principle regional aquifer. The methodology and data used to make the susceptibility map also need to be reviewed to assure that the map is accurate and of acceptable quality.

In some areas, susceptibility mapping may not be very useful. These include settings where hydrogeologic conditions are fairly uniform or aquifers are deep and of low susceptibility. Examples of areas with uniform aquifer conditions include shallow valley fill alluvial aquifers, deep basalt aquifers, and semi-confined sedimentary rock aquifers. The Rathdrum aquifer in northeastern Washington is an example of a large, fairly homogenous regional aquifer that has a uniformly high susceptibility to contamination.

The limitations of susceptibility mapping should also be considered. A carefully done DRASTIC type map may not be capable of addressing specific local management objectives.

A useful step in determining the need for susceptibility mapping is to create a simple map using the predetermined hydrogeologic settings defined in the DRASTIC method. This will give a good indication of the range of susceptibility indexes in the study area and some idea of the applicability of these methods.

Susceptibility mapping cost is dependent on the amount of effort required to acquire the individual data layers and the amount of analysis performed on hydrogeologic data to create the final map. Compiling a susceptibility map such as a DRASTIC map can require as much as several months of data editing, map production and report writing. Depending on the availability of usable data layers, level of effort and quality control, the production of a map using multiple data layers and a summary report could take one to four months to complete.

GIS Data Sets

All the information used in this method is stored and analyzed as computerized maps and related data tables. The GIS is the software and hardware system that stores and facilitates analysis and retrieval of digital data sets. All data incorporated into the Clark County method has to be a GIS map or converted from other map and table formats.

Increasingly detailed land use and inventory data enhances the usefulness of the GIS as a management tool. For example, detailed site or parcel specific land use data can provide the basis for source inventory and management programs. An example is parcel specific information describing the presence or absence of a sanitary sewer connection. As management programs progress, increasingly detailed information is collected and incorporated into the data base. As increasing volumes of data are acquired, greater effort is required to assure accuracy and update data sets.

The total cost for GIS systems includes the hardware, software and technical staff required to effectively use a GIS. There are several GIS systems available that operate on PCs and computer platforms. Their cost can range from a few hundred dollars for simple grid based systems to several thousand dollars for a UNIX work station compatible version of the widely used ARC/INFO software. Use of a GIS should require a commitment to have at least one staff person dedicated to analysis and maintenance of data and system management.

Because much of the data used for this method was collected by the Groundwater Management Program, the data collection cost is primarily for compiling and maintaining the data sets. The total cost to the US Geological Survey and Clark County was about $40,000, attributed primarily to compiling data, establishing data management systems and data transfer. Some effort was expended on acquisition of data sets, digitizing maps and verifying data. Department of Assessment and GIS mapping of tax parcels and mapping done for Growth Management planning are not considered in the cost of the project.

Cost Estimate Checklist

A checklist of project elements is included in this section (Figure 1). The checklist provides a basis to begin to assess the costs involved in using this methodology. The cost of each element should be estimated by the organization planning to use the methodology, due to large differences in local groundwater conditions, financial resources and resource management objectives within the region.

COST ESTIMATE CHECKLIST

- Identification of area of interest
- Description of purpose and objectives for methodology
- Computer and operating system
- Output devices/ printers, plotters etc.
- Digitizing devices
- GIS software
- Groundwater flow model software
- Particle tracking or solute transport model software
- Software for processing groundwater flow model and particle tracking output to the GIS system
- Groundwater flow model development
- Particle tracking model development
- GIS library compilation
    - Water well locations and data tables
    - Public supply well inventory
    - Compiled water quality data for public supply wells
    - Compiled water quality data for private wells
    - Spring locations
    - On-site waste disposal systems
    - Dry wells
    - Sanitary sewer lines
    - Infiltration devices
    - Census population
    - General land use
    - Parcel land use
    - Zoning
    - Roads
    - Rail corridors
    - Pipeline locations
    - Solid waste disposal sites
    - Underground storage tanks
    - Groundwater and soil contamination site map
    - Sludge application sites
    - Animal waste application sites
    - Pesticide application areas
    - Fertilizer application areas
    - Contaminant by land use data tables
- Groundwater susceptibility map
    - General geology map
    - Aquifer distribution map
    - Soil map
    - Depth to water map
    - Recharge rate map
    - Aquifer hydraulic properties
    - Topography map
- Technical staff for model development and use
    - Hydrogeologist/groundwater professional
    - Resource management planner
    - GIS technician
    - GIS analyst

Figure 1. Cost Estimate Checklist

EVALUATION OF OTHER METHODS

Each vulnerability method is designed to meet certain objectives. Vulnerability methods are often designed for general application to groundwater quality management. As such, they have severe limitations for site specific risk assessment investigations. Detailed risk analysis models are applied to potentially contaminated sites under federal and state regulatory programs. These site risk analysis models were not evaluated.

The following vulnerability and susceptibility methods were compiled from the methods that were developed for general use.

SITE SPECIFIC ASSESSMENTS

Manual for Evaluating Contamination Potential of Surface Impoundments (EPA, December 1983)

The manual was prepared by a work group specifically for implementing a standardized evaluation system for the EPA Office of Drinking Water Surface Impoundment Assessment and was intended to serve as the training manual for that assessment. The manual is based on the work of LeGrand (1964) describing a system for evaluating the contamination potential of certain waste sites. The method was intended to provide an approximation of the groundwater contamination potential of impoundments at a minimal cost using available site data or general data table values where site data is lacking. The method is separated into two phases. Phase one rates contamination potential of groundwater. Phase two rates relative magnitude of potential endangerment to current groundwater users.

The groundwater contamination potential rating phase considers:

1) The thickness and type of material in the unsaturated zone
2) The relative hazard of the impoundment waste
3) The quantity and quality of groundwater beneath the site

The potential for endangerment of current groundwater users rating phase includes:

1) Whether the source is groundwater or surface water
2) Whether the source is down gradient from the impoundment
3) The distance between the impoundment and the water source

The manual provides examples and tables of parameter and rating values. There is an appendix describing relative rankings of waste classified by Standard Industrial Classification (SIC) code that can be used for general vulnerability mapping where site land use is available. Another appendix ranks contaminant hazard potential for a number of waste materials. The manual is useful for a description of a method to assess vulnerability. Contaminant hazard tables in the appendix are a useful tool for categorizing risk from various industries.

Managing Groundwater Contamination Sources In Wellhead Protection Areas: A Priority Setting Approach (EPA, October 1991)

This methodology was designed to provide a risk screening tool for human health risk posed to public supply wells by specific groundwater contamination sources. It is intended to support local implementation of wellhead protection programs. EPA reports that this is a one of a kind product that was designed for use by local planners.

The approach calculates a health risk score by multiplying two risk components: likelihood of well contamination and severity of well contamination. Likelihood of well contamination is defined as the likelihood that the contaminant will be released from the source to soil and the likelihood that the contaminant will reach the well within a specified planning period. Severity of contamination is estimated for a specific contaminant at a mapped source and is a function of three elements: 1) the quantity that is likely to be released, 2) the likely degree of attenuation due to transport, and 3) the contaminant toxicity.

The method is meant to be applied to source risk ranking in wellhead protection areas. It can screen a particular source as representing a high, medium or low risk and rank different types of sources. In addition, the method provides a tool for selecting management options by comparing likelihood of contamination and the health hazard of contamination for a specific source or contaminant.

The method uses general data and is not a substitute for site specific analysis. It is limited to the number of contaminants and sources documented in the manual. The method uses paper manual and evaluation forms and is not computerized, making it labor intensive for application to large areas or data sets.

SUSCEPTIBILITY MAPPING METHODS

DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings (Aller and others, 1987)

The authors of the DRASTIC methodology set out to develop a model to systematically and with relative simplicity map groundwater susceptibility for any hydrogeologic setting in the United States. DRASTIC uses two steps: 1) the designation of mappable hydrogeologic settings and 2) the superposition of mappable hydrogeologic susceptibility parameters.

DRASTIC describes 110 generic hydrogeologic settings intended to represent all areas of the United States. Within the mapped hydrogeologic setting, seven factors representing the DRASTIC acronym: **D**epth to water, **R**echarge rate, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone, and aquifer hydraulic **C**onductivity are rated and summed using factor weights to determine relative DRASTIC susceptibility index.

The DRASTIC method, or variations, has been used in many areas as a part of groundwater resource assessments, as a part of vulnerability assessments and as a tool to characterize sample site vulnerability for statistical analysis of water quality data.

The most appropriate use of DRASTIC mapping is to identify areas where groundwater is most easily contaminated by releases to land surface. It is a relatively simple and unsophisticated method to systematically discriminate highly susceptible aquifers from less susceptible aquifers. This sort of mapping allows planners to prioritize areas where source control management should be implemented.

SEEPAGE: A System for Early Evaluation of the Pollution Potential of Agricultural Groundwater Environments (Moore, 1989)

SEEPAGE was developed by the US Soil Conservation Service as a practical method to evaluate the groundwater pollution potential, or susceptibility, of sites proposed for resource management systems that could degrade groundwater quality. Ease of use was an overriding objective during development of the system.

SEEPAGE is a combination and refinement of selected elements from DRASTIC (Aller and others, 1987), LeGrand (1983), and Wisconsin susceptibility mapping methods (Schmidt, 1987). Evaluated factors include: the horizontal distance between the site and point of water use, land slope, depth to water table, vadose zone material, aquifer material, soil depth and the attenuation potential of soil. As is the case with the source methods, SEEPAGE sums weighted rating factors to arrive at a relative index called the Site Index Number.

The method is reported to be widely used within the Soil Conservation Service since its first release in 1988 (Moore, 1989). Specified uses include preliminary screening of project sites, comparison of sites to identify the best site for a project and the determination of whether more detailed site analysis is required. The method also provides a concise tool for explaining design rationale to landowners. A principle weakness of the system is that it does not consider groundwater flow direction.

VULNERABILITY MAPPING BY OVERLAYING POTENTIAL SOURCES ONTO SUSCEPTIBILITY MAPS

The advent of GIS and computerized drafting has led many to create or test vulnerability maps by overlaying potential contaminant sources or general land use characteristics onto susceptibility maps in order to compare contaminant loading potential and susceptibility. State and local groundwater protection programs use this method with varying degrees of sophistication.

Contaminant loading potential and susceptibility based vulnerability mapping can be as simple as overlaying maps of known sources of contamination onto a geologic map. More elaborate analysis can use factor weighting and ratings to superposition several regional potential loading factor maps with susceptibility to create a vulnerability map or maps.

Suitable application for this type of vulnerability assessment is to identify areas where groundwater is most at risk to one or more types of contamination. This information can help educate the public, guide water quality monitoring site selection and provide a basis to prioritize source control management programs.

Groundwater flow directions are not considered in most susceptibility assessments. This results in a map that indicates the vulnerability of groundwater directly beneath the mapped contaminant loading and does not consider the down gradient area at risk. Critical aquifers may be incorrectly assessed due to incomplete or incorrect susceptibility mapping. Recharge and discharge areas are not identified.

COMBINED GIS AND ANALYTICAL MODELS

Automated Wellhead Area Analysis in Harris County, Texas (Rifai and others, 1993)

This wellhead protection program pilot project produces and demonstrates an interface between the widely used EPA semi-analytical wellhead protection area delineation models (Blandford and Huyakorn, 1991) and a GIS. The method allows calculation of contributing areas to public supply wells and overlaying potential contamination sources in a GIS. The principal use is to track and check potential contamination sources in wellhead contributing areas.

Contributing area modeling is done by selecting wells and running the wellhead protection area delineation models using pre-loaded data for each well. The output can then be overlaid with any GIS data set or sets to create a map showing the risk factors in the contributing area. Further analysis of these data is possible using the GIS.

The principle limitation of this method is the use of the simple, semi-analytical wellhead protection area model for flow modeling. The wellhead protection area delineation model results are subject to severe limitations that include two dimensional flow, a uniform groundwater flow field model that cannot simulate water table irregularities and an inability to simulate any complex boundary condition. The EPA semi-analytical models are only appropriate for simulating particle tracking to a pumping well and cannot be used to simulate regional groundwater flow.

The strong point is that the method can be used by a GIS analyst or a planner with some GIS training. Another important consideration is that the cost of doing several well specific analytical models is likely to be much less that a numerical modeling project.

CAD ANALYSIS USING FLOW MODELING AND DATA MAPS

The advent of commercial graphic data processors for groundwater flow models and particle-tracking models has facilitated the use of computer mapping with groundwater flow modeling. Many site investigations for groundwater contamination and wellhead protection and management have used this approach.

LIST OF LOCAL CONTACTS

Eric Bohard - GIS Analyst, Clark County Department of Assessment and GIS (206) 699-2391

Jerri Bohard - Growth Management Planner, Clark County Department of Community Development (206) 699-2375

Richard Cyr - Director, Clark Public Utilities Water System (206) 699-3260

Patrick Easley - Engineer, City of Vancouver (206) 699-8223

Terry Keyes - Water Quality Manager, Clark County Department of Community Development (206) 699-2375

Kevin Masterson - Hazardous Waste Reduction Coordinator, Southwest Washington Health District (206) 696-8428

Clifton McCarley - GIS Analyst, Clark County Department of Assessment and GIS (206) 699-2391

Aaron Odegard - Engineer, City of Vancouver (206) 699-8008

Earl Rowell - Water Quality Planner, Clark County Water Quality Division (206) 699-2375

Dan Snyder - Hydrologist, U.S. Geological Survey - Water Resources Division, Oregon District (503) 251-3287

Rod Swanson - Groundwater Geologist, Clark County Water Quality Division (206) 699-2375

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APPENDICES B - F

METHOD TO EVALUATE AQUIFER VULNERABILITY THROUGH CONJUNCTIVE USE OF A GROUNDWATER FLOW MODEL AND A GEOGRAPHIC INFORMATION SYSTEM

Clark County Water Quality Division
Department of Community Development

CLARK COUNTY
Water Quality Division

Completed under Washington Department of Ecology
Centennial Grant Water Fund Grant TAX 91016
in Cooperation with US Geological Survey-Water Resources Division,
the City of Vancouver and Clark Public Utilities

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Clark County, Washington

January 1994

APPENDIX B

GROWTH MANAGEMENT ACT CRITICAL RECHARGE AREA DESIGNATION FOR CLARK COUNTY, WASHINGTON

By Rodney D. Swanson

Clark County Water Quality Division
Department of Community Development

CLARK COUNTY Water Quality Division

Completed under Washington Department of Ecology
Centennial Clean Water Fund Grant TAX 91016
in Cooperation with the City of Vancouver and Clark Public Utilities

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Clark County, Washington

January 1994

MEMORANDUM

Date: March 1, 1994
To: Jim Seeley
From: Rod Swanson RS

Subject: Critical Recharge Areas Analysis

The attached report: Growth Management Act Critical Recharge Area Designation for Clark County, Washington describes drinking water aquifers and their recharge areas, an evaluation of areas that are most likely to have groundwater contamination, and areas where groundwater quality protection is most critical (Critical Groundwater Resource Areas) as described under WAC 365-190-080. The report was prepared under a Washington Department of Ecology Centennial Cleanwater Grant in cooperation with the US Geological Survey, the City of Vancouver and Clark Public Utilities.

The purpose of the grant project, Method to Evaluate Aquifer Vulnerability was to develop methods to map aquifer vulnerability to contamination using geographic information systems (GIS) and groundwater flow modeling. Critical recharge area evaluation is one application of the methodology. The attached report is intended to serve as a tool for local GMA planning and be an example of aquifer vulnerability evaluation using a GIS and groundwater flow modeling.

Most of the report is presentation of data collected during the last five years by the Groundwater Management Program, the aquifer vulnerability project and associated activities. It should be noted that the maps and analysis in the attached report are intended as a guide for regional planning purposes and are not necessarily appropriate for parcel by parcel planning. The proposed Critical Groundwater Resource Areas are one alternative to designate areas for special groundwater quality management. They are not a sole option. The proposed Critical Groundwater Resource Areas include the groundwater resources for much of the present and future Clark County population, as well as the majority of areas where groundwater is degraded or most vulnerable.

Even though the report maps only some parts of Clark County as being critical, the GMA requires protection of all potable water. In addition, state environmental law prohibits the degradation of groundwater.

An evaluation of groundwater availability is not included in the attached report. The report does however, include some general recommendations for groundwater availability assessment based on strategies in the Clark County Groundwater Management Plan.

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FIGURES

TABLES

DISCLAIMER

The maps presented in this report are derived from data compiled from many sources. Maps show data that may not be completely current. Some information may contain errors or not represent current conditions at a site. The maps in this report are intended to show regional conditions for planning purposes and are not intended for site specific use.

INTRODUCTION

Clean groundwater is critical to sustaining life and commerce in Clark County. Almost all of the water used for domestic consumption, business and industry is drawn from groundwater. While most of Clark County's groundwater is of good quality, there are areas where water quality is degraded or contaminated due to human activities. Unfortunately, groundwater contamination often occurs in areas where water demand and consumption is greatest.

Groundwater quality protection is critical because once contaminated, aquifers are almost impossible to restore. The high cost of groundwater clean-up and the potential health risks make prevention by controlling potential contamination sources the accepted practice for assuring groundwater quality.

Protecting water quality by preventing contamination requires that activities that can pollute groundwater be managed in areas where groundwater quality is a critical concern. Under the State Growth Management Act (GMA), these are defined as Critical Recharge Areas, which are "areas with a critical recharging effect on aquifers used for potable water," or "areas where an aquifer that is a source of drinking water is vulnerable to contamination that would influence the certifiable potability of the water."

The stated reason for identification of all critical areas under the GMA is to protect and preserve them from degradation or loss. This is to prevent inefficient and uneconomical resource use and to protect the quality of life and public safety. In addition to protecting the quality of groundwater, the GMA includes language that suggests that the availability of groundwater should be considered in growth management planning and management programs as a critical resource.

PURPOSE AND SCOPE

The purpose of this report is to document a method to delineate critical recharge areas and to produce maps of these areas in Clark County. The results of this investigation also provide an example of vulnerability mapping under Department of Ecology Grant TAX 91016 Method to Evaluate Aquifer Vulnerability.

The minimum guidelines to classify critical areas and resource areas (Chapter 365-190 Washington Administrative Code, or WAC) were reviewed to establish criteria and a procedure to delineate critical aquifer areas. This report identifies recharge areas for Clark County aquifers, areas vulnerable to groundwater contamination, critical aquifers and recharge areas to critical aquifers.

DESCRIPTION OF CRITICAL AQUIFER RECHARGE AREA DELINEATION

The classification and delineation of critical areas is intended to preclude land use activities that are incompatible with groundwater protection. Critical recharge areas should be viewed as groundwater resource areas requiring long-term conservation and protection. Classification and designation of critical areas are intended to encourage county and city governments to develop regulatory and non-regulatory measures to minimize risk to groundwater. In cases where the risk is unacceptably large or cannot be effectively reduced, some activities might be prohibited.

GMA guidelines suggest that each county make a groundwater vulnerability assessment as a step toward identifying and classifying critical recharge areas. Vulnerability assessments map areas where groundwater contamination is more likely to occur. Vulnerability mapping is done by evaluating the likelihood that contaminants are released to the ground and the relative ease with which contaminants could move to groundwater.

The GMA guidelines suggest two differing management strategies for relatively lower and higher vulnerability areas. In low vulnerability areas, the GMA goal is to maintain the potable quality of groundwater used as a drinking water source. In areas of high vulnerability, GMA guidelines suggest additional investigation to determine if groundwater contamination has occurred and more intensive management activities to prevent contamination. Management strategies for contaminated areas should consider the significance of the aquifer as a potable water source and identify measures to preclude further degradation and maintain potability. The GMA also suggests that alternative water sources be identified.

The Growth Management Act lists examples of critical areas. These include:

- Sole source aquifer recharge areas designated pursuant to the Federal Safe Drinking Water Act, where there is evidence that the aquifer is vulnerable to contamination that would create a hazard to public health.
- Areas established for special protection under a groundwater management program established under Chapter 173-100 WAC.
- Areas designated for wellhead protection.
- Areas meeting the critical recharge area guidelines of Chapter 365-190 WAC.

Critical Recharge Area Management Objectives Based on GMA Guidelines

The following objectives for Critical Recharge Area Designation were defined by reviewing state GMA guidelines. They are:

1. Identify all recharge areas to all groundwater used as drinking water. At a minimum, the potability of these groundwater sources should be maintained.

2. Categorize recharge areas by vulnerability to identify areas with the greatest potential for groundwater contamination.

3. Identify areas where drinking water sources should receive special management to prevent water quality degradation.

Critical Recharge Area Management Objectives not Specified by GMA Guidelines

The GMA does not specifically address prevention of groundwater depletion due to overuse or decrease in recharge due to urbanization. The GMA goals do include preserving resources that require long term conservation management. Identification of areas where water consumption may outstrip known resources is compatible with the GMA goal of discouraging development where resources are least available or inadequate.

The state issues groundwater right certificates for public supply, industrial, commercial, and agricultural consumption. Individual domestic wells are exempted. Water rights allocation and enforcement is based on the principle of priority through seniority, or first in time, first in right to use the water. Often, aquifer depletion problems are not identified and addressed until there is an excessive number of water users because groundwater flow systems respond slowly to increased water use.

Groundwater resource management for quantity or availability is not addressed in this report. Analysis by the Clark County Groundwater Management Program (Clark County Groundwater Advisory Committee, 1992) has examined strategies related to water availability issues. Clark Public Utilities is currently developing a management program for aquifers in the lower Salmon Creek basin.

Investigations by the Clark County Groundwater Management Program (McFarland and Morgan, in press) and the investigations by Clark Public Utilities (Dan Matlock personal communication) show that water level declines are occurring in much of the Vancouver urban area. The Vancouver area water level declines are linked to groundwater consumption by public water systems. Outside the Vancouver urban area, aquifer water levels appear to be fairly stable. However, the number of wells used to monitor water levels is small and there could be areas where localized groundwater declines are occurring.

Under the GMA, specific objectives for groundwater resource quantity assessment may include the following:

- Identify areas where groundwater levels are declining.
- Identify areas where groundwater levels may decline with increased water consumption.
- Evaluate water rights availability.
- Identify areas where decreases in recharge will have the greatest impact on groundwater.
- Evaluate the impact of artificial recharge to groundwater.
- Identify areas where groundwater availability is a potential problem.

METHODOLOGY

During the Groundwater Management Program, a large amount of information was collected describing Clark County groundwater conditions. Information gathering and analysis continues; this report is part of an ongoing effort to develop methods to assess groundwater vulnerability. A computerized geographic information system (GIS) database is used to store, analyze and compile the maps for this report.

The methodology used to define critical recharge areas involves three principal steps, each of which is described in a section of this report. The first section identifies recharge areas to aquifers used as drinking water sources. The second section is a vulnerability assessment to identify areas most likely to have groundwater contamination. The third section maps critical aquifer areas, including wellhead protection areas and defines a 50 year recharge area to these critical areas.

Each of the principal steps requires analysis of hydrogeologic and land use information. Identification of recharge areas includes determining the recharge area for each aquifer and the parts of the aquifer used as a source of drinking water. A vulnerability assessment requires a hydrogeologic characterization of the ease with which contaminants can move to groundwater, an estimation of contaminant loading potential and a method to combine the two in order to determine relative vulnerability. Mapping other sensitive groundwater areas such as wellhead protection areas includes compiling maps of these areas and defining parts of aquifers that are most critical to future water consumption. The Portland Basin groundwater flow model is used to map the recharge area to critical aquifer areas.

CONCLUSIONS

The results of this analysis show that:

1. The entire county is a recharge area and that groundwater beneath all populated areas is used as drinking water.

2. Much of the urban area of Clark County is moderately to highly vulnerable to groundwater contamination. Of special concern are areas with urban residential, industrial and commercial land uses, developed urban areas that do not have sanitary sewer, urban areas with stormwater disposal wells (drywells), areas near certain sites of groundwater contamination and areas where shallow aquifers underlie urban areas.

3. Suggested critical aquifer areas are drinking water supply protection areas for public supply wells (wellhead protection areas), critical aquifers that include the area within the urban growth boundary and 50 year recharge areas for critical aquifers and drinking water supply protection areas.

RECHARGE AREAS TO DRINKING WATER AQUIFERS

The GMA requires steps be taken to maintain the potability of all groundwater used for drinking water. The following section describes aquifer units, identifies aquifers used as drinking water sources, and characterizes aquifer recharge areas.

Previous investigations and analysis for this report show that nearly all populated areas of Clark County overlie groundwater resources (Mundorff, 1964; McFarland and Morgan, in press; and Swanson and others, 1993). Shallow aquifers are a drinking water source in most of the county. Shallow aquifers receive recharge directly from land surface as rainfall infiltration, drywell discharge, septic system discharge and infiltration from rivers and other surface water bodies. In most areas, deeper aquifers are recharged by groundwater moving downward from shallower aquifers.

AQUIFERS PROVIDING DRINKING WATER

Aquifers used as potable water sources were mapped by comparison of water well distribution and aquifer unit extent. Water wells are located throughout developed Clark County. Because most of the geologic units in the county can yield sufficient water for domestic use, the shallowest geologic unit is or can be used as an aquifer. In many areas the uppermost geologic unit is a drinking water source. However, the most important aquifer is often not the uppermost water-bearing geologic unit.

Clark County Aquifers

A map showing the water table aquifer and geologic unit was compiled from several hydrogeologic and geologic reports (Figure 1). Principal aquifer units are described by the US Geological Survey (Swanson and others, 1993) for the Groundwater Management Program. An older US Geological Survey report describing Clark County geology and water resources (Mundorff, 1964) is the basis for recent US Geological Survey investigations. It also provides good aquifer descriptions and information about historical water well and water use. The water table aquifer mapped for DRASTIC groundwater susceptibility analysis is probably the best existing map showing the shallowest aquifer used for drinking water in Clark County (Swanson, December 1991). It is derived from analysis of the shallowest groundwater depth using water well records. Figure 1 shows the water table aquifer mapped for the DRASTIC investigation. Geologic units are grouped and colored to match aquifers mapped by the US Geological Survey (Swanson and others, 1993).

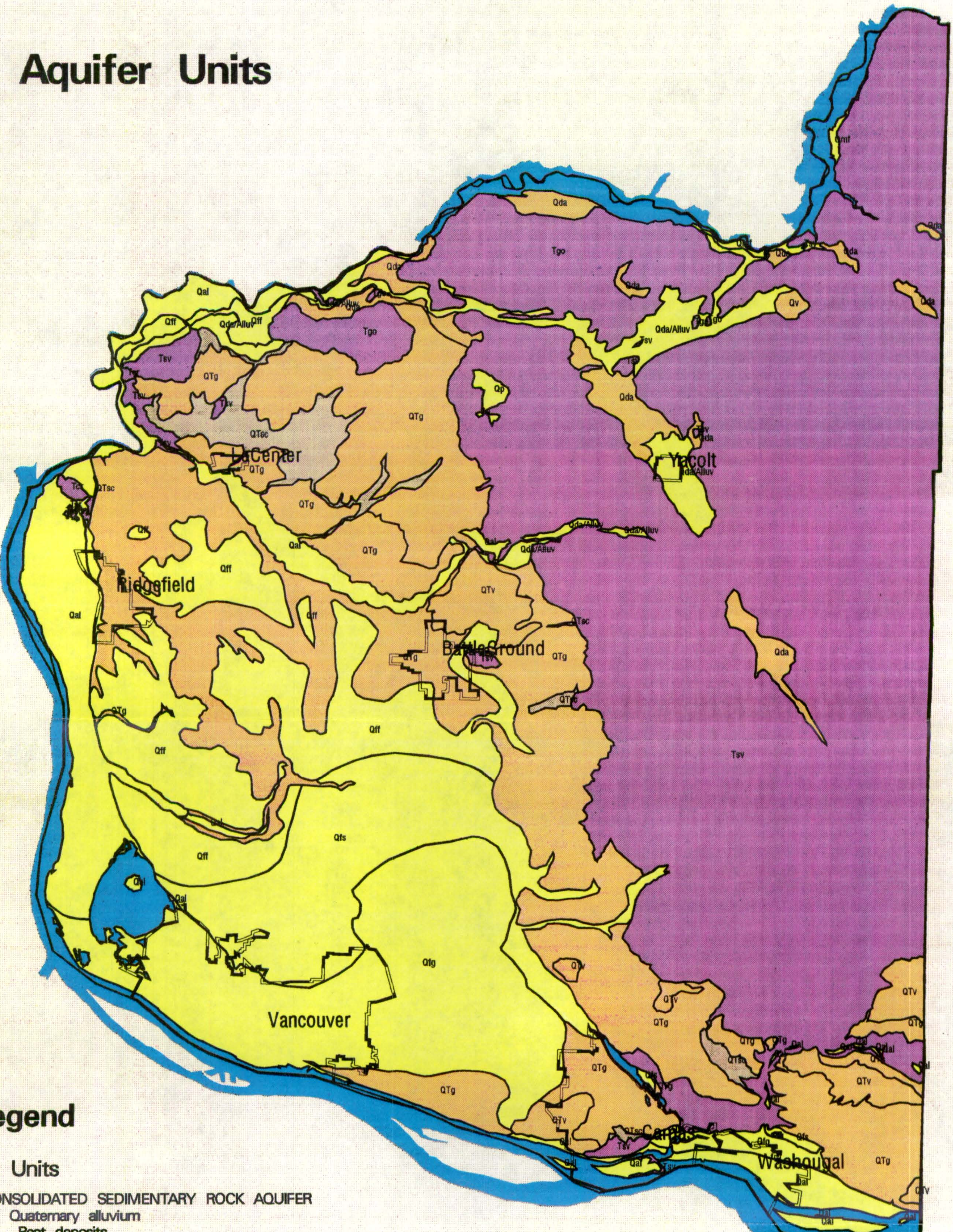
The principal aquifers are the Troutdale gravel aquifer, the unconsolidated sedimentary rocks aquifer and the older rocks aquifer. The older rocks aquifer and unconsolidated sedimentary rocks aquifer comprise units with several geologic formations. Figure 2 (from Swanson and others, 1993) lists the various geologic and hydrogeologic units that have been mapped by investigations in Clark County and the Portland area. Mundorff (1964) and McFarland and Morgan (in press) identify the upper member of the Troutdale Formation gravel and Quaternary sedimentary rocks as the principle Clark County aquifers. A deeper, less used sedimentary unit is also a significant water source in some areas where the Troutdale gravel aquifer and unconsolidated sedimentary rocks aquifer are not present. These deeper rocks are also a source of water to several public supply wells owned by Clark Public Utilities and the City of Vancouver. In the Cascade foothills, older volcanic rocks, thick soils over the volcanic rocks and glacial deposits are the principal aquifers.

Distribution of Water Wells

The significance of an aquifer as a drinking water resource increases as the number of people using the aquifer increases. This section attempts to document the areas and aquifers that are used for drinking water. Water well inventories are used to map the distribution of groundwater users. The generally good availability of groundwater in Clark County is reflected by relatively shallow well depths. Of 7,111 wells in the Groundwater Management Program data base 31 percent are under 100 feet deep, 78 percent are under 200 feet deep, and 91 percent are under 300 feet deep.

No complete inventory of wells exists for Clark County. Several partial inventories catalog over one half of the estimated 17,000 wells used for domestic consumption. The most complete compilation of well records is the Washington Department of Ecology driller report files which document well construction. These records, however, include few wells drilled before the mid 1970s when universal well construction reporting became required.

Aquifer Units



Legend

Aquifer Units

UNCONSOLIDATED SEDIMENTARY ROCK AQUIFER
- Qal Quaternary alluvium
- Qp Peat deposits
- Qmf Mudflow deposits
- Qda Glacial drift and alluvium (Qda/Alluv)
- Qff Fine grained catastrophic flood deposits
- Qfc Coarse grained catastrophic flood deposits

TROUTDALE GRAVEL AQUIFER
- Qda Glacial drift
- QTg Quaternary and Pliocene gravels
- QTv Quaternary and Pliocene lavas
- Qv Quaternary volcanic rocks
- QTtg Troutdale Formation gravels

UNDIFFERENTIATED FINE GRAINED AQUIFER
- QTsc Lower Troutdale Formation

OLDER ROCKS AQUIFER
- Tcr Columbia River basalts
- Tsv Skamania volcanics with glacial drift
- Tgo Goble volcanics with glacial drift

N

1 0 5 Miles

SOURCES:
This map includes aquifer units mapped by the USGS (Swanson, McFarland, Gouthier, and Wilkinson 1993) and geologic units modified from Phillips (1987) by the Inter-governmental Resource Center. Clark County GIS performed the data compilation and associated cartographic services. All additional data are standard elements of the CC GIS database.

CLARK COUNTY Water Quality Division

It is the policy of the Clark County GIS to provide the highest quality mapping product available. However, the diversity of scales and sources available precludes the issuance of warranty and prevents any guarantee as to the data accuracy.

CLARK COUNTY WASHINGTON

Department of Assessment and GIS

Figure 1

Figure 2.

SYSTEM	SERIES	Trimble 1963 (Portland)	Mundorff 1964 (Clark County)	Hogenson and Foxworthy, 1965 (East Portland)	Willis 1977,1978 (Portland Well Field)	Hoffstetter 1984 (Portland Well Field)	Noble and Ellis 1960 (Vancouver)	Carr and Associates 1985 (South Clark County)	Hartford and McFarland, 1989 (Portland Well Field)	THIS REPORT (Portland Basin)	
		REFERENCE (AREA)									
QUATERNARY	Holocene	Alluvium and younger terrace deposits	Alluvium	Alluvium and younger terrace deposits	Un-named clayey silt and sand ? Columbia River Sands aquifer	Alluvium and flood plain deposits Columbia River Sands aquifer	Orchards aquifer	3A and 1A	Overbank deposits Columbia River Sand aquifer	Upper sedimentary subsystem	Unconsolidated sedimentary aquifer
QUATERNARY	Pleistocene	Lacustrine deposits Estacada Formation Gresham Formation Loess Springwater Formation Walters Hill Formation	Pleistocene alluvial deposits Glacial drift	Fluviolacustrine deposits Piedmont deposits	? Blue Lake aquifer ? Troutdale gravel aquifer	Blue Lake aquifer Parkrose gravel aquifer	Troutdale aquifer	1B and 2B	Blue Lake gravel aquifer Unconsolidated gravel/ Troutdale gravel aquifer	Upper sedimentary subsystem	Troutdale gravel aquifer
QUATERNARY / TERTIARY	Pleistocene / Pliocene	Boring Lava	Boring Lava	Boring Lava				4B			
TERTIARY	Pliocene	Troutdale Formation Sandy River Mudstone	Troutdale Formation (upper member) Troutdale Formation (lower member)	Troutdale Formation Sandy River Mudstone	Un-named confining layer Troutdale sandstone aquifer Un-named confining layer Sandy River Mudstone aquifer ? ?	Parkrose aquitard Troutdale sandstone aquifer Rose City aquitard Rose City aquifer ? ?	?	1B and 2B ? 3B ? 1C	Confining unit 1 Troutdale sandstone aquifer Confining unit 2 Sand and gravel aquifer	Lower sedimentary subsystem Fine-grained sedimentary rocks	Confining unit 1 Troutdale sandstone aquifer Confining unit 2 Sand and gravel aquifer ?
TERTIARY	Miocene	Rhododendron Formation Columbia River Basalt Group Scappoose Formation	Older rocks	Older rocks				4C		Older rocks	
TERTIARY	Oligocene	Skamania Volcanic Series									
TERTIARY	Eocene										

Comparison of hydrogeologic unit terminology for the Portland Basin.

Local well data exists in three separate digital data bases. The largest set was compiled for the Groundwater Management Program by the US Geological Survey and includes about 7,100 wells. The Groundwater Management Program water well data base includes all Department of Ecology well records filed prior to 1989 (McCarthy and Anderson, 1990). Clark Public Utilities has field inventoried about 4,300 wells as part of a water quality sampling program. About 3,500 of the Clark Public Utilities wells were not in state records when the Groundwater Management Program well data base was compiled. The Southwest Washington Health District catalogs new wells under the GMA.

Another source of well data is the US Geological Survey water supply paper completed by Mundorff (1964). Mundorff compiled a table with hundreds of wells located by US Geological Survey field personnel in the late 1940s and early 1950s. This table is particularly valuable because it contains information describing old shallow hand dug wells that predate the use of deeper drilled wells. Mundorff's shallow well information was used to aid mapping of the shallowest aquifers used for drinking water.

Clark Public Utilities and Groundwater Management Program well records are combined to create a map showing the distributions of water wells, public supply wells and aquifer units (Figure 3). This map shows the widespread use of wells as the water source in all developed parts of Clark County. There are many private domestic water wells serving people within the area served by public supply systems. The highest well densities tend to correspond to suburban residential areas outside of, or alongside the fringes of expanding water supply systems.

Public Supply Systems

Groundwater pumping data for public supply systems collected by the US Geological Survey (Collins and Broad, 1994) shows that the major water consumers draw water from the uppermost aquifers, which are the Troutdale gravel aquifer and unconsolidated sedimentary rocks aquifer. Major public supply system wells and the aquifer unit each well taps are included on Figure 3.

GROUNDWATER RECHARGE AREAS

Aquifer recharge area mapping requires quantifying recharge rates and hydrogeologic analysis of groundwater flow directions. Estimated recharge rates and groundwater flow model simulation show that almost all of the county is a recharge area for aquifers supplying drinking water.

Estimated Recharge Rates

Recharge usually comes from rainfall or snow melt infiltrating through soil. In some cases, significant amounts of recharge may derive from streams or rivers losing water to groundwater.

Rainfall infiltration to groundwater is very difficult to measure and estimate due to problems of sampling in soil and rock media, the large number of hydrologic factors that must be considered, the length of time required to collect accurate data, and the hydrogeologic and land use variability of most areas. Typically, recharge rates are estimated based on simple relationships between factors such as rainfall, temperature, vegetal cover, and soil characteristics. The most sophisticated recharge rate estimates for Clark County were made by the US Geological Survey (Snyder and others, 1994a) for the characterization of the Portland Basin groundwater flow system as a part of the Clark County Groundwater Management Program.

To estimate rainfall infiltration recharge, the US Geological Survey used regression analysis of detailed recharge modeling for three large sub-basins. This produced a general equation that could be used to estimate recharge at all points in the Portland Basin. The general equation resulting from sub-basin analysis has terms that include rainfall, the percent of impervious area due to pavement and buildings, and elevation. Recharge estimates were made for the area of the Portland Basin groundwater flow model using the general equation.

Human activities can influence recharge rates. When land is covered with pavement and buildings; rainfall from these surfaces is routed to streams, reducing groundwater recharge. In many areas of Clark County, however, stormwater disposal wells, also known as drywells, actually increase recharge rates by routing stormwater directly into the ground. Septic systems can contribute a significant fraction of the total recharge in areas having many small lots with septic systems.

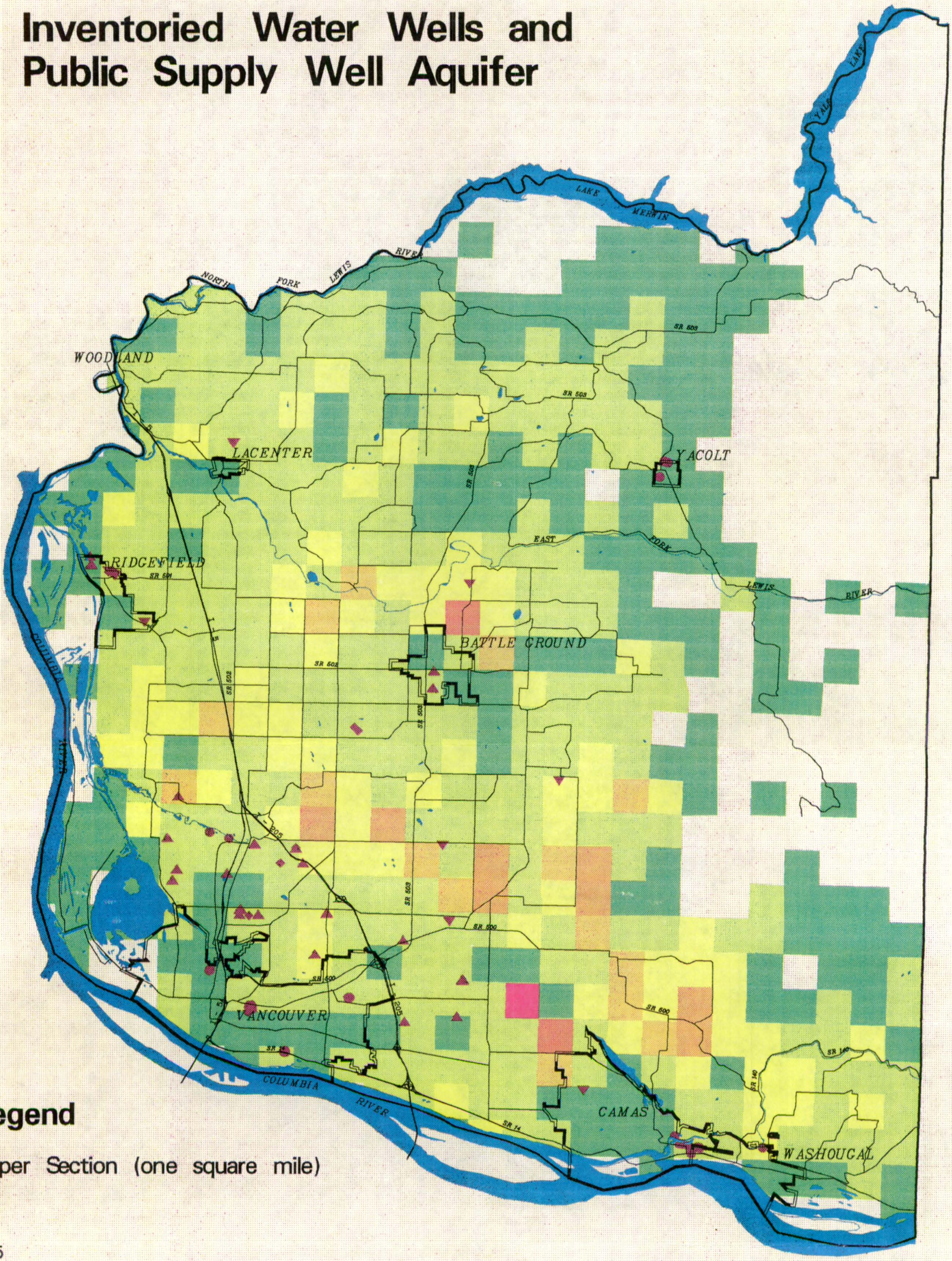
Recharge from drywells and septic systems was large enough in many areas to be a significant part of the total recharge. It is also important to map recharge from septic systems and drywells for water quality management purposes because it can contain contaminants.

Total recharge was estimated by adding together rainfall infiltration, drywell recharge and septic system recharge. The US Geological Survey analysis shows that almost all of Clark County is receiving relatively large amounts of recharge. The average total recharge for the Portland Basin is 22 inches per year. Analysis of Salmon Creek basin gave an average recharge rate of 27 inches per year. Figure 4 shows total recharge from rainfall infiltration, drywells and septic systems.

Aquifer Recharge Areas

In some areas of the world, layers of impermeable rock overlie aquifers separating them from land surface. In such areas, aquifer recharge may occur where the aquifer is exposed at land surface, many miles from the point at which water is pumped from the aquifer. In Clark County, aquifers are often exposed at land surface or are overlain by relatively thin layers of slightly to highly permeable sediments. Because of these geologic conditions, aquifers are directly recharged by infiltration from land surface or downward flow from overlying aquifers.

Inventoried Water Wells and Public Supply Well Aquifer



Legend

Wells per Section (one square mile)

- 0
- 1-10
- 11-35
- 36-60
- 61-85
- 86-110
- 111-135
- 136-160

Major Public Well Aquifer Unit

- Unconsolidated sedimentary rock aquifer
- Troutdale gravel aquifer
- Older aquifer units
- Unrecorded

SOURCES:
This map was constructed using a well location map created by Clark County GIS from water well data provided by the USGS and Clark Public Utilities (Pacific Groundwater group, March 1991). All additional data are standard elements of the Clark County GIS database.

It is the policy of the Clark County GIS to provide the highest quality mapping product available. However, the diversity of scales and sources available precludes the issuance of warranty and prevents any guarantee as to the data accuracy.

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Figure 3

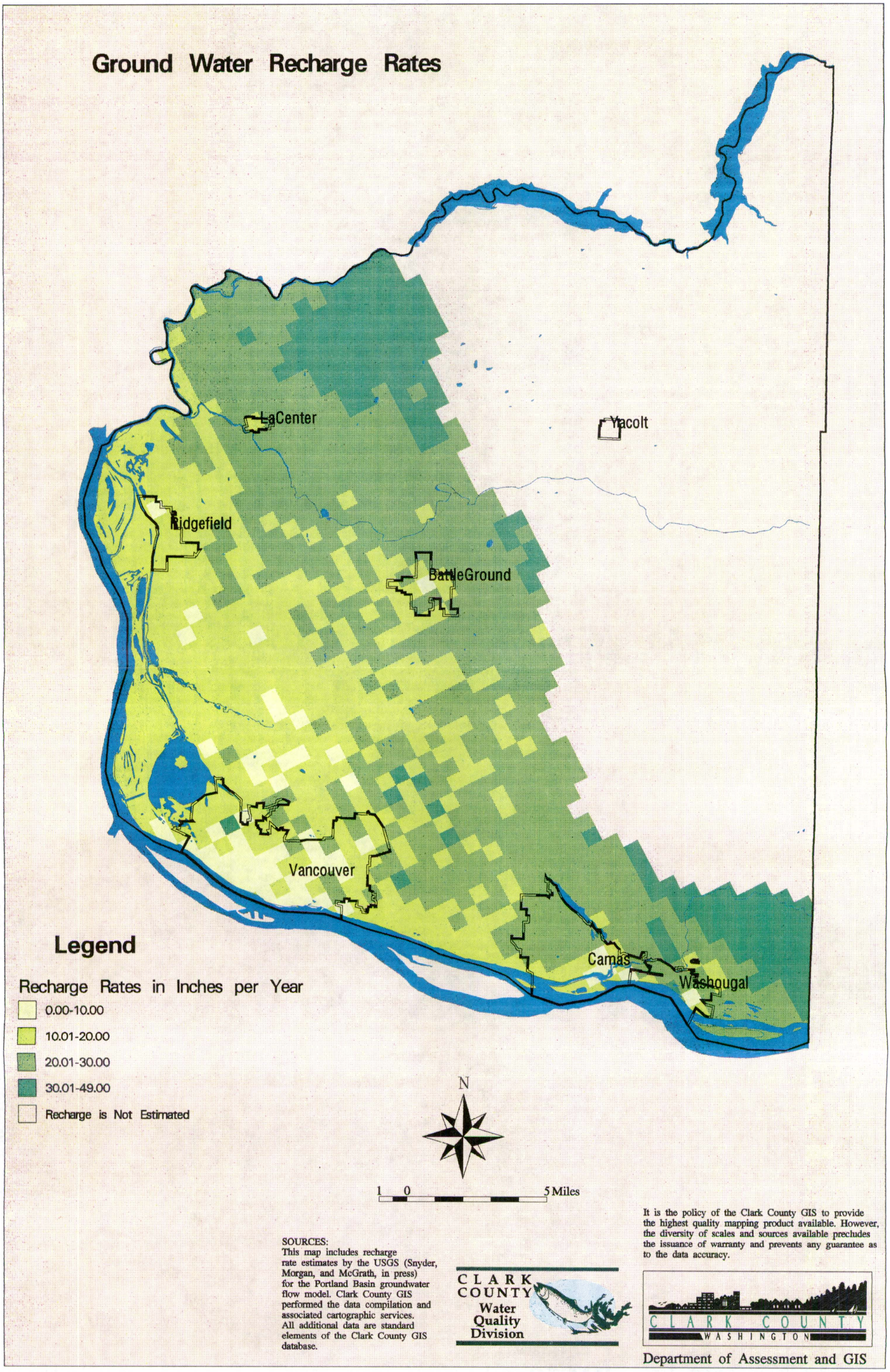
Ground Water Recharge Rates
LaCenter
Yacolt
Ridgefield
BattleGround
Vancouver
Camas
Washougal
Legend
Recharge Rates in Inches per Year
0.00-10.00
10.01-20.00
20.01-30.00
30.01-49.00
Recharge is Not Estimated
N
1 0 5 Miles
SOURCES:
This map includes recharge rate estimates by the USGS (Snyder, Morgan, and McGrath, in press) for the Portland Basin groundwater flow model. Clark County GIS performed the data compilation and associated cartographic services. All additional data are standard elements of the Clark County GIS database.
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Figure 4

The risk that regional aquifers will be degraded by contaminants released at land surface is greatest in areas where groundwater is moving downward from land surface to the water table aquifer and deeper aquifers. Groundwater moves in three dimensions through geologic materials. Generally, groundwater moves downward from the point where it enters the flow system, then laterally toward a regional or local discharge point such as a stream, river or lake. In groundwater discharge areas, groundwater moves upward to rivers, streams or lakes. Figure 5 is a general diagram of how recharge from rainfall infiltrates and flows through the groundwater flow system.

Recharge areas for each aquifer are mapped using the Portland Basin groundwater flow model (Morgan and McFarland, in press) and a particle tracking model (Snyder and others, 1994b). Simulated recharge points for major aquifers are shown in Figures 6, 7, and 8. Modeling shows that aquifers are recharged throughout much of the area they underlie. Recharge points do not consider the length of time for travel from the recharge point to some predetermined part of the aquifer. Recharge point density does not directly correspond to recharge volume.

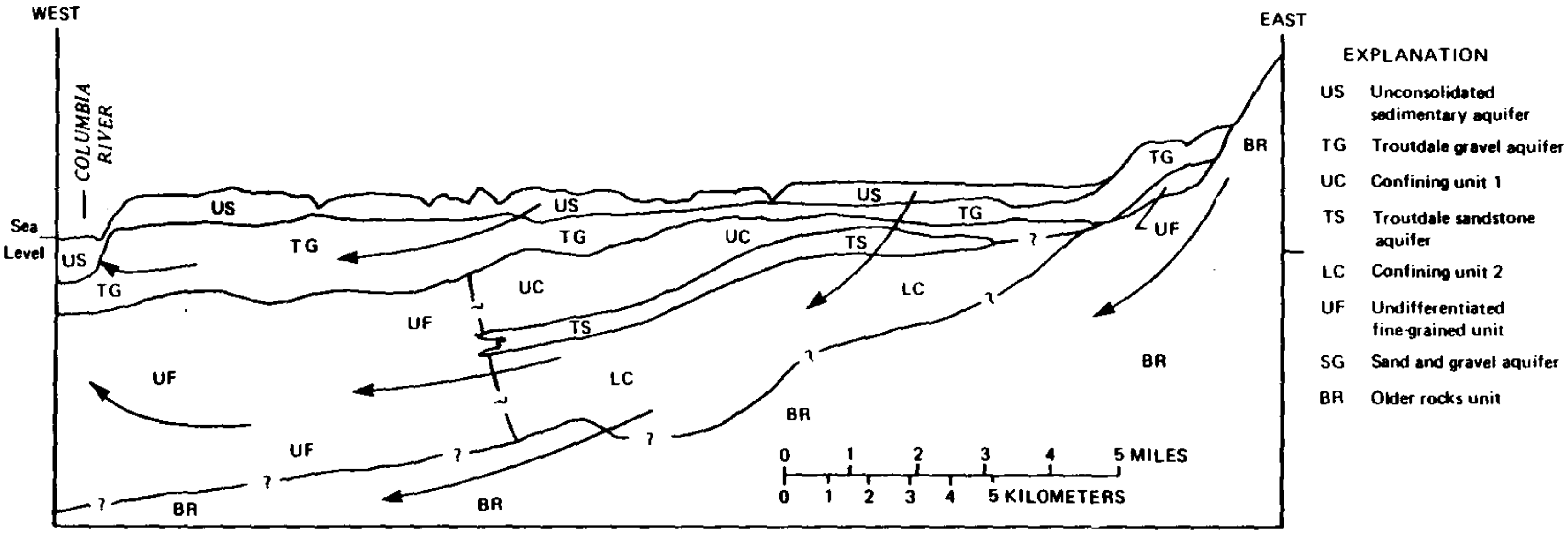
Regional recharge areas occur on topographic highs. Local recharge areas occur throughout much of the area. Regional discharge areas, where groundwater moves upward toward major rivers, occur in the lowlands along the Columbia River and along major tributaries. Shallow aquifers in discharge area are also recharged locally.

VULNERABILITY ASSESSMENT

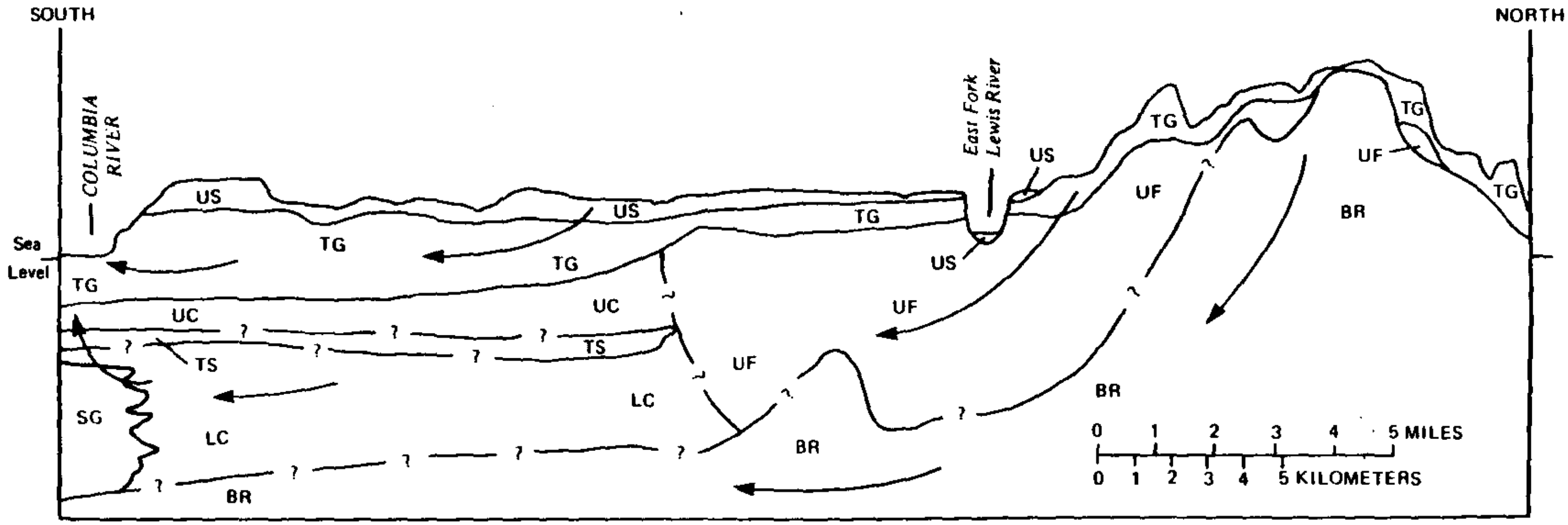
Highly vulnerable areas are most likely to have groundwater contamination now or in the near future. Highly vulnerable areas should be subject to further investigation to determine the extent of existing contamination. Activities in highly vulnerable areas should be managed to minimize the risk of groundwater contamination.

Vulnerability mapping is not an exact science or assessment method, but a characterization of risk factors. The process involves combining the natural sensitivity of groundwater to contamination, called *susceptibility*, together with the likelihood that contaminants will be released to the ground, referred to as *contaminant loading potential.*

This vulnerability assessment includes four phases of analysis. A summary of existing water quality describes the areas where water quality degradation is known to currently exist. Hydrogeologic susceptibility mapping characterizes the relative ease with which contaminants can move from land surface into groundwater. Contaminant loading potential mapping describes the likelihood that contaminants are released to groundwater by using general criteria such as land use, and septic system density. Finally, vulnerability maps are created by computerized addition of selected contamination loading factors and susceptibility.



Vertical exaggeration X 17



Vertical exaggeration X 20

Figure 5. Generalized geohydrologic sections through Clark County showing direction of ground-water flow. Adapted from W.D. McFarland, U.S. Geological Survey, written commun., 1988; and R.D. Swanson and others, U.S. Geological Survey, written commun., 1989.

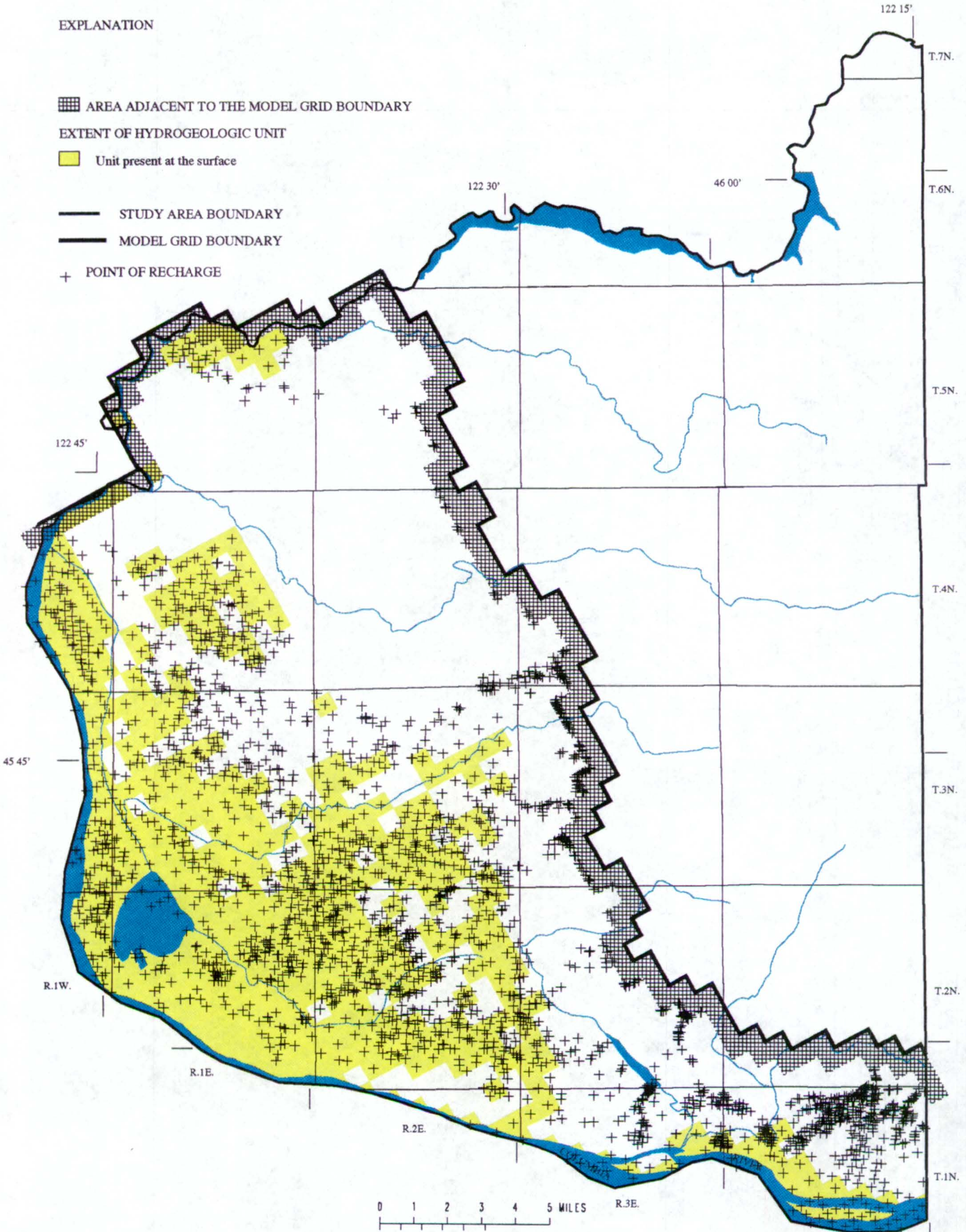


Figure 6. --Distribution of recharge points as derived from particle tracking for the unconsolidated sedimentary aquifer.

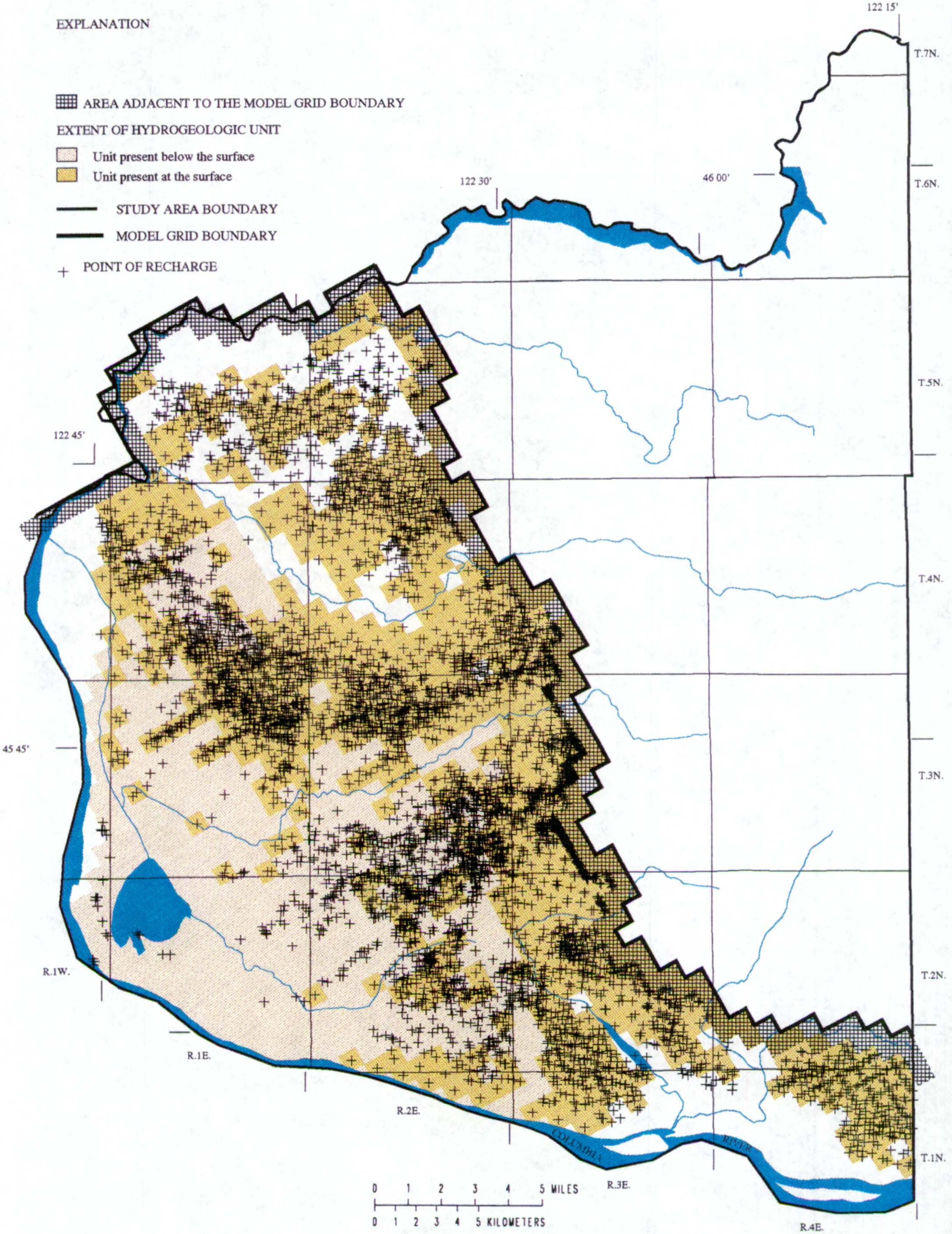


Figure 7. Modeled Recharge Points to the Troutdale Gravel Aquifer

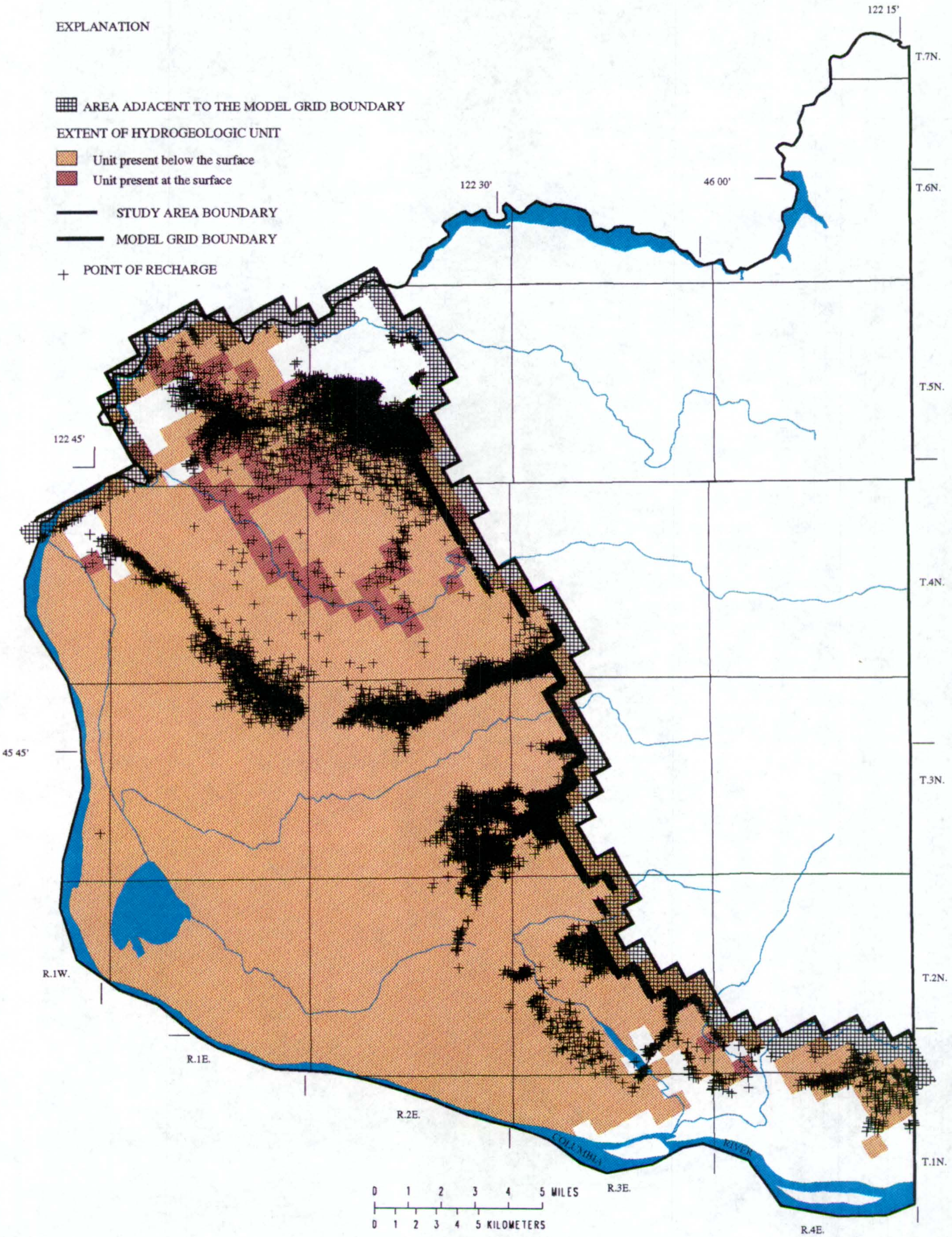


Figure 8. Modeled Recharge Points to the Lower Troutdale Formation

WATER QUALITY ASSESSMENT

An evaluation of land use, water quality and hydrogeologic conditions should be completed locally to directly link land use patterns and water contamination. Water quality data can be used to characterize the influence of human activities on groundwater quality. Nitrate is the most commonly analyzed contaminant in Clark County and most other areas. Other, more costly analyses are rare and are usually performed on public supply systems or as a part of special investigations of contaminated sites.

Despite intensive efforts to characterize Clark County groundwater, limited detailed water quality data for the broad range of contaminants exists for most areas of Clark County. One study performed for the Clark County Groundwater Management Program, Turney (1990) systematically collected water quality data throughout Clark County. Turney sampled a total of 76 wells for major ions, silica, nitrate, phosphorus, aluminum, iron, manganese, radon and bacteria. A 20 well subset was analyzed for concentrations of selected trace elements and organic compounds, including most of those on the US EPA priority pollutant list, Safe Drinking Water Act, and National Primary Drinking Water Standards. Turney identified the aquifer sampled by each well.

In addition to the Turney report, water quality data has been collected and compiled by Clark Public Utilities and the Southwest Washington Health District. Clark Public Utilities tested 4,210 wells for basic water quality through an offer of free water quality sampling. Well samples were tested for nitrate, iron, manganese, coliform bacteria, pH, and specific conductivity (Pacific Groundwater Group, March 1991). The Southwest Washington Health District compiles water quality data for domestic wells and public supply system wells with fewer than 15 hookups. All other public supply systems are monitored by the Washington Department of Health. State records show that about 72 public supply wells or well fields have been monitored for a wide range of contaminants since early 1988.

Nitrate

The nitrate ion is a common environmental form of nitrogen that can derive from nitrogen released through fertilizer application, animal waste disposal or domestic on-site waste disposal systems, such as septic systems (Canter and Others, 1987). The EPA established a drinking water maximum contaminant level for nitrate of 10 parts per million as nitrogen, principally to protect against infantile methemoglobinemia, otherwise known as blue baby syndrome. Nitrate analysis is relatively inexpensive and widely used to test basic water quality.

Nitrate concentrations higher than naturally occurring concentrations (usually less than 0.5 parts per million) are used as an indicator of groundwater degradation by human activities. While there are no definite links between nitrate contamination and less commonly analyzed contaminants such as pesticides and volatile organic compounds, the presence of elevated nitrate concentrations should be considered an indication that other urban and agricultural contaminants may be present.

Nitrate tends to be very stable in groundwater. Denitrification, the process that converts nitrate into other nitrogen compounds occurs mainly in shallow soil layers. Because many activities can contribute nitrate to groundwater, some level of nitrate contamination is common.

Figure 9 shows the distribution of nitrate concentrations in water wells, based upon data from a survey conducted by Clark Public Utilities (Pacific Groundwater Group, March 1991). Variation in the mapped nitrate concentration is due to several factors. Probably the most important are the rate of nitrate or nitrate-forming constituents release to soil and the soil conditions that promote the nitrate formation and movement to groundwater. Well construction can also be a factor in nitrate concentration. Wells that are not properly "sealed" to land surface permit runoff and septic system discharges into the well. Preliminary analysis of Clark County nitrate data (Swanson, September 1993a) shows that wells in areas with more people per acre have higher median nitrate concentrations. Areas with geology that promote nitrate formation also have higher groundwater nitrate concentrations. In many cases, contaminant loading and geological factors promoting nitrate formation overlap.

Volatile Organic Compounds

Solvents and cleaners used by industry, businesses and households contain volatile organic compounds (VOCs). Many are carcinogens with EPA minimum contaminant levels that range from under 1.0 parts per billion to about 10 parts per million. One part per billion is roughly equivalent to one gallon of a VOC equally distributed in an aquifer 50 feet thick and about one third of a square mile in area.

Many VOCs are both very stable and mobile in groundwater. They can move rapidly through aquifers resulting in low level contamination in large areas. VOC contamination by concentrations below state and federal maximum contamination levels for drinking water is commonly found in shallow aquifers underlying industrial and urban areas.

In Clark County, shallow aquifers under urban areas commonly have at least trace amounts of VOC contamination. Figure 9 shows the distribution of VOC detections based on Washington Department of Health data for public supply wells and US Geological Survey water quality monitoring (Turney, 1990). The map does not include all sites where VOCs may have been detected but gives an approximate mapping of the areas where VOCs have been detected in groundwater. In some cases, VOCs have moved from the shallowest aquifer into the underlying Troutdale Formation gravel. This has occurred in the Vancouver area near Water Station 4 and the Boomsnub/Airco site east of the Hazel Dell area.

Known Sites of Contamination

There are numerous sites in Clark County with groundwater or soil contamination due to improper materials handling, spills or dumping. Where identified, these sites are inventoried

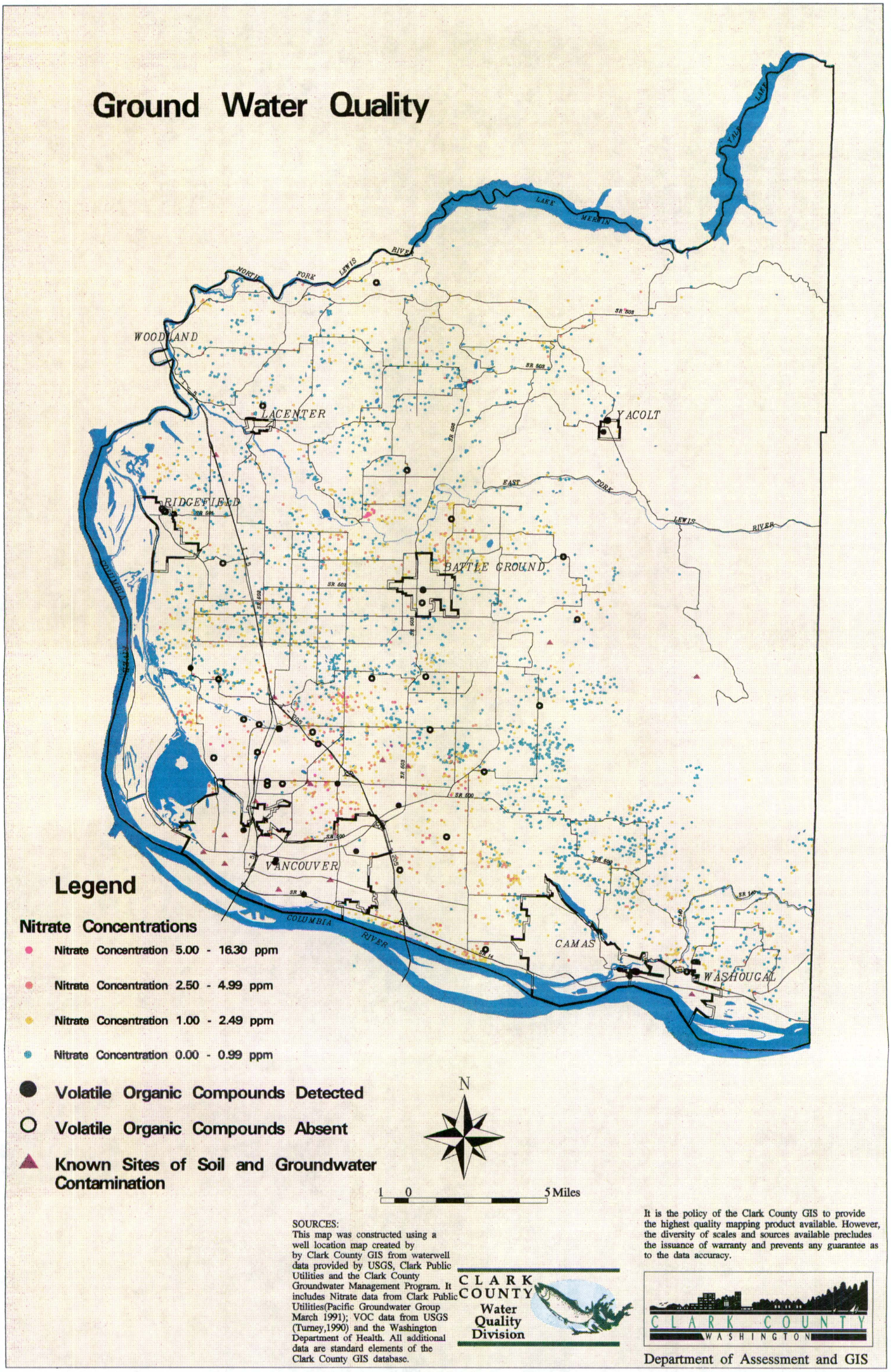

Ground Water Quality
NORTH FORK LEWIS RIVER
LAKE MERWIN
YALE LAKE
WOODLAND
LACENTER
YACOLT
RIDGEFIELD
BATTLE GROUND
EAST FORK LEWIS RIVER
VANCOUVER
CAMAS
WASHOUGAL
COLUMBIA RIVER
SR 503
SR 500
SR 14
Legend
Nitrate Concentrations
Nitrate Concentration 5.00 - 16.30 ppm
Nitrate Concentration 2.50 - 4.99 ppm
Nitrate Concentration 1.00 - 2.49 ppm
Nitrate Concentration 0.00 - 0.99 ppm
Volatile Organic Compounds Detected
Volatile Organic Compounds Absent
Known Sites of Soil and Groundwater Contamination
N
1 0 5 Miles
SOURCES:
This map was constructed using a well location map created by by Clark County GIS from waterwell data provided by USGS, Clark Public Utilities and the Clark County Groundwater Management Program. It includes Nitrate data from Clark Public Utilities(Pacific Groundwater Group March 1991); VOC data from USGS (Turney,1990) and the Washington Department of Health. All additional data are standard elements of the Clark County GIS database.
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Figure 9

by the Washington Department of Ecology, EPA and local agencies. Figure 9 includes sites with known groundwater or soil contamination.

HYDROGEOLOGIC SUSCEPTIBILITY

Groundwater susceptibility describes the relative ease with which a contaminant can move from land surface into groundwater. Susceptibility is characterized by examining hydrogeologic conditions or factors that can influence the rate at which recharge carrying contaminants can reach groundwater and spread through an aquifer. The most commonly used methods of determining susceptibility are based on the DRASTIC method (Aller and others, 1987) or earlier methods that the DRASTIC method is modeled after.

Susceptibility and some measure of contaminant loading are combined to produce a vulnerability assessment map. An area with high susceptibility is unlikely to suffer groundwater contamination if there is no source of contaminants. Conversely, an area with relatively low susceptibility could have extensive groundwater contamination due to a long history of polluting land uses. In other words, even a low susceptibility area is likely to become contaminated if contaminant loading exists and sufficient time has passed to allow contaminants to move to groundwater.

Three methods to assess susceptibility are described and used in this report. They are DRASTIC mapping, geochemical groundwater age dating, and groundwater age simulation using a groundwater flow model. Each provides a different perspective on the susceptibility of Clark County aquifers to contamination.

DRASTIC Mapping

A groundwater susceptibility map for Clark County was completed for the Clark County Groundwater Management Program (Swanson, December, 1991) using the EPA DRASTIC method (Aller and others, 1987). DRASTIC is a standardized method to assess relative groundwater susceptibility within any region of the United States.

DRASTIC is an acronym representing the seven hydrogeologic factors combined to create the DRASTIC aquifer susceptibility map. These are:

D = Depth to Water
R = Net **R**echarge
A = **A**quifer Media
S = **S**oil Media
T = **T**opography (slope of land surface)
I = **I**mpact of Vadose Zone Media (unsaturated media)
C = Hydraulic **C**onductivity of the Aquifer

Assumptions, Limitations, and Applications of DRASTIC Mapping

A DRASTIC map provides the user with a simple means to characterize relative groundwater susceptibility to pollution for areas of 100 acres or greater. The degree of susceptibility depends upon a combination of hydrogeologic properties such as depth to water, geology, soil and recharge rates. The relative DRASTIC susceptibility index can be used to help identify areas where groundwater protection is critical, allowing resources to be directed toward the most significant potential problem areas.

At best, susceptibility maps can identify areas where there is a significantly higher or lower ease of contaminant bearing recharge movement to groundwater. Subtle differences in susceptibility are not mappable using methods like DRASTIC. Detailed site specific or contaminant specific susceptibility assessment would require detailed analysis of soil and rock characteristics, recharge characteristics, and physical and chemical characteristics of the modeled contaminant. DRASTIC by itself, cannot determine the suitability of a specific site for a particular use such as solid waste disposal.

DRASTIC mapping only allows evaluation of one aquifer at each point on a single map. In Clark County, this is the water table aquifer and is based on water well data. DRASTIC does not consider the direction or rate of groundwater movement. While recharge rates and topography are incorporated, the direction of groundwater movement is not considered. Areas where groundwater discharges to rivers, lakes and wetlands are not specifically identified. DRASTIC assumes that contaminants are discharged to land surface and are flushed into groundwater by rainfall or other water, such as irrigation, applied to land surface. Another important assumption is that the contaminant has the mobility of water and is carried with water.

The data used to create the Clark County DRASTIC map are generally as accurate as the data used to create the groundwater flow model. Some generalization was done to simplify mapping of complex features such as the variability of hydraulic conductivity within aquifers. A complete description of the process to make the Clark County DRASTIC map is in Swanson (December 1991).

Method

The goal of the DRASTIC methodology is to classify areas by hydrogeologic setting and relative groundwater susceptibility resulting from characteristics of these settings. The DRASTIC method has three major parts: the designation of hydrogeologic settings describing general hydrogeologic characteristics for geographic areas, the assignment of susceptibility ratings to seven hydrogeologic factors based on a predetermined ranking system, and the calculation of a DRASTIC index for each map unit. Calculation of the index number requires multiplication of each DRASTIC factor rating by a specified weighing factor. Weighing values assigned to the individual factor by Aller and others (1987) reflect the relative importance of each factor. Numerical ranges for factor ratings are specified in the DRASTIC manual.

The DRASTIC map presented here (Figure 10) is a simplified version of the original map (Swanson, December 1991). This map includes only high, medium and low DRASTIC index ranges:

Highest Susceptibility = Index of greater than 180
Medium Susceptibilty = Index of 140 to 179
Lowest Susceptibilty = Index of 100 to 139

Geochemical Groundwater Age Dating

Groundwater age dating using geochemical analysis is an unusual way of estimating the susceptibility of an aquifer. Aquifers with relatively young age dates are receiving recharge that has moved from land surface to the aquifer in less than 50 years. Younger aged water suggests that an aquifer is relatively more susceptible to contamination. Age dating was done by the US Geological Survey to evaluate the accuracy of flow rates calculated by the Portland Basin groundwater flow model.

In Clark County, water samples from 46 wells were age dated by the US Geological Survey using a method analyzing for chlorofluorocarbon (CFC) concentrations (Henkle and Snyder, in press). These gases are common to the atmosphere and have been increasing at a known rate since they were first introduced about 60 years ago. Because CFCs are very stable in groundwater, the amount of CFCs in groundwater is assumed to match the amount of CFCs in the atmosphere when that rainwater entered the soil.

The oldest age that can be modeled by CFC age dating is 1944. This is due to inability of analytical techniques to detect increasingly smaller CFC concentrations prior to this date. An "old" CFC age is used to describe water older than 1944. The term "modern" is used to describe water dated at 1944 or younger. The term "contaminated" describes young water with CFC levels that are greater than present atmospheric concentrations. Possible sources of contaminants are refrigerants from industrial activity or discarded cooling equipment.

While data is inadequate to make groundwater age maps for Clark County aquifers, some general statements can be made from CFC age dating. The regional gravel aquifer, which is the Troutdale gravel aquifer, has chiefly modern water. The deeper lower Troutdale Formation aquifers have older water in over half of the sampled wells. The shallowest aquifer, unconsolidated sedimentary aquifer has equal numbers of wells with modern and older water. A possible explanation for older water in the shallowest aquifer is that some of the sampled wells are in areas of regional discharge where older water is moving upward toward rivers. Table 1 shows chlorofluorocarbon age dates for Portland Basin aquifers.

Table 1. Chlorofluorocarbon Groundwater Age Dates for Portland Basin Aquifers.

Aquifer	Wells with modern or contaminated water	Wells with old water	Total wells sampled
Unconsolidated sediment aquifer	3	3	6
Troutdale gravel aquifer	20	2	22
Lower Troutdale aquifers	7	11	18
Older rocks	5	3	8

The limited CFC data suggests that the regional aquifers, used for much of the areas drinking water, are susceptible to migration of contaminants from land surface within 1 to 40 years. The time for recharge to travel from land surface to the aquifer could range from as short as days or weeks for aquifers exposed at land surface to years or several decades for deeper aquifers.

Groundwater Flow Model Ages

The Portland Basin groundwater flow model was used to estimate groundwater ages for the principal Clark County aquifers. Ages were calculated using a particle-tracking model (Snyder and others, 1994b). Maps of model results show the minimum age for each model cell in the aquifer. The minimum age for water table aquifers is near zero years. Minimum ages show a conservative age.

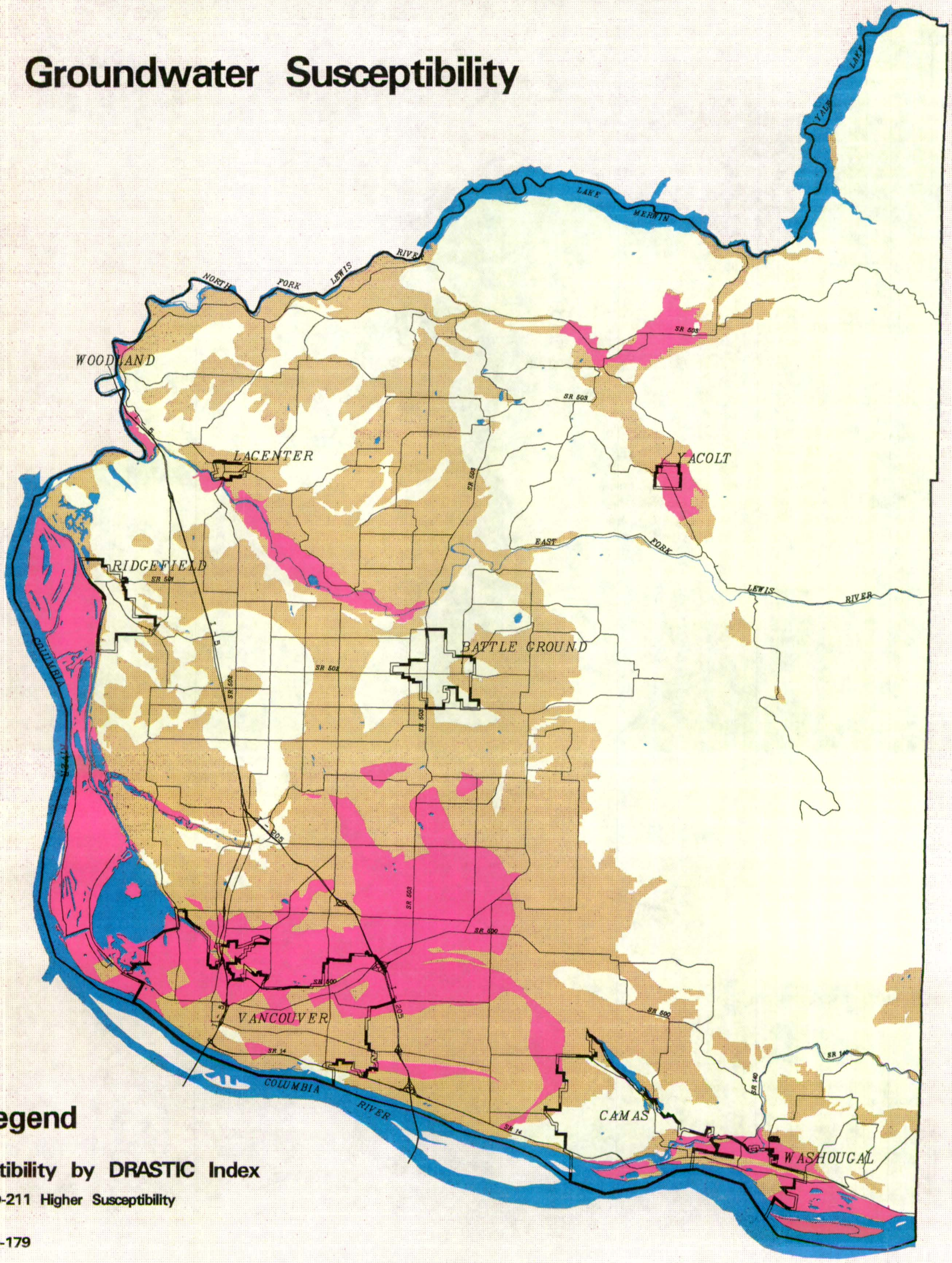
The unconsolidated sedimentary aquifer is the water table aquifer and is very susceptible to contamination. Figure 11 shows that minimum ages for the unconsolidated sedimentary aquifer are generally less than 10 years.

The Troutdale gravel aquifer is the regional gravel aquifer. It underlies the unconsolidated sedimentary aquifer in the valley floor and is exposed at land surface above altitudes of about 350 feet. The model shows that the Troutdale gravel aquifer generally has minimum groundwater ages between 10 and 100 years in areas where it is overlain by the unconsolidated sedimentary aquifer (Figure 12). Minimum groundwater ages of 1000 years or more are simulated for the westernmost part of the aquifer.

CONTAMINANT LOADING POTENTIAL

Contaminant loading potential is a term used to describe the general likelihood that groundwater contamination will occur beneath some type of activity, facility, or land use. A number of characteristics are mapped as contaminant loading potential factors. They include existing land use, population density, transportation corridors, known sites of contamination, solid waste disposal sites, underground storage tanks and potentially contaminated recharge sources such as areas with drywells, areas with septic systems and animal waste application areas. A more complete description of contaminant loading potential ratings is presented in Swanson (September 1993b), describing contaminant loading potential ratings and how they were derived.

Groundwater Susceptibility



Legend

Susceptibility by DRASTIC Index

- 180-211 Higher Susceptibility
- 140-179
- 100-139 Lower Susceptibility

N

1 0 5 Miles

SOURCES:
This map represents data contained in the Clark County DRASTIC map created by Clark County GIS from mapping by the Clark County Groundwater Management Program (Swanson,1991). All additional data are elements of the Clark County GIS database.

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Figure 10

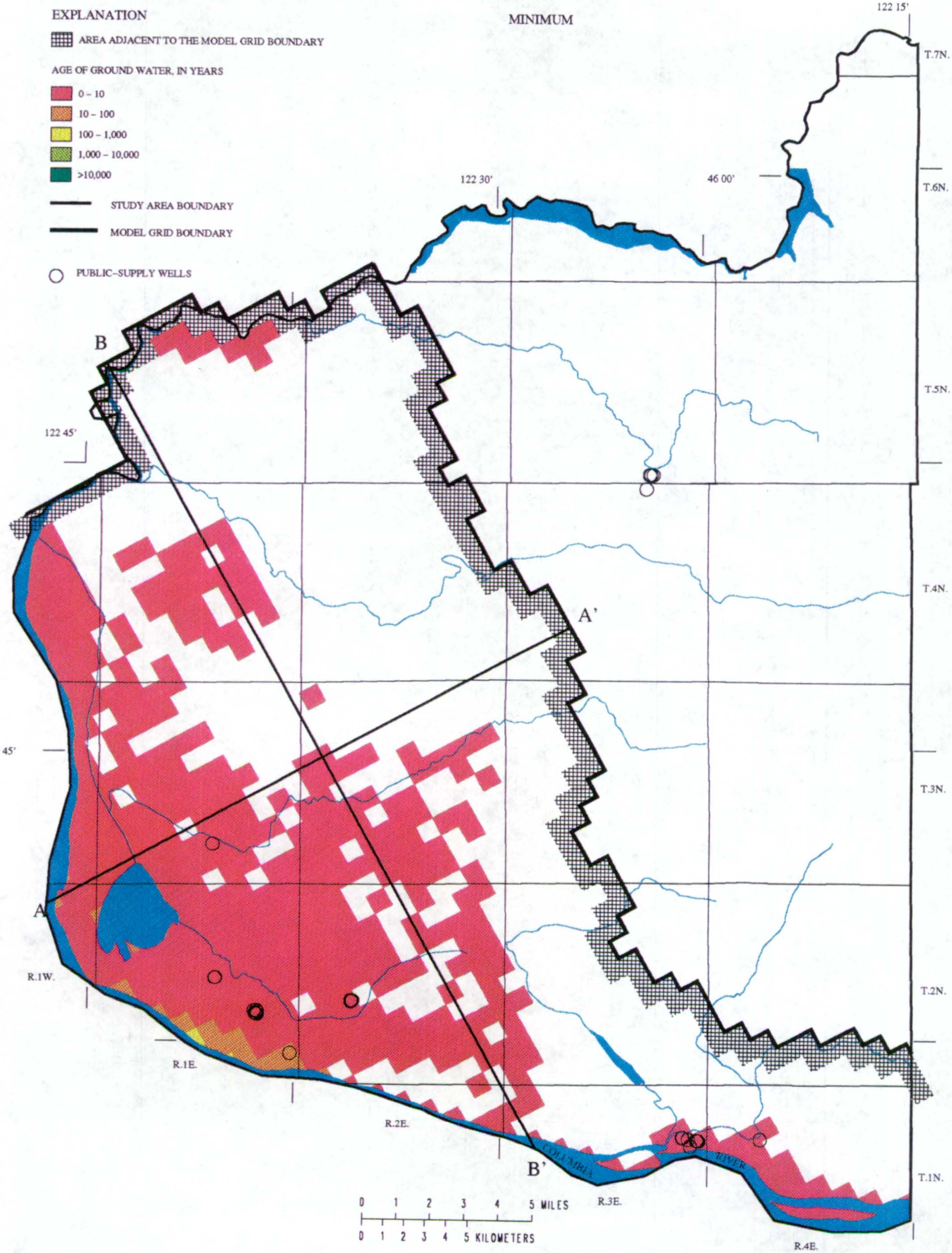


Figure 11. Minimum Travel Times for the Unconsolidated Sedimentary Rocks Aquifer

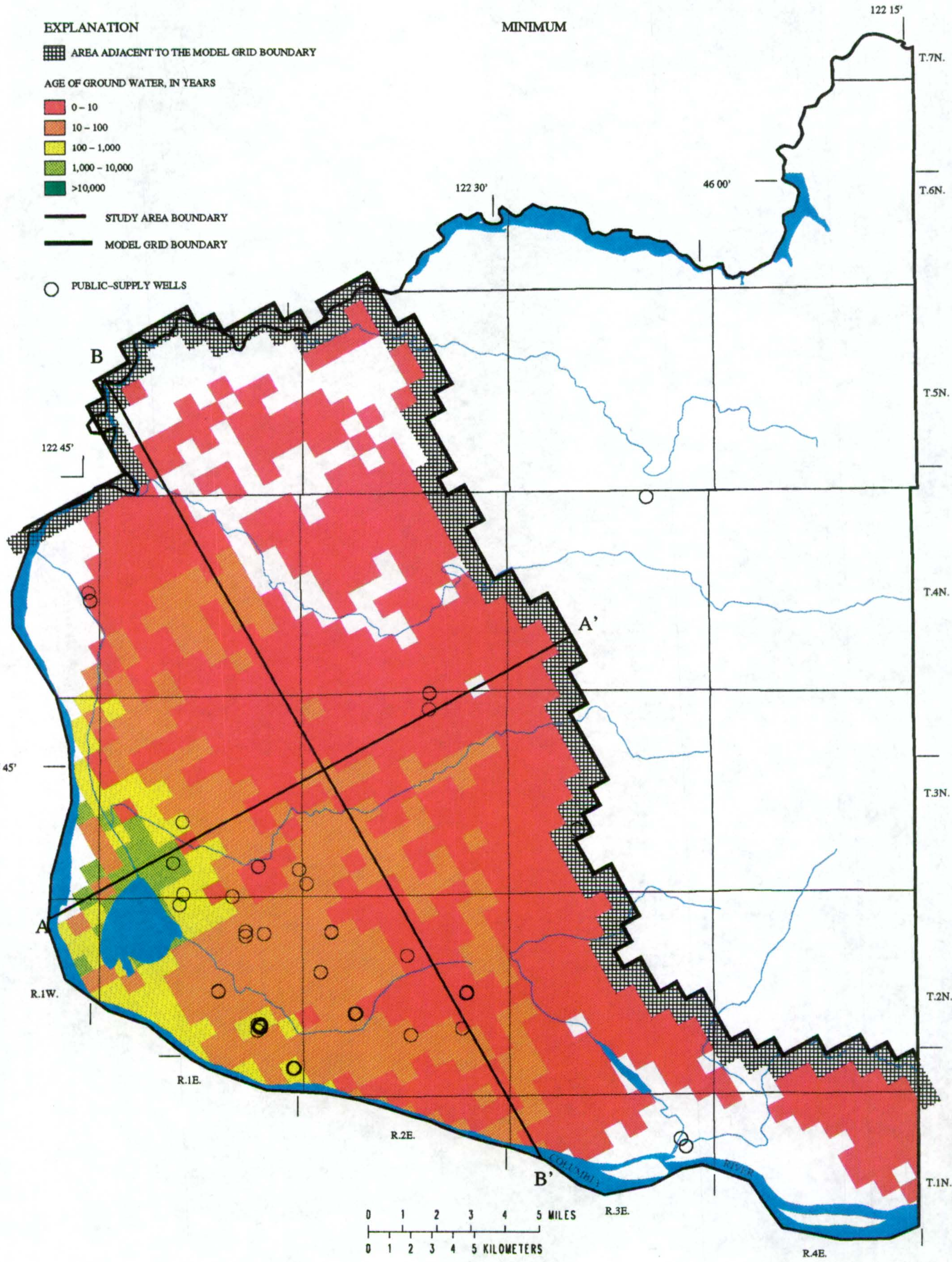


Figure 12. Minimum Travel Times for the Troutdale Gravel Aquifer

A high, medium, and low ratings system is used to describe relative risk for categories within contaminant loading factors such as land use. This simple system is used because little actual data exists to give a more quantitative rating system. Some factors such as septic systems can have no risk mapped for areas where no septic systems occur.

Ratings are made for general groups of contaminants. Urban/industrial loading rating includes contaminants commonly found in groundwater beneath urban and industrial areas that have a mix of commercial, residential and industrial land use. These contaminants include VOCs, metals, and inorganic constituents such as nitrate. The agriculture loading rating principally includes nutrients or inorganic compounds from fertilizer and waste application and pesticides. A general rating was established for all contaminant types.

Data sets for contaminant loading potential can represent both county-wide area maps such as general land use, localized risk factors such as drywell density, or discrete point sources such as known groundwater contamination sites.

Existing Land Use

Land use and the potential for groundwater contamination are directly linked. One thorough study in New York (Eckhardt and others, 1989) and analysis of Clark County water quality show that areas with urban and industrial land use are most likely to have groundwater contamination by industrial solvents and nitrates. Eckhardt and others found statistically significant relationships between general land use and groundwater contamination. The investigation examined the upper glacial aquifer on Long Island, New York. Ten types of land use categories were statistically compared to 14,000 analyses from 903 wells. Water quality samples were collected between 1978 and 1984. Land use was characterized by the predominant land use within a one half mile radius of the sampled well.

Existing land use for GMA planning was mapped by the Clark County Department of Assessment and GIS. Table 2 presents a set of high, medium and low rankings for existing land use. The table is from Swanson (September 1993b) and is based largely on summary text in Eckhardt and others (1989) and analysis done at the former Intergovernmental Resource Center and Clark County Water Quality Division. Figures 13 and 14 show high, medium, and low rated areas for urban/industrial and agriculture/nutrient contaminant loading potential. These maps do not represent actual groundwater contamination at specific sites.

In the case of agriculture/nutrient contamination loading potential, agricultural land use alone is not a very good evaluation method because types of crops, livestock and management vary greatly from farm to farm. These variations are not reflected in land use mapping.

Table 2. Contaminant Loading Potential Ratings for Existing Land Use.

Land Use	Urban/Industrial rating	Agricultural/Nutrient rating	General Rating
Forest	Low	Low	Low
Agriculture	Low	High	Medium
Commercial service	High	Medium	High
Commercial retail	Medium	Medium	Medium
Commercial highway	High	Medium	High
Commercial freeway	Medium	Low	Medium
Heavy industrial and mining	High	Medium	High
Light industrial	High	Medium	High
Public facilities	Medium	Low	Medium
Parks/schools/recreation	Low	Medium	Medium
Institutional	Medium	Medium	Medium
Single family residential	Medium	Medium	Medium
Duplex residential	Medium	Medium	Medium
Multi-family residential	Medium	Medium	Medium
Rural residential	Low	Low	Low
Roads	Medium	Medium	Medium
Vacant	Low	Low	Low

Population Density

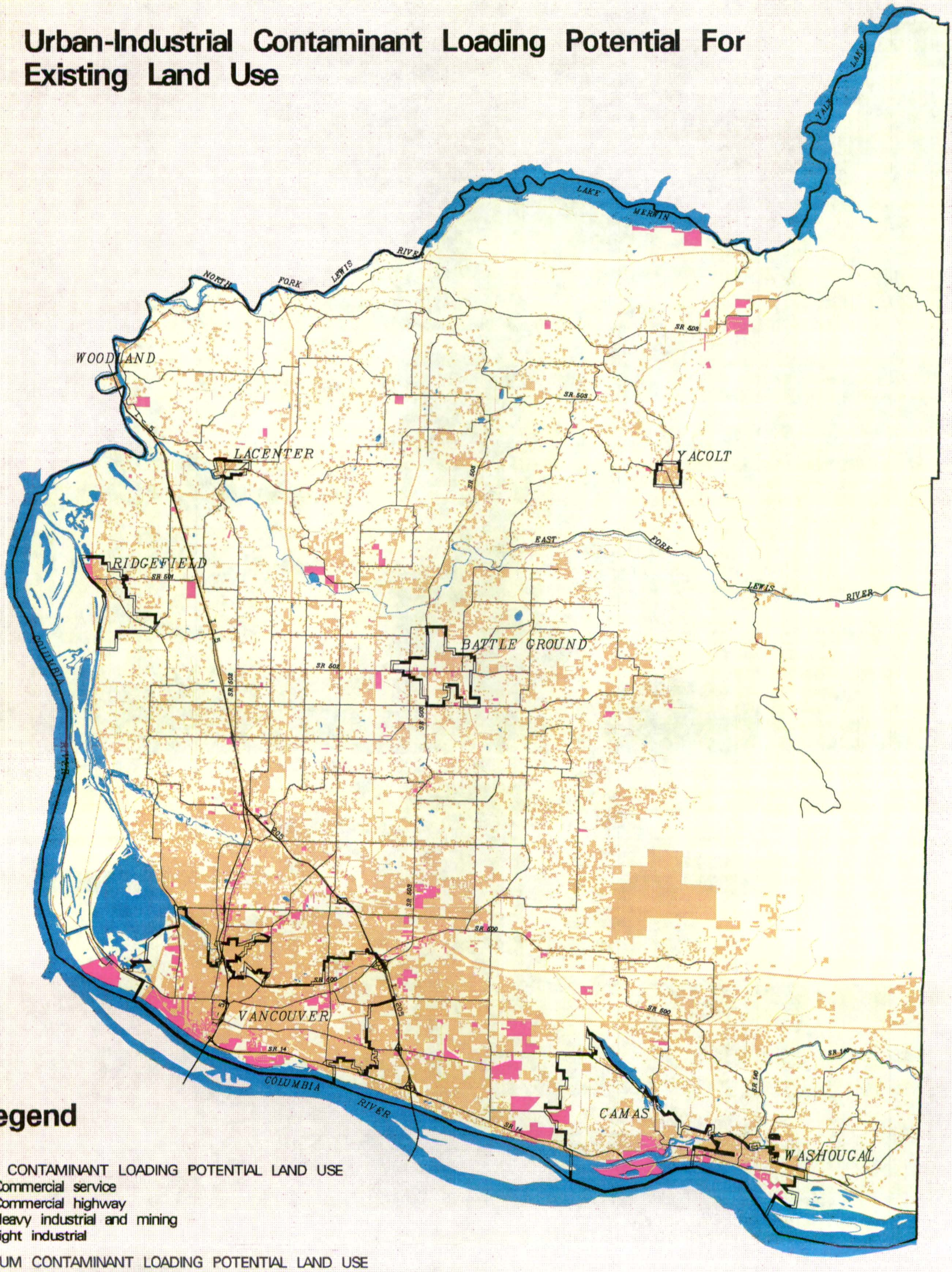
Groundwater contamination in urbanized areas has been correlated with population density Eckhardt and others (1989). High population density is associated with urban areas where mixed commercial, residential, and industrial land use occurs. Population density can be associated with groundwater nutrient and pesticide contamination due to septic system discharge of nutrients, excessive yard and garden chemical use, and improper disposal of pesticides and household and automotive wastes.

Table 3 shows high, medium and low ratings are assigned to population density using housing density based on analysis from Eckhardt and others (1989) and local nitrate and VOC data (Swanson, September 1993a and c). When population is less than one person per acre, there appears to be very low population-related risk. Figure 15 shows contaminant loading potential ratings for population density.

Table 3. Contaminant Loading Potential Ratings for Population Density.

Population Density	Urban/Industrial rating	Agricultural/Nutrient Rating	General Rating
More than 5 persons/acre	High	Medium	High
1 to 5 persons/acre	Medium	Low	Medium
Less than 1 person/acre	Low	Low	Low

Urban-Industrial Contaminant Loading Potential For Existing Land Use



Legend

HIGH CONTAMINANT LOADING POTENTIAL LAND USE
- Commercial service
- Commercial highway
- Heavy industrial and mining
- Light industrial

MEDIUM CONTAMINANT LOADING POTENTIAL LAND USE
- Commercial retail
- Commercial freeway(motel, hotel etc.)
- Public facilities
- Institutional
- Single family residential
- Duplex residential
- Multi-family residential
- Roads

LOW CONTAMINANT LOADING POTENTIAL LAND USE
- Forest
- Agriculture
- Parks/schools/recreation
- Rural residential
- Vacant

N

1 0 5 Miles

SOURCES:
This map was constructed from contaminant loading potential ratings for land use categories developed the Clark County Water Quality Division. These ratings were applied to GIS Existing Land Use. Additional data are standard elements of the Clark County GIS database.

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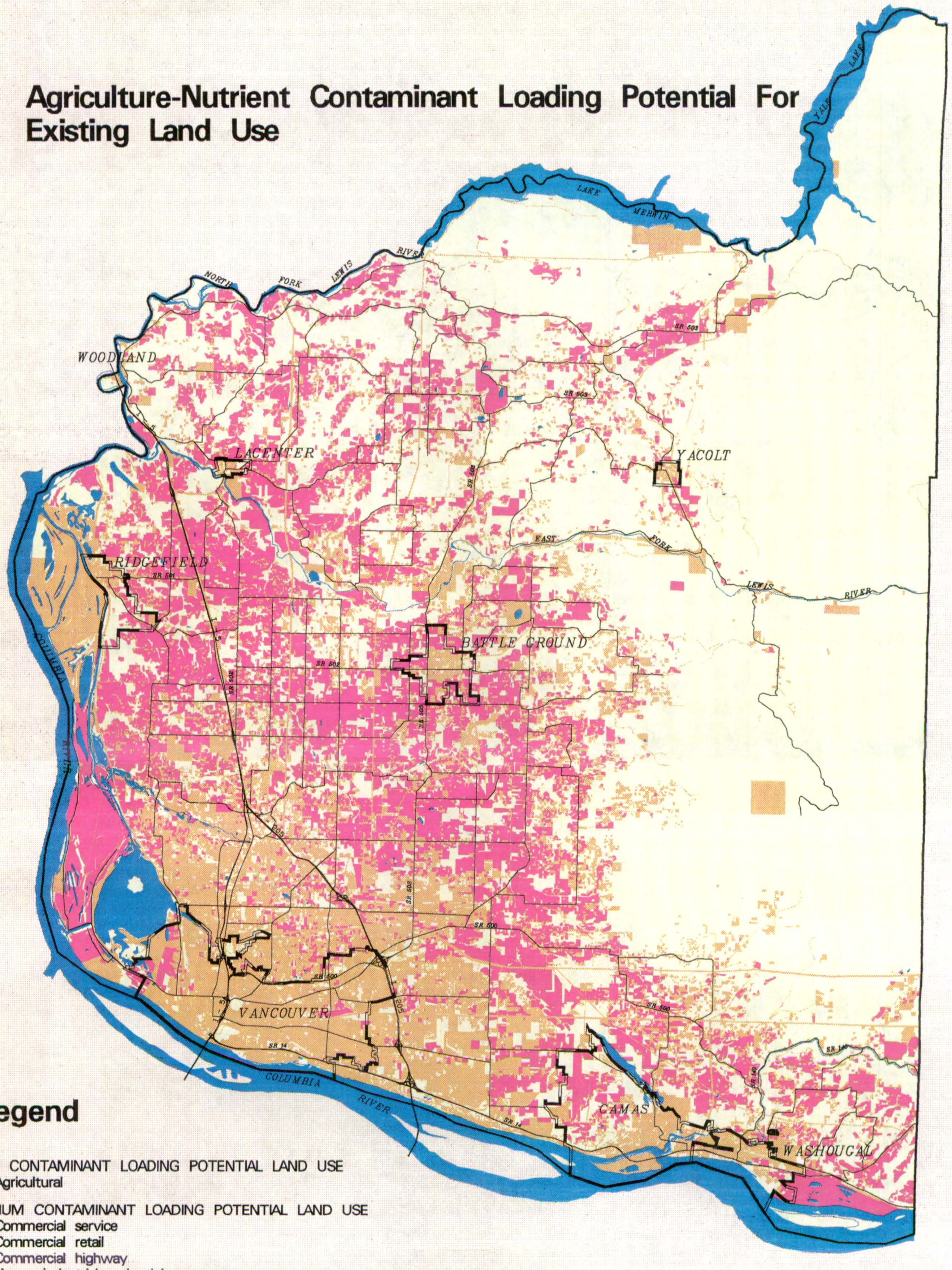
Figure 13

Agriculture-Nutrient Contaminant Loading Potential For Existing Land Use



Legend

- HIGH CONTAMINANT LOADING POTENTIAL LAND USE
  - Agricultural
- MEDIUM CONTAMINANT LOADING POTENTIAL LAND USE
  - Commercial service
  - Commercial retail
  - Commercial highway
  - Heavy industrial and mining
  - Light industrial
  - Parks/schools/recreation
  - Institutional
  - Single family residential
  - Duplex residential
  - Multi-family residential
  - Roads
- LOW CONTAMINANT LOADING POTENTIAL LAND USE
  - Forest
  - Commercial freeway(hotel, motel)
  - Public facilities
  - Rural residential
  - Vacant

N

1 0 5 Miles

SOURCES:
This map was constructed from contaminant loading potential ratings for land use categories developed the Clark County Water Quality Division. These ratings were applied to GIS Existing Land Use. Additional data are standard elements of the Clark County GIS database.

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Figure 14

Urban-Industrial Contaminant Loading Potential For Population Density
WOODLAND
LACENTER
YACOLT
RIDGEFIELD
BATTLE GROUND
VANCOUVER
CAMAS
WASHOUGAL
NORTH FORK LEWIS RIVER
LAKE MERWIN
EAST FORK LEWIS RIVER
COLUMBIA RIVER
SR 503
SR 502
SR 500
SR 14
Legend
HIGH CONTAMINANT LOADING POTENTIAL
More Than Five People Per Acre
MEDIUM CONTAMINANT LOADING POTENTIAL
One to Five People Per Acre
LOW CONTAMINANT LOADING POTENTIAL
Less Than One Person Per Acre
N
1 0 5 Miles
It is the policy of the Clark County GIS to provide the highest quality mapping product available. However, the diversity of scales and sources available precludes the issuance of warranty and prevents any guarantee as to the data accuracy.
SOURCES:
This map was constructed from contaminant loading potential ratings for population density developed the Clark County Water Quality Division. These ratings were applied to GIS calculated densities from block data of the Bureau of Census TIGER files Additional data are standard elements of the Clark County GIS database.
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Figure 15.

Point Sources Mapping

The term point sources is used here to describe discrete, inventoried or permitted sites where activities or facilities that pose a risk to groundwater quality exist or may have existed in the past. Point source locations are usually derived from site inventories for regulatory or permitting purposes. Point sources mapped in this investigation are known contamination sites, inventoried underground storage tanks, and landfills and dumps. Each site is mapped with a symbol on Figure 16.

Known Sites of Contamination

Known sites of contamination are locations where documented contamination of soil or groundwater exists. The map and data tables were compiled by the former Intergovernmental Resource Center from public records at the Washington Department of Ecology, EPA, and the Southwest Washington Health District. Site categories that are compiled to the known sites map are:

- National Priorities List (NPL) Sites; Federal Lead These sites are on the EPA National Priorities List (NPL) and are a high priority for investigation and cleanup by EPA.
- National Priorities List; State Lead NPL sites at which Washington Department of Ecology is chiefly responsible for investigation, cleanup and monitoring.
- State Sites; Confirmed Hazardous Substance Sites These are sites where the presence of hazardous substances has been confirmed by laboratory or field determinations. These sites may require further investigation, cleanup, and monitoring. The state is responsible for assuring site cleanup if necessary.
- State Sites; Potential Hazardous Substance Sites Department of Ecology staff have done an initial investigation and determined that further investigation is needed.
- State Sites; Those Undergoing Long Term Monitoring Sites that have undergone remedial action and are being monitored to assure attainment of cleanup levels.

Only sites with confirmed groundwater or soil contamination are mapped on Figure 16. Sites that have actual groundwater contamination are rated highest. The next level of risk is for sites where soil has been contaminated and there is either potential, unknown, or suspect groundwater contamination. Sites where soil has been contaminated but groundwater is tested uncontaminated pose the lowest immediate risk among known sites. Sites that have no confirmed soil or groundwater contamination are not rated or mapped as known sites.

Solid Waste Disposal Sites

Solid waste disposal sites pose a significant risk to groundwater because they potentially hold large quantities of a wide variety of contaminants. The Clark County Groundwater Management Program researched data at several sources and collected anecdotal reports of solid waste disposal sites in Clark County. Three types of sites are included in Figure 16:

- Existing permitted landfills
- Abandoned landfills
- Uncontrolled dump sites

Generally the most complete data is available for existing permitted landfills, less for abandoned landfills, and little or no information for uncontrolled dumps. All existing permitted and abandoned landfills are generally considered to have a high risk for discharging contaminants to groundwater. Uncontrolled dump sites are of uncertain risk.

Regulated Underground Storage Tanks

Underground storage tanks (USTs) usually contain flammable fluids such as motor fuels and heating oil, or other hazardous industrial materials. Underground storage tanks that are not exempt from EPA underground storage tank rules are regulated by the Department of Ecology. Most of the regulated tanks hold motor fuel. Exempt tanks include heating oil tanks and agricultural use tanks under 1,100 gallons. A complete inventory of all non-exempt underground tanks receiving fluids is completed by the Department of Ecology as a part of the UST regulatory and permitting process. Figure 16 shows underground tanks regulated and permitted by the Washington Department of Ecology.

ARTIFICIAL RECHARGE AND WASTE WATER DISCHARGES

Artificial recharge is used in this report to describe recharge due to irrigation, waste water disposed to land surface or infiltration devices, or stormwater disposal into drywells. In Clark County, the principal sources of artificial recharge are stormwater disposal wells (drywells) and on-site waste disposal systems (septic systems). A map shows inventoried septic systems, drywell recharge areas, and areas with significant animal waste application (Figure 17).

Septic Systems

Septic systems treat and discharge waste water from households and commercial sites not hooked up to public sewer systems. Septic systems treat effluent for nutrients and microorganisms but are not designed to remove many common contaminants. The US

Sites with Known Groundwater and Soil Contamination, Underground Storage Tanks, Landfills and Uncontrolled Dumping Sites

Legend

- ◆ Sites with Known Groundwater or Soil Contamination
- ◆ Underground Storage Tanks
- ▲ Existing or Abandoned Landfill Sites
- ▲ Uncontrolled Dumping Sites

SOURCES:
This map is constructed from data compiled by the Clark County Groundwater Management Program. All additional data are standard elements of the Clark County GIS database.

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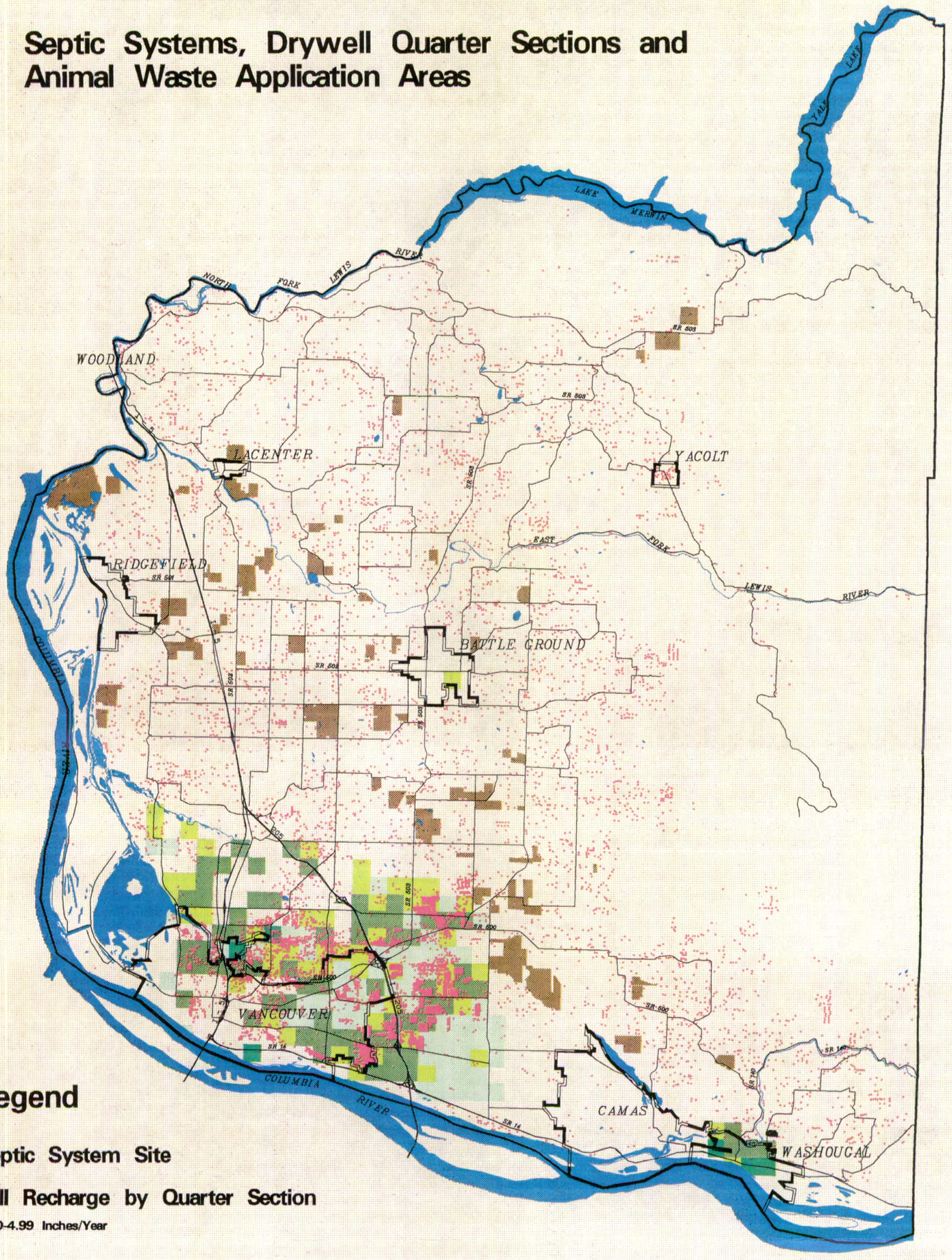
Figure 16

Septic Systems, Drywell Quarter Sections and Animal Waste Application Areas



Legend

- Septic System Site

Drywell Recharge by Quarter Section

- 0.00-4.99 Inches/Year
- 5.00-9.99 Inches/Year
- 10.00-19.99 Inches/Year
- 20.00-25.25 Inches/Year
- Animal Waste Application Areas

N

1 0 5 Miles

SOURCES:
This mapping combines inventory data from the Burnt Bridge Creek Utility, the City of Vancouver and SW Washington Health District. Drywell recharge is from USGS. Animal waste application areas were mapped by Clark County Water Quality Division using information from SCS, Lacamas Lake Restoration and WSU Extension. All additional data are standard elements of the Clark County GIS database.

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Figure 17.

Geological Survey estimated that the average household septic system contributed about 117 gallons per day to groundwater recharge and that the average commercial apartment complex or institutional septic system contributed about 3,400 gallons per day to recharge. The septic system recharge was mapped by Snyder and others (1994a) for the Burnt Bridge Creek basin, where septic system density is greatest.

Good septic system inventories were compiled for the Vancouver metropolitan area in 1991 and 1992. The Burnt Bridge Creek Utility checked sewer connections at every building in its service area. The City of Vancouver completed a similar inventory of the Columbia Slope area. The rest of the county has a partial inventory from Southwest Washington Health District records. The Health District has site records dating from 1986 in a computer database. Septic systems from these three sources are mapped in Figure 17. It should be noted that many uninventoried and umapped septic systems exist outside the inventoried Burnt Bridge Creek Utility and City of Vancouver area.

Drywells

Drywells recharge groundwater by injecting stormwater via large-diameter shallow disposal wells. Stormwater entering drywells is routed from paved areas and roofs and can contain many urban contaminants including metals and petroleum products. In addition, drywells can receive contaminants carried from drains routed from indoor and outdoor vehicle maintenance areas, materials handling areas, and other commercial and industrial facilities.

Drywells were inventoried by the Department of Ecology in 1986 (B. Bowen written communication, 1988), counting drywells in a windshield survey and totaling them by quarter section. The accuracy of this survey is deemed to be poor, with many uncounted drywells (B. Bowen, WDOE, personal communication, March 1992). The Water Quality Division and County Maintenance are completing an inventory of drywells as part of a stormwater system inventory. This inventory will be completed and tabulated in summer 1994.

The US Geological Survey used the Department of Ecology inventory to estimate groundwater recharge for the Portland Basin groundwater flow model Snyder and others (1994a). Drywell recharge contributes large amounts of water to aquifers in urbanized Clark County; in some cases over one-half of an area's recharge. US Geological Survey estimated drywell recharge is shown by quarter section in Figure 17.

Animal Waste Application Areas

Animal waste and waste water from dairy facilities and other livestock operations is routinely disposed of by spraying or spreading onto fields. These wastes contain plant nutrients and pathogenic microorganisms. Under optimal conditions nutrients are taken up by field crops and microorganisms are trapped in soil. If application rates exceed crop capacity for nutrient consumption contaminants such as nitrate can move through the soil into groundwater.

Animal waste application is mapped for many of the larger livestock operations. These include dairies, beef operations with about 40 or more head and poultry farms. Map source information came from Clark County Conservation District staff, University of Washington extension staff and Lacamas Lake restoration staff. County staff checked reported application areas against 1989 infrared aerial photos to provide a first level of verification. The map is considered preliminary in nature and may include areas where waste application does not currently occur.

The application areas were identified by tax parcel and digitized into a GIS map using the Department of Assessment tax parcel boundaries map. All sites are mapped as animal waste application sites with no discrimination in size or rate of application because complete information was not readily available. Waste application sites are included in Figure 17.

GROUNDWATER VULNERABILITY MAPS

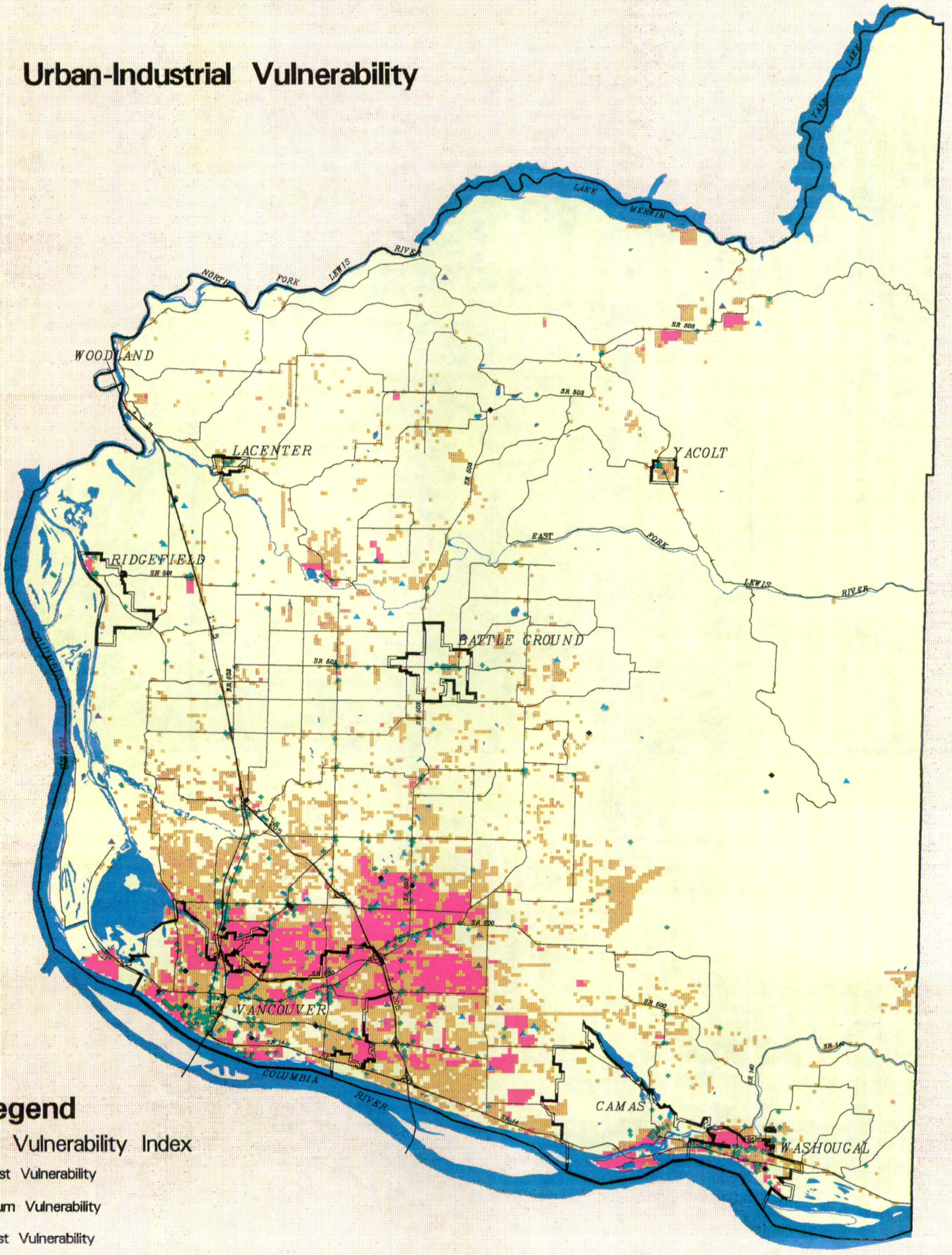
Three groundwater vulnerability maps for urban/industrial groundwater contamination are presented in this section. Each map is made using the same general method and shows areas of relatively highest, medium and lowest vulnerability to groundwater contamination. One map, Figure 18, shows county-wide vulnerability for the water table aquifer. Two maps show vulnerability for specific aquifers using simulated groundwater ages from the Portland Basin groundwater flow model to estimate groundwater susceptibility. Vulnerability for the unconsolidated sedimentary rocks aquifer is shown in Figure 19. Vulnerability for the Troutdale gravel aquifer is shown in Figure 20.

Vulnerability Map Methodology

Vulnerability methods generally use an approach of overlaying or adding together numerical ratings for maps of hydrogeologic and contaminant loading information. The maps produced by these methods show areas where land use activities pose a relatively greater risk to groundwater quality. The underlying assumption is that an evaluation of relative risk can be made by mapping risk factors. Such mapping provides a qualitative method to define areas where groundwater is at risk when data are lacking to measure the actual contamination or potential for contamination.

The method to calculate vulnerability indexes for Figures 18, 19 and 20 uses an additive procedure to compile weighted numerical rating values for each vulnerability factor. A model for this type of analysis is the DRASTIC method to define hydrogeologic susceptibility (Aller and others, 1987). In general terms, a series of maps with numerical ratings are overlaid and the ratings summed using computerized mapping programs. Weighting values are used to accentuate map layers that are deemed of greater importance. The mathematical equation to calculate vulnerability indexes for each map point using weighted rating factors can be expressed as:

Urban-Industrial Vulnerability



Legend

Aquifer Vulnerability Index

- Highest Vulnerability
- Medium Vulnerability
- Lowest Vulnerability
- Sites with Known Groundwater or Soil Contamination
- Underground Storage Tanks
- Existing or Abandoned Landfill Sites
- Uncontrolled Dumping Sites

N

1 0 5 Miles

It is the policy of the Clark County GIS to provide the highest quality mapping product available. However, the diversity of scales and sources available precludes the issuance of warranty and prevents any guarantee as to the data accuracy.

SOURCES:
This map is constructed from an analysis of data compiled by the Clark County Groundwater Management Program, Clark County Water Quality Division and the Clark County GIS. All additional data are standard elements of the Clark County GIS database.

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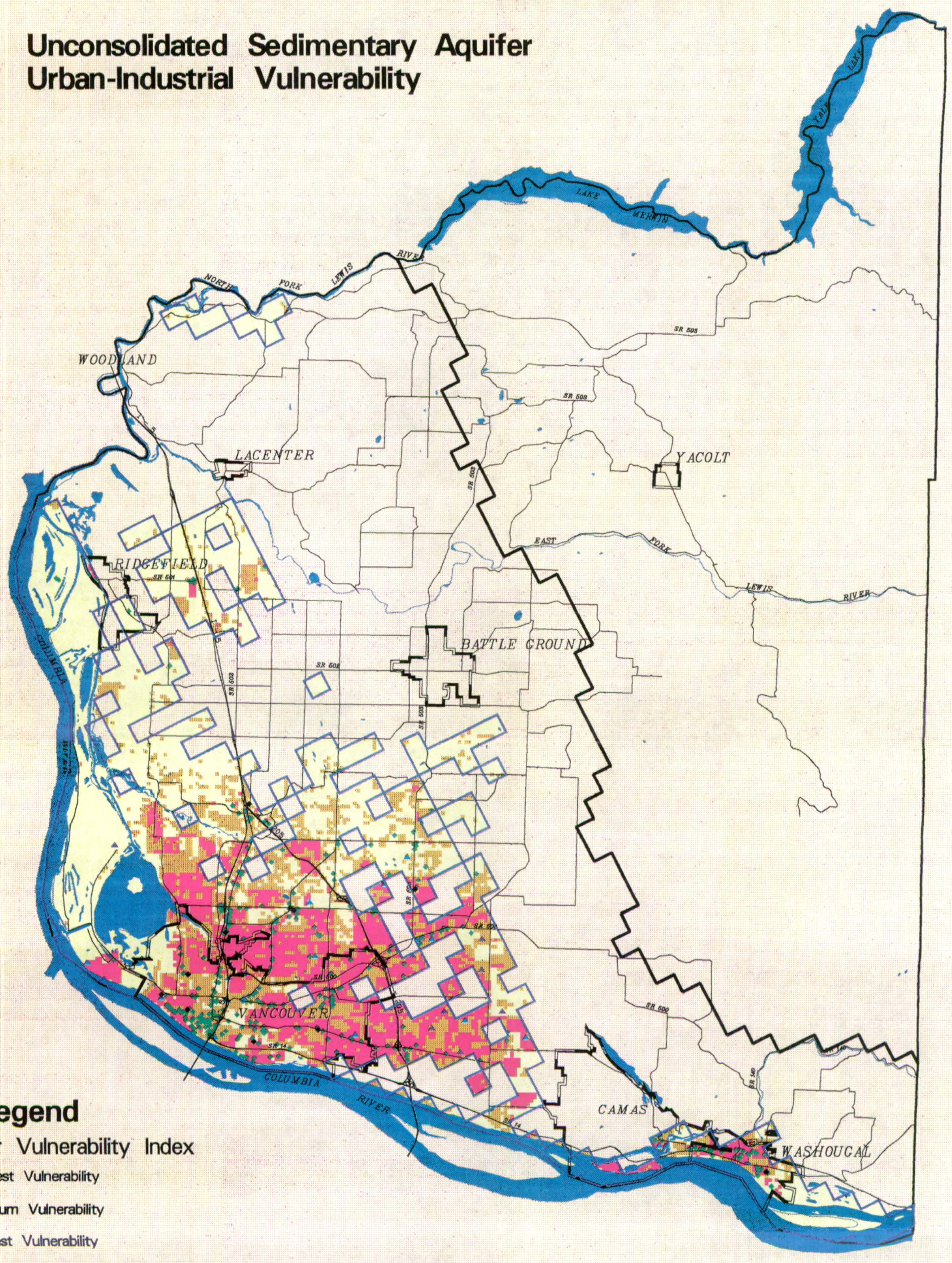
Unconsolidated Sedimentary Aquifer Urban-Industrial Vulnerability



Legend

Aquifer Vulnerability Index

- Highest Vulnerability
- Medium Vulnerability
- Lowest Vulnerability
- Unconsolidated Sediment Aquifer Not Modeled
- Sites with Known Groundwater or Soil Contamination
- Underground Storage Tanks
- Existing or Abandoned Landfill Sites
- Uncontrolled Dumping Sites
- Boundary of the Portland Basin Groundwater Flow Model
- Modeled Extent of the Unconsolidated Sedimentary Aquifer

N

1 0 5 Miles

SOURCES:
This map is constructed from an analysis of data compiled by the Clark County Groundwater Management Program, Clark County Water Quality Division and the Clark County GIS. All additional data are standard elements of the Clark County GIS database.

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Figure 19

Troutdale Gravel Aquifer
Urban-Industrial Vulnerability
WOODLAND
LACENTER
RIDGEFIELD
BATTLE GROUND
YACOLT
VANCOUVER
CAMAS
WASHOUGAL
NORTH FORK LEWIS RIVER
LAKE MERWIN
EAST FORK LEWIS RIVER
COLUMBIA RIVER
SR 503
SR 500
SR 14
Legend
Aquifer Vulnerability Index
Highest Vulnerability
Medium Vulnerability
Lowest Vulnerability
Troutdale Gravel Aquifer Not Modeled
Sites with Known Groundwater or Soil Contamination
Underground Storage Tanks
Existing or Abandoned Landfill Sites
Uncontrolled Dumping Sites
Boundary of the Portland Basin Groundwater Flow Model
Modeled Extent of the Troutdale Gravel Aquifer
N
1 0 5 Miles
SOURCES:
This map is constructed from an analysis of data compiled by the Clark County Groundwater Management Program, Clark County Water Quality Division and the Clark County GIS. All additional data are standard elements of the Clark County GIS database.
CLARK COUNTY Water Quality Division
It is the policy of the Clark County GIS to provide the highest quality mapping product available. However, the diversity of scales and sources available precludes the issuance of warranty and prevents any guarantee as to the data accuracy.
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Figure 20

Vulnerability index at a map location = Ws(Rs) +Wl(Rl) + Wa(Ra)

Where:

Ws = the weighting for the susceptibility factor
Rs = the rating for the susceptibility factor at any map area
Wl = the weighting for the existing land use factor
Rl = the rating for the land use factor at any map area
Wa = the weighting for the artificial recharge factor
Ra = the rating for the artificial recharge factor at any map area

Vulnerability indexes were calculated using the grid function in ARC/INFO to sum the weighted numerical ratings for the various factors. A 500 foot by 500 foot grid was used for the entire county. The grids are visible as small squares and jagged lines between different vulnerability index areas in Figures 18, 19 and 20. As is the case with factor ratings, relatively high, medium and low ranges were assigned to ranges of vulnerability indexes.

Factor Ratings and Weighting

Numerical factor ratings were assigned based on analysis in Swanson (September, 1993b). Factor ratings and weights for susceptibility, existing land use and artificial recharge are presented in Table 4. Features such as landfills and dumps, USTs, and known sites of contamination are simply printed on the vulnerability map to show their distribution.

Two types of susceptibility mapping are used to create the vulnerability maps. However, the numerical ratings are the same for each susceptibility method; numerical ratings of 3, 2 and 1 are assigned to high, medium or low ratings from either the DRASTIC index or minimum simulated groundwater age. Table 4 has susceptibility numerical ratings and ranges of values for the ratings.

Existing land use numerical ratings of 3, 2, and 1 for high, medium and low urban/industrial contaminant loading potential are mapped on Figure 13.

The numerical rating for artificial recharge is the sum of numerical ratings for several recharge and waste disposal activities. Increasing numbers of activities and increasing septic system density result in a higher artificial recharge rating. The highest possible rating for artificial recharge is 5. However, this is an unlikely occurrence because this would require drywells, septic systems and animal waste application to occur in the same location.

Table 4. Vulnerability factor numerical ratings.

Factor	Range	Rating
DRASTIC Susceptibility	Index of 180 or greater	3
	Index of 140 to 179	2
	Index of 100 to 139	1
Groundwater Age Susceptibility	0 to 10 years	3
	10 to 100 years	2
	greater than 100 years	1
Existing Land Use	High	3
	Medium	2
	Low	1
Artificial Recharge		Sum of Values:
	Animal Waste Application Occurs	1
	Drywell Recharge Occurs	1
	1 to 2 Septic Systems per Acre	1
	More Than 2 Septic Systems per Acre	2

Factor Weighting

A weighting scheme was used to increase the importance of land use as a vulnerability factor. Exiting land use was rated twice as high as susceptibility because the risk of contaminant release is the greatest concern. Table 5 shows weights for the three vulnerability factors.

Table 5. Vulnerability factor weights.

Factor	Weight
Susceptibility	1
Existing Land Use	2
Artificial Recharge	1

Vulnerability Index Ranges

The possible range of vulnerability indices is 3 to 14. The actual range of total vulnerability indices was 3 to 10. The minimum index of 3 is for areas with a low existing land use rating, low susceptibility and no artificial recharge factors.

Total vulnerability index for each 500 foot grid was assigned to a high, medium or low range. The range for low includes 3, 4 and 5. A total vulnerability index of 5 can include areas with a high hydrogeologic susceptibility (3) but low contaminant loading potential (2). The minimum vulnerability index for a high vulnerability is 8. This includes areas with high existing land use contaminant loading rating (6) and medium or higher hydrogeologic susceptibility (2 or 3).

CRITICAL GROUNDWATER RESOURCE AREAS

Under the GMA, critical groundwater resource areas can include special management areas and areas designated through the GMA process. Special protection areas may include sole source aquifers, wellhead protection areas and special protection areas designated by groundwater management programs. This section identifies wellhead protection areas and drinking water aquifers within the urban growth boundary as proposed critical aquifer areas. Areas providing recharge to critical aquifer areas for the next 50 years are also identified using Portland Basin groundwater flow model particle-tracking methods developed by Snyder and others (1994b). Figure 21 is a map of the proposed critical aquifer areas defined by wellhead protection areas and the urban growth boundary, and the 50 year recharge area to critical areas.

WELLHEAD PROTECTION AREAS

Wellhead protection programs are intended to protect drinking water quality by focusing management where aquifer protection is most critical to preserving public drinking water supplies. The federal Safe Drinking Water Act established a nation-wide program through the EPA to establish wellhead protection programs in each state. In Washington, the Department of Health has created a program that requires each public supply system with more than 15 hookups or 25 persons to have a wellhead protection program (Washington Department of Health, December 1993).

Several Clark County municipalities and water utilities have started wellhead protection programs. Clark County has adopted an interim wellhead protection ordinance for areas around most of the principal public supply wells. A comprehensive ordinance is expected to be put in place in summer 1994. The county has also delineated or compiled maps of wellhead protection areas for active wells used by the principal public supply systems. The Town of Yacolt has adopted a wellhead protection program approved by the EPA. Clark Public Utilities and the City of Vancouver are also implementing wellhead protection programs.

Wellhead protection areas have been mapped for public supply wells that serve the principal water utilities, towns and cities in Clark County, and are shown as bright blue areas in Figure 21. These delineations, using a variety of models and methods, were completed by Clark Public Utilities (Pacific Groundwater Group, written communication, March 1993), the former Intergovernmental Resource Center (Swanson and Leschuk, 1992), the US Geological Survey (Orzol and Truini, in press), and the Clark County Water Quality Division. Wellhead protection areas are defined as the area over the part of an aquifer that will contribute water to a well within a ten year period. In some cases, local aquifer boundaries and arbitrary distance criteria are used to define wellhead areas.

PROPOSED CRITICAL AQUIFER AREAS

The identification of high priority aquifers allows planners and regulators to develop programs to more effectively manage areas where aquifer protection is most critical to the largest segment of Clark County's population. Critical parts of the major water supply aquifers are defined using the Urban Growth Boundary. The critical aquifers are included on Figure 21 as green area. In many cases the critical aquifer area also includes wellhead protection areas which are colored bright blue.

Designation of critical aquifer recharge areas *does not* in any way suggest that there are areas where groundwater is not protected in Clark County. Federal, state and local laws require groundwater quality protection.

The past and current trend for siting water supply wells in Clark County has been to place the wells in areas where the demand occurs. If the current pattern of groundwater development continues, wells will be placed in aquifers beneath developing urban areas. The principal aquifers will continue to be the upper Troutdale Formation gravel and Pleistocene gravel deposits in south Clark County. Deeper aquifers are being explored as an alternative source, but existing information is not sufficient to suggest that these aquifers could supply the majority of future consumption.

Aquifers that underlie areas planned for urban development are selected for protection. Urban areas are mapped using the Urban Growth Boundary proposed by Growth Management Act planning. The use of the proposed Urban Growth Boundary as the critical aquifer area is based upon the following assumptions:

- Large public supply systems are the most desirable means of providing water to urban areas;
- Urban areas are given priority because they have both the largest number of users and the greatest risk to water quality; and
- The current trend of siting water supply wells in populated areas will continue.

Several successively deeper aquifers occur within the critical aquifer areas. The definition of these proposed critical areas assumes that all water-bearing units, regardless of depth below land surface will be considered part of the critical aquifer.

Areas with current industrial and commercial land use and areas with known water quality problems are included within the critical aquifer area defined by the Urban Growth Boundary. These areas with water quality problems are in some cases over high yielding aquifers that could be future groundwater sources or are currently within areas that contribute water to drinking water supply wells.

FIFTY-YEAR RECHARGE TO CRITICAL AQUIFERS AND WELLHEAD PROTECTION AREAS

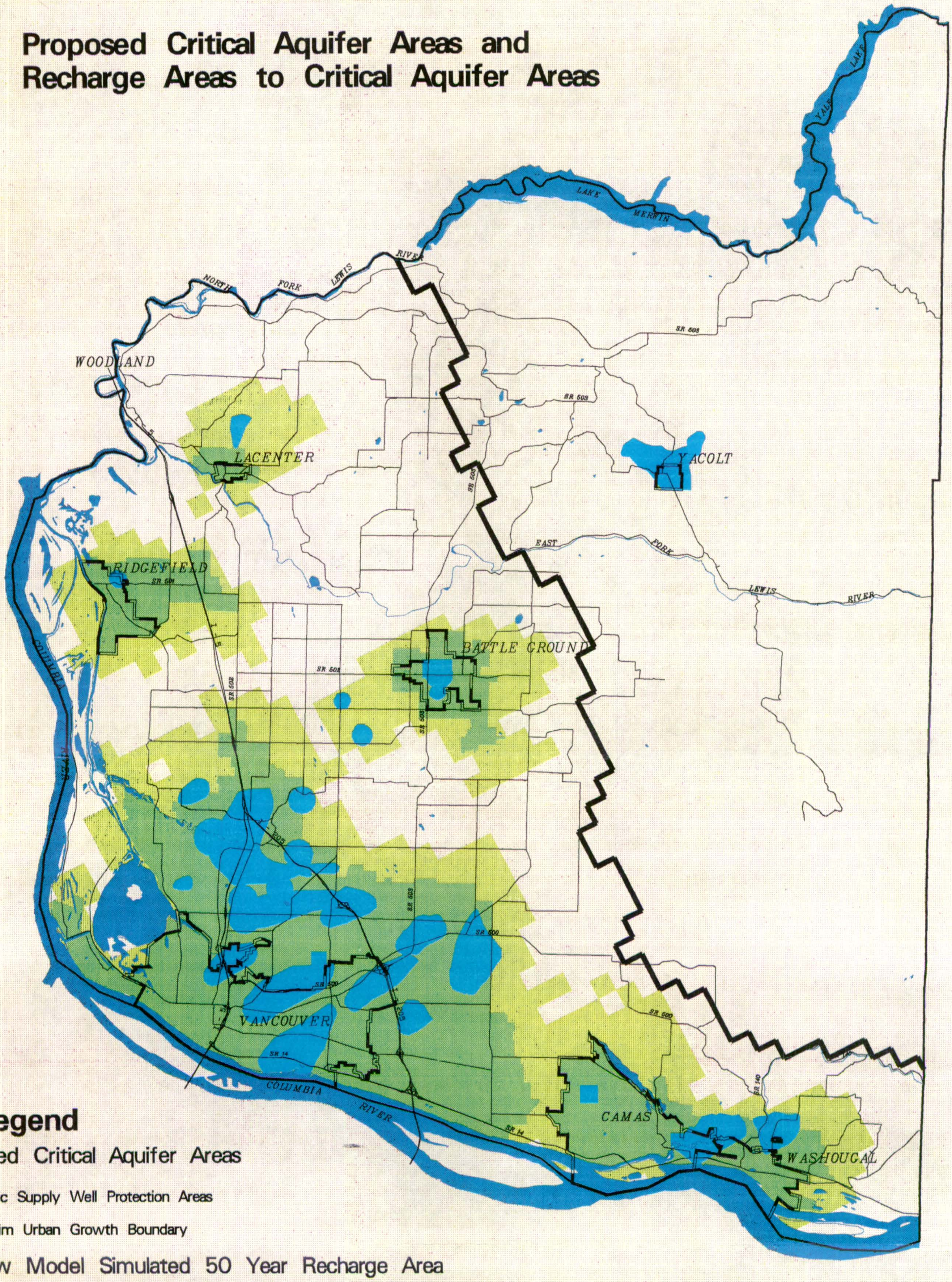
Areas outside the critical aquifer and wellhead areas that provide groundwater recharge to the critical areas should be managed. The areas providing recharge for the next fifty years are determined using the Portland Basin groundwater flow model and a particle-tracking model that can simulate groundwater movement. The long term, 50 year planning horizon incorporated into the Clark County Community Framework Plan (Clark County, 1993) is used to somewhat arbitrarily select a time frame for recharge area modeling. The recharge mapping should be considered as preliminary because it is based on a small sample of possible recharge points to the critical area.

The Portland Basin model was developed by the US Geological Survey by Morgan and McFarland (in press) as a part of the Clark County Groundwater Management Program. The model simulates average conditions for the year 1987-1988. It was designed to characterize regional groundwater flow system of aquifers, rivers, streams, water use and groundwater recharge. The model was also designed to provide a tool for regional groundwater management planning. A particle-tracking model was also developed by the US Geological Survey by Snyder and others (1994b) as a tool for examining the actual paths water takes through the region's aquifers.

Fifty-year recharge areas were defined using computerized particle-tracking maps created by the US Geological Survey. The particle-tracking maps were made by tracking flow backward from each model cell to the ultimate recharge point. Each model cell, a 3,000 foot by 3,000 foot area, representing critical drinking water aquifers, was matched to its recharge area. The model cells that have recharge entering the critical areas within 50 years are mapped as dark yellow on Figure 21.

One urban growth area, Yacolt, lies outside the Portland Basin groundwater flow model and does not have a 50 year recharge area defined.

Proposed Critical Aquifer Areas and Recharge Areas to Critical Aquifer Areas



Legend

Proposed Critical Aquifer Areas

- Public Supply Well Protection Areas
- Interim Urban Growth Boundary

Flow Model Simulated 50 Year Recharge Area

Boundary of Area Simulated by the Portland Basin Groundwater Flow Model

N

1 0 5 Miles

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SOURCES:
This map is constructed from an analysis of data compiled by the Clark County Groundwater Management Program, Clark County Water Quality Division and the Clark County GIS. All additional data are standard elements of the Clark County GIS database.

CLARK COUNTY Water Quality Division

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Figure 21

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APPENDIX C

METHOD TO ESTIMATE GROUNDWATER CONTAMINANT LOADING POTENTIAL RATINGS

By Rodney D. Swanson

Clark County Water Quality Division
Department of Community Development

Completed under Washington Department of Ecology
Centennial Clean Water Fund Grant TAX 91016
in Cooperation with the City of Vancouver and Clark Public Utilities

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INTRODUCTION

Groundwater vulnerability mapping can identify areas where groundwater faces likely contamination, either now or in the future. The driving force behind the need to make vulnerability assessments is the lack of information describing groundwater quality.

An estimate of contaminant loading is required to delineate areas most likely to suffer groundwater contamination. However, contaminant loading rates and environmental fate are almost impossible to measure or estimate accurately. In the absence of empirical data describing water quality and contaminant loading, surrogate measures are used. Investigations in several areas of the United States and Europe have shown a relationship between land use, population density, and groundwater contamination (Cain and others, 1989; Nazari and others, 1993).

In this report the term *contaminant loading potential* is used to describe the relative likelihood that some degree of groundwater contamination from land use activities can occur. A single activity, or factor, such as septic system density can be used to map a contaminant loading potential. A more complex map of contaminant loading potentials can be created by combining several factors.

Hydrogeologic conditions that either aid or inhibit contaminant movement into and through aquifers can be characterized as groundwater susceptibility. When some measure of groundwater susceptibility is combined with contaminant loading potential, a vulnerability assessment is performed.

PURPOSE AND SCOPE

Several reports were completed by the Water Quality Division and the US Geological Survey supporting development of a method to assess groundwater vulnerability in Clark County. This report documents a method to assess contaminant loading potential. The results of this report can be used in other analysis such as Critical Recharge Area delineation under the state Growth Management Act (ESHB 2929 and 1025).

The report presents a set of tables and analysis that can be used to assess contaminant loading potential to groundwater by analyzing regional land use and waste disposal characteristics. Contaminant loading potential ratings are used for vulnerability analysis in Clark County. This report focuses on developing the ratings for each factor and does not present a fixed system for combining them. The actual method used to map contaminant loading potential will depend on local management objectives and concerns as well as the type and quality of data that is available.

Contaminant loading potential ratings are largely based on water quality and land use analysis done in other areas. Additional analysis of nitrate and volatile organic compounds (VOCs) data for selected Clark County wells was also used. In most cases, relative ratings of *high*, *medium* and *low* are used to describe the relative contaminant loading potential of factor categories.

LIMITATIONS

The ratings presented in this report are relative and do not present any quantitative measure of actual groundwater contamination. They are intended for regional analysis of groundwater contaminant loading potential, not for site specific analysis or risk analysis. While ratings are based on limited statistical analysis of water quality data and land use characteristics, they are not rigorous and are subject to individual judgment.

The information used to create these rating systems is limited in size and accuracy and derives from analysis that has many limitations. The land use descriptors assigned to sampled wells are often very general, describing the predominant land use in the area of the well or in the limited area of the well. There is no control over time and groundwater flow direction in most of the analysis. Due to the period of time required to transport contaminants from the point of discharge to groundwater sampling points, land use activities that occurred years ago may be currently affecting water quality while current land use may not. In most cases, it is very difficult to accurately estimate the recharge area and aquifer zone from any particular well sample. This means that the contaminant loading potential assigned to a particular well sample is an approximation.

METHODOLOGY

Existing reports and data describing land use and water quality are summarized to provide a basis for estimating ratings for various land use and waste disposal factors. Local water quality data for nitrates and volatile organic compounds are compared to contaminant loading factors to help develop contaminant loading potential ratings.

For this report, the term *factor* is used to describe a particular contaminant loading potential characteristic that can be mapped. Examples include general land use, population density, and septic system density. Within each contaminant loading potential factor, several categories are usually defined. An example is the industrial category within the factor of land use. Categories were assigned relative ratings within each factor after reviewing the existing water quality information.

Ratings were made for three broad categories of contaminants. There is a general contaminant loading rating that includes any type of groundwater contamination. An *urban/industrial* rating estimates contaminant loading potential for urban/industrial pollutants such as metals and volatile organic compounds. An *agriculture/nutrient* rating gives the contaminant loading potential for fertilizers, animal waste, and pesticides.

Where possible, a summary table presents ratings for each category within a loading factor. An example is the land use factor, which has several different land use categories, each assigned a rating. In some cases, a single rating or no rating was made for a factor. For example, underground storage tanks are all rated equally because they almost all contain petroleum products and are generally similar in construction. Detailed site specific analysis would be required to assign relatively higher and lower ratings to individual tank sites. In other cases, the map presentation of a factor influences how it is rated or presented. Railroad lines are an example of a feature that is not rated because they can be mapped as line features. Underground storage tanks could also be mapped as simple points with no rating.

WATER QUALITY DATA AND CONTAMINANT LOADING POTENTIAL

An evaluation of local land use, water quality, and hydrogeologic conditions should be completed to make a direct link between land use patterns and water contamination. In the absence of detailed local information describing water quality, results of investigations evaluating the relationship between water quality and land use can provide general information to predict the risk to groundwater due to local land uses.

Few investigations evaluating the relationship between groundwater contamination and land use have been published. Several US Geological Survey investigations completed during the 1980s provide good baseline analysis of land use affects on water quality. The US Geological Survey work was done under a program to evaluate the effects of human activities on regional groundwater quality as a part of the Toxic Waste - Groundwater Contamination Program (Cain and others, 1989).

The US Geological Survey Toxic Waste - Groundwater Contamination Program investigated water quality and land use for unconfined aquifers in New York, New Jersey, Connecticut, Florida, Nebraska, and Colorado. Of these investigations, the Long Island, New York investigation of the upper glacial aquifer (Eckhardt and others, 1989) is the most useful for estimating land use effects on water quality in Clark County. The Long Island investigation has statistically significant numbers of samples from ten land use types. It is also an area with similar hydrogeologic conditions and urban, suburban, and rural land uses similar to populated parts of Clark County.

SUMMARY OF CONTAMINANT LOADING POTENTIAL RATINGS BASED ON STATISTICAL WATER QUALITY ANALYSIS IN ECKHARDT AND OTHERS (1989)

Eckhardt and others (1989) found statistically significant relationships between general land use and groundwater contamination. The investigation examined the upper glacial aquifer on Long Island, New York. Ten types of land use categories were statistically compared to 14,000 analyses from 903 wells. Water quality samples were collected between 1978 and 1984. The predominant land use within a one-half mile radius of the sampled well was assigned as the land use of the well. The relationship between land use and water quality is somewhat qualified because other land use types occur within the one-half mile radius. This circular area may also include areas that do not contribute water to the sampled well.

The following is a set of high, medium and low ratings based on summary text by Eckhardt and others (1989). The statistical analysis of Eckhardt and others (1989) is the primary basis for the land use contaminant loading potential (CLP) ratings presented in this report. Ratings were not assigned by Eckhardt and others, only statistically significant groups.

Inorganic Compounds

These ratings are based on a general summary of statistical analysis by Eckhardt and others (1989). The constituents selected for statistical analysis were nitrate, chloride, sulfate, potassium and calcium.

High CLP rating land uses:
- Agriculture
- Commercial
- High density residential

Medium CLP rating land uses:
- Institutional
- Transportation
- Industrial

Low CLP rating land uses:
- Undeveloped
- Low density residential
- Medium density residential
- Recreational

Nitrate

Rating groups for nitrate concentration alone are presented as a separate list from the inorganic compounds. The following list is based on Tukey's honest significant difference test designations which identify land use categories that do not differ statistically (Eckhardt and others, 1989).

High CLP rating land uses:
- Agriculture

Medium CLP rating land uses:
- High density residential
- Commercial
- Medium density residential
- Low density residential
- Institutional
- Industrial

Low CLP rating land uses:
- Transportation
- Recreational
- Undeveloped

Volatile Organic Compounds Based on Detected TCA

High, medium, and low ranking groups for VOC's are assigned by using the percentage of wells with detections for 1-1-1 trichloroethane (TCA), the most commonly detected VOC in the upper glacial aquifer of Long Island. Divisions are arbitrarily made using 25 percent of wells with detects as a cutoff between medium and high loading potential. The low loading potential land uses were identified by the absence of TCA.

High CLP rating land uses (detections in 29 to 45 percent of wells):

- Industrial
- High density residential
- Institutional
- Medium density residential
- Commercial

Medium CLP rating land uses (detections in 12 to 19 percent of wells):

- Recreational
- Low density residential
- Transportation

Low CLP rating land uses (detections in no wells):

- Agriculture
- Undeveloped

VOC Detections Related to Population Density

Eckhardt and others (1989) found a strong correlation between population density and percentage of wells with detected trichloroethylene and 1-1-1 trichloroethane. The analysis was only for areas with fewer than 11 people per acre due to lack of data in higher density areas. The highest rates of detection (greater than 25 percent) are found in areas with population densities greater than 5 persons per acre. Detection rates approach 0 percent at 1 person per acre.

Areas of Long Island with more than 5 persons per acre are characterized as a mixture of medium to high density residential, commercial, industrial, institutional and transportation land uses.

High CLP rating population density:

- More than 5 persons per acre

Medium CLP rating population density:

- 1 to 5 persons per acre

Low CLP rating population density:

- Fewer than 1 person per acre

Pesticides

Pesticides were found in very few wells. Detections were found in recreational, agricultural, institutional, high density residential, transportation, and commercial land uses. The data is limited; only aldicarb, carbofuran, DDT, heptachlor epoxide, and chlordane were tested. The report by Eckhardt and others (1989) suggested that more data was required to make any evaluation of the extent of contamination outside of agricultural areas.

Due to the lack of data, any ranking for general pesticide risk is considered tentative. A contaminant loading potential rating is made here based on significant presence, some presence, or no detection of pesticides, to which a high, medium or low risk is assigned. Additional data could move several of the low ranked land uses to a medium rank.

High CLP rating land uses:

- Agriculture (88 samples analyzed, 42% of 43 analyses for carbofuran)

Medium CLP rating land uses:

- Recreation (41 samples analyzed, 6% of 16 analyses for carbofuran and 33% of 3 samples for heptachlor epoxide)
- Institutional (37 samples analyzed, 22% of 9 DDT analyses, 11% of 9 chlordane analyses)
- High Density Residential (50 samples analyzed, 20% for 15 heptachlor epoxide and 7% for 15 chlordane analyses)
- Transportation (55 samples analyzed, 7% of heptachlor epoxide analyses)
- Commercial (19 samples analyzed, 25% of 4 heptachlor epoxide analyses and 25% of 4 chlordane analyses)

Low CLP rating land uses:

- Undeveloped (80 samples analyzed, 0 detects)
- Low density residential (6 samples analyzed, 0 detects)
- Medium density residential (26 samples analyzed, 0 detects)
- Industrial (3 samples analyzed 0 detects)

Sanitary Sewer and Water Quality

Generally, Eckhardt and others (1989) found no difference between sewered and unsewered areas, or that some sewered areas had higher levels of contamination compared to similar unsewered land uses. Possible explanations include non-septic system contamination effects of development, residual contamination from septic systems in recently sewered areas and leakage from sewer systems.

ANALYSIS OF LOCAL WATER QUALITY

Local water quality data from several monitoring programs was compared to land use, susceptibility and population factors using a computerized geographic information system (GIS). The following section describes the water quality data sources and results of comparison to vulnerability factors.

Sources of Local Water Quality Data

Despite intensive efforts to characterize groundwater, little detailed water quality data for a broad range of contaminants exists. In addition, little data is collected in a format that allows analysis of specific aquifer units. The following management programs are the sources of water quality information used in this project.

Ground Water Management Program (Turney, 1990)

In one study, Turney (1990) systematically collected water quality data throughout Clark County. In 1988, Turney sampled a total of 76 wells for major ions, silica, nitrate, phosphorus, aluminum, iron, manganese, radon and bacteria. A 20 well subset was analyzed for concentrations of selected trace elements and organic compounds, including most of those covered by the US EPA priority pollutant list, Safe Drinking Water Act, and National Primary Drinking Water Standards. Turney's report is especially useful because the sampled aquifer unit is identified for each well. The well analysis by Turney includes too few wells for use in the analysis of land use and water quality. It does however, provide information that can be compared to trends observed elsewhere. Turney's VOC analysis is added to other public water system data to compare VOC detections with land use hydrogeologic factors.

Washington Department of Health Public Water System Monitoring Database

The Washington Department of Health has a database compiling public water system source water quality monitoring results. The monitoring is conducted under the Clean Water Act and in most cases includes all constituents monitored under the Act. Monitoring data from the Department of Health included 72 public supply wells or well fields that had reported results at least once since early 1988. Only VOC data was used for this analysis but data for many synthetic organic compounds and metals are also available.

Clark Public Utilities Water Quality Survey

Water quality data have been collected by Clark Public Utilities since early 1990. Over 4,200 domestic wells were sampled in 1990 and early 1991, during the most active part of the program. The program is summarized in a report by Pacific Groundwater Group (March 1991). Clark Public Utilities sampled wells whose owners responded to an offer of free water quality analysis.

Sampling and field and chemical analysis were done by Clark Public Utilities staff. Temperature, pH, and electrical conductivity were measured during well purging. Water samples were analyzed for nitrate, iron and manganese using spectrophotometer methods of Hach Inc. Total coliform bacteria was analyzed by the Southwest Washington Health District.

Contaminated Site Investigations

The water quality of numerous sites has been monitored as a part of site contamination investigations. Some of the larger investigations include Vancouver Water Stations 1 and 4, Leichner Land Fill, Boomsnub Plating, Frontier Hard Chrome, and Alcoa. In addition, Washington Department of Ecology source investigation programs have identified several areas that appear to have had numerous incidences of groundwater contamination by solvents and metals in the southwest industrial area of Vancouver.

Summary of Local VOC and Nitrate Analysis

This section summarizes the results of local analysis of VOC data (Swanson, September 1993a) and nitrate data (Swanson, September 1993b). Data from Turney (1990) and the Washington Department of Health public supply well water monitoring data was combined to compare the presence or absence of VOCs with land use and hydrogeologic factors. The nitrate analyses from the Clark Public Utilities sampling are compared to land use, population density and DRASTIC index.

Land Use

Both nitrate and VOC data were compared to 1974 land use mapping. This was the only digital land use map available at the time the comparison was done.

VOC Detections and Land Use

Detection rates for volatile organic compounds showed that shallower aquifers in urban areas often have VOC concentrations at or above detection levels. Wells in the Vancouver area, Camas, Battle Ground and Yacolt had VOC detections. Wells in agricultural areas had few detections. Aquifer depth appears to play a role in the presence of VOCs. VOCs were not found in Clark Public Utilities wells in the semi-confined Troutdale Formation, even though land use in the area of these wells is similar to that of shallower wells in which VOCs were detected.

The most severe VOC contamination is associated with spills in industrial areas. These are identified using the Washington Department of Ecology Toxics Cleanup Program Affected Media Reports.

High CLP rating land uses based on local VOC data are:

- Industrial
- Urban/commercial
- Residential

Low CLP rating land uses based on local VOC data are:

- Forest
- Agriculture

Nitrate Concentrations and Land Use

Nitrate concentrations did not vary greatly among different land uses. There was a general trend toward higher median nitrate concentrations for urban areas and with increasing population density. Most of the wells in agricultural areas had low nitrate concentrations. The highest nitrate concentrations however, appeared to be associated with the agricultural practice of livestock waste application to land. The relationship between livestock waste application and high nitrate levels in groundwater has also been confirmed in some cases by Health District water quality monitoring (J. Louderback, verbal communication).

Wells with high nitrate concentrations (5 parts per million or greater NO_3 as nitrogen) were examined to determine if certain areas had relatively more wells with significant nitrate contamination. The proportion of high nitrate wells for each land use category was compared to the proportion of all wells for each category. The proportion of high nitrate wells was greater for agricultural, urban and residential land uses compared to the proportion of all wells. Forest use had very few high nitrate wells relative to the proportion of all wells in forest land use. No wells were located in industrial areas.

High CLP rating land uses based on local nitrate data are:

- Urban/Commercial
- Residential

Medium CLP rating land uses based on local nitrate data are:

- Agriculture

Low CLP rating land uses based on local nitrate data are:

- Forest

Population Density

VOC and nitrate data were compared to 1990 census data and the results were tabulated for classes in the nitrate analysis. The VOC analysis compared mapped population density to VOC detections.

VOC Detections and Population Density

The VOC data suggested that wells in areas with more than one household per acre (2.5 persons/acre) are likely to have VOC detections. VOCs were detected in about half of the wells in areas with population densities over 2.5 persons per acre.

Nitrate Concentrations and Population Density

Nitrate data showed slightly increasing nitrate concentrations with increasing population density. Most of the sampled wells were from low population density areas, with almost 70 percent of the wells in areas with fewer than 0.5 persons per acre. Only one percent of the wells were from areas with over 5 persons per acre. An examination of wells with high nitrate concentrations (5 parts per million and greater) showed that areas with population densities of 2.5 persons per acre or greater had a disproportionately greater number of wells compared to the group as a whole.

Nitrate data suggest that in Clark County, wells in areas with one or more persons per acre have some water quality degradation due to nitrate loading. Also, the nitrate data suggest that population density is not related to any nitrate concentrations over the maximum contaminant level of 10 parts per million.

Drywells

VOC data was compared to drywell distribution and it was found that areas with many drywells appear to have more wells with detected VOCs. One significant consideration is that drywells are more common in built-up urban areas that have higher population densities and more intensive land use.

Septic Systems

VOC data was compared to the US Geological Survey septic system inventory. While the data is limited, it shows that most of the sampled well's shallower aquifers in areas with more than 40 septic systems per quarter section (less than 4 acres per system) had detections.

CONTAMINANT LOADING POTENTIAL (CLP) RATINGS

Early in this process a decision was made to use the relative ratings of *high*, *medium*, and *low* to characterize the contaminant loading potential. Many of the rating systems found in literature use a numerical range (such as 1 to 10, low to high) to rate factors such as land use or artificial recharge. Often, little information is presented to explain the apparently arbitrary process of grouping and ranking evident in these rating systems. A rationale for using relative ratings of high, medium, and low can be found in the analysis of Eckhardt and others (1989), where three to four statistically significant groups were identified for several contaminant types and land use. The descriptive character of this method to assess aquifer vulnerability also supports using a simple rating scheme.

Contaminants are grouped into two categories in an effort to create a system that addresses the two principle areas of concern, contamination due to urban/industrial and agricultural/nutrient activities. Groundwater contamination due to urban and industrial activities is typically due to metals, petroleum compounds and VOCs. Groundwater contamination due to agricultural activities which discharge animal waste, fertilizers and pesticides to land surface contribute pollutants such as nitrate and pesticides. A third, general contaminant loading rating (encompassing both contaminant groups) is also given for each factor category.

Contaminant loading potential ratings describe the general likelihood that groundwater quality will be degraded in the area of a particular land use or activity. Studies comparing water quality to land use examine water quality contaminants in aquifers. They do not link water quality with analysis of particular sites. Ratings from this type of analysis therefore represent the likelihood of groundwater degradation under various types of land use or activities. They do not describe the risk that a particular facility will contaminate groundwater with a particular pollutant.

Eckhardt and others (1989) showed a definite variation in water quality according to general land use type and population. Statistical analysis showed that land use type could be assigned to groups by percentage of wells with detectable contamination or by statistical description of constituent concentrations for each category. While general water quality trends can be associated with land use, the actual risk to groundwater is not easily described because land use activities are usually mixed and actual waste management practices vary from site to site.

Rating factors can be shown using several types of maps. Each factor may require a slightly different method of assigning ratings and mapping to incorporate into a contaminant loading model. Land use maps cover the entire County. Each area can be assigned to a particular category or rating. In some cases the mapped characteristic refers to entire areas, in which a particular feature, such as drywells, is common. Other factors are best represented at regional scale as an individual point or line, representing a point source such as a known groundwater contamination site, landfill or rail line.

GENERAL LAND USE

Land use is the principal factor to consider when assessing regional contaminant loading potential. The most complete analysis linking water quality to human activity evaluates land use. In addition, almost every area has a general land use map. Since contamination can persist in groundwater for years or decades, previous land uses are important in assessing existing contamination or current vulnerability conditions. Current or planned land uses are important tools for identifying areas where there is potential for existing or future contamination if current waste management activities continue. Review of historical land use could be useful for finding areas with a long history of high risk land use.

Clark County is a growing area where changes in land use have occurred as the population has increased. Two county-wide general land use maps exist. One was completed by the US Geological Survey using 1974 aerial photography. An existing land use map is maintained by the Clark County Department of Assessment and a geographic information system. Both maps are digital products.

Ratings of high, medium, or low are assigned to land use categories for Urban/industrial, agricultural/nutrient, and general contaminant loading potential. Ratings are based on statistical analysis of groundwater quality and land use by Eckhardt and others (1989) and local water quality data and summary information in Chomowicz and Palmquist (1991).

Contaminant Loading Potential Ratings for US Geological Survey General Land Use Map Categories (1974)

The US Geological Survey General Land Use Map has been used in a number of groundwater related projects. The map was produced from 1974 aerial photographs and is at a scale of 1:250,000. Categories are to level II accuracy of the US Geological Survey digital cartographic standards. The map has 24 land use categories using classifications listed in Fegeas and others (1983). Table 1 shows the CLP ratings for US Geological Survey General Land Use Map categories.

Table 1. CLP Ratings for US Geological Survey General Land Use Map Categories.

Land use	Urban/ industrial rating	Agricultural/ nutrient rating	General rating
11 = Residential	Medium	Medium	Medium
12 = Commercial and services	High	Medium	High
13 = Industrial	High	Low	High
14 = Transportation, communications and service 16 = Mixed urban or built-up land 17 = Other urban or built-up land	High	Medium	High
21 = Cropland and pasture	Low	High	Medium
22 = Orchards, groves, vineyards, nurseries, and ornamental horticultural areas 23 = Confined feeding operations	Medium	High	Medium
24 = Other agricultural land	Low	Medium	Medium
31 = Herbaceous rangeland 32 = Shrub-brushland rangeland 33 = Mixed rangeland	Low	Low	low
41 = Deciduous forest land 42 = Evergreen forest land 43 = Mixed forest	Low	Low	Low
51 = Streams and canals 52 = Lakes 53 = Reservoirs	0	0	0
61 = Forested wetland 62 = Nonforested wetland	Low	Low	Low
75 = Strip mines, quarries, and gravel pits	Medium	Low	Medium

Contaminant Loading Potential Ratings for Existing Land Use Map Categories (1993)

The Department of Assessment and GIS maintains a detailed existing land use map made by integrating aerial photography interpretation and GIS parcel land use (Department of Assessment and GIS, 1993). Aerial photography identifies areas of used and unused land and different types of vegetal cover for parcels greater than five acres in size. Parcel boundaries and assessor land use codes identify specific categories of land use in built-up areas. Parcel land use codes and corresponding existing land use categories are listed in Appendix A. Assessor parcel land use codes and their descriptions are listed in Appendix B. CLP ratings for existing land use appear in Table 2.

The existing land use map can be applied to regional assessments of vulnerability or water quality characteristics. The high level of detail in this map makes it suitable for use at a local scale. Use at a regional or county-wide scale could require some simplification of the map.

Table 2. CLP Ratings for Existing Land Use Map Categories (1993).

Land use	Urban/industrial rating	Agricultural/nutrient rating	General rating
Forest	Low	Low	Low
Agriculture	Low	High	Medium
Commercial service	High	Medium	High
Commercial retail	Medium	Medium	Medium
Commercial highway	High	Medium	High
Commercial freeway	Medium	Low	Medium
Heavy industrial and mining	High	Medium	High
Light industrial	High	Medium	High
Public facilities	Medium	Low	Medium
Parks/schools/recreation	Low	Medium	Medium
Institutional	Medium	Medium	Medium
Single family residential	Medium	Medium	Medium
Duplex residential	Medium	Medium	Medium
Multi-family residential	Medium	Medium	Medium
Rural residential	Low	Low	Low
Roads	Medium	Medium	Medium
Vacant	Low	Low	Low

Contaminant Loading Potential Ratings for Combined Land Use Map Categories

A land use map with five general land use categories was created in order to compare the US Geological Survey 1974 land use map and current land use. Land uses were grouped into the five general categories of forest, agriculture, residential, industrial, and urban. Table 3 shows the combined land use categories and the corresponding categories on the original land use maps. Ratings for the combined land use categories are presented in Table 4.

Table 3. Combined Land Use Categories for US Geological Survey and Existing Land Use Maps.

Combined Land Use Categories	Existing Land Use Map Categories (1993)	US Geological Survey Map Categories (1974)
Forest	Forest	Deciduous forest land, evergreen forest land, mixed forest, forested wetlands, nonforested wetlands
Agriculture	Agriculture, vacant	Cropland and pasture, orchards, groves, vineyards, nurseries, and ornamental horticultural areas, confined feeding operations, other agricultural land, herbaceous rangeland, shrub-brushland, rangeland, mixed rangeland
Residential	Single family, duplex, multi-family, rural residential, parks/schools/recreation	Residential
Industrial	Heavy industrial, light industrial, mining	Industrial, mining
Urban	Service, retail, highway, freeway (motel, hotel, RV, etc.), public facilities, utilities, institutional	Commercial and services, transportation, communications and services, mixed urban or built-up land, other urban or built-up land

Table 4. CLP ratings for Combined Category Land Use Map Categories.

Land use	Urban/industrial rating	Agricultural/nutrient rating	General rating
Forest	Low	Low	Low
Agriculture	Low	High	Medium
Residential	Medium	Medium	Medium
Industrial	High	Medium	High
Commercial	High	Medium	High

PARCEL LAND USE

The Clark County Department of Assessment and GIS maintains a computerized map of every tax parcel in the County. Tax parcels can range in size from small lots to hundreds of acres. Many pieces of information are included in databases that are keyed to the parcel map. Each tax parcel has a land use code that can be very specific in many cases. County land use codes are patterned after Standard Industrial Classification (SIC) codes (US Office of Management and Budget, 1987). The SIC codes use up to 4 digits to describe every type of industrial, commercial or public activity. A table cross-referencing SIC and County land use codes was made to connect general information for industrial and commercial activity to parcels in Clark County.

Parcel scale mapping is most suitable for detailed land use analysis. Parcel land use descriptions and parcel mapping facilitate computerized inventory of areas where groundwater protection is critical. Examples might be to augment underground storage tank inventory data with a map of parcels with activities that normally house fueling stations or identify high risk land uses within wellhead protection areas. The Clark County Wellhead Protection Program inventoried land use at each parcel for 31 wellhead protection areas (Swanson, 1993c).

POPULATION DENSITY

The rationale for using population density as a factor to evaluate contaminant loading potential is that people direct activities that can contaminate groundwater. Increasing population adds larger numbers of potential sources for household wastes. Eckhardt and others (1989) showed a good correlation between population density and percentage of wells with VOC detects. Ratings are assigned to population density categories using analysis from Eckhardt and others (1989) and local nitrate and VOC data. There appears to be very low population related risk associated with densities below one person per acre.

The 1990 census population is available in digital format describing population by census block (US Bureau of the Census, 1991 and US Bureau of the Census, 1989). There are a total of 4,278 census blocks in Clark County. Of these, 3,425 were populated in 1990. Block groups are larger counting areas that are literally groups of census blocks. There are 182 block groups in Clark County. Table 5 has contaminant loading potential ratings for population density.

Table 5. CLP Ratings for Population Density Categories.

Population density	Urban/industrial rating	Agricultural/nutrient rating	General rating
More than 5 persons/acre	High	Medium	High
1 to 5 persons/acre	Medium	Low	Medium
Less than 1 person/acre	Low	Low	Low

ARTIFICIAL RECHARGE

Artificial recharge is defined here as groundwater recharge from manmade sources. In Clark County, the principal sources of artificial recharge are stormwater disposal wells and on-site waste disposal systems (Snyder and others, 1993). Other sources of artificial recharge include irrigated agriculture, land application of waste water, and stormwater infiltration ponds. The US Geological Survey compiled maps showing recharge due to drywells and septic systems as a part of recharge rate estimation for the Portland Basin groundwater flow model. Recharge due to rainfall infiltration, drywell discharge, and septic system discharge is mapped for each active model cell in the Portland Basin model. Each cell encompasses an area of about 200 acres.

Drywells and septic systems can be mapped as point sources or distributed nonpoint sources. The approach to mapping and incorporating these sources into a method depends largely on the goals of the assessment and available data. A general vulnerability map might identify the presence of any artificial recharge method and add it as a contaminant loading potential factor.

Contaminant Loading Potential Ratings for Drywells

Drywells are large-diameter shallow wells that discharge stormwater from pavement and roofs into the ground. Stormwater entering drywells can contain many urban contaminants including metals and petroleum products. In addition, drywells may receive contaminants routed from drains in indoor and outdoor vehicle maintenance areas, materials handling areas and other commercial and industrial facilities.

Drywell recharge contributes large amounts of water to aquifers in urbanized Clark County. In some urban areas, over one half of the total groundwater recharge is from drywells (Snyder and others, 1993).

No complete digital drywell inventory exists for Clark County. The Department of Ecology conducted a windshield survey which inventoried the number of drywells per 160 acre quarter sections (Bert Bowen, 1988, written communication). The accuracy of this survey is deemed to be poor, with many uncounted drywells (B. Bowen, Washington Department of Ecology, personal communication, March 1992). The US Geological Survey used this inventory to estimate groundwater recharge for the Portland Basin groundwater flow model (Snyder and others, 1993). Drywells are also mapped for many areas by County Road Maintenance staff. These records are inventoried on quarter section maps, but have not been compiled into a database or GIS.

Generally, in areas where there are drywells, the amount of recharge due to drywells is proportional to the amount of impervious area and the amount of rainfall. The actual drywell density is probably controlled by several factors. A review of inventoried drywells, soil conditions, reported areas where drywells exist, and street maps suggest that drywells are most heavily concentrated in developed areas over gravel soils. Table 6 shows contaminant loading potential ratings for areas with drywells.

Table 6. CLP Ratings for Areas with Drywells.

	Urban/industrial rating	Agricultural/nutrient rating	General rating
Areas with drywells	High	Medium	High

Contaminant Loading Potential Ratings for Septic Systems

Septic systems treat and discharge waste water from buildings not connected to public sanitary sewer systems. Septic systems treat effluent mainly to remove pathogenic microorganisms. Nutrients can be removed by septic systems, depending on soil conditions and the design of the septic system. Septic systems are not designed, however, to remove household chemicals or industrial contaminants such as solvents or trace metals. Snyder and others (1994) estimated that the average household septic system contributed about 117 gallons per day to groundwater recharge and that the average commercial, apartment complex or institutional septic system contributed about 3,400 gallons per day to recharge.

Good inventories of parcels with septic systems have been compiled for the Burnt Bridge Creek basin (Burnt Bridge Creek Stormwater Utility, 1993 written communication) and the City of Vancouver Columbia Slope area (City of Vancouver, 1993, written communication). The Health District has digital site records dating to 1985 in a computer data base (SWHD, 1993, written communication). The septic and sanitary sewer inventory results were coded to parcel serial number. This facilitated the creation of a septic system map by matching the septic system parcel serial numbers to the Assessor's GIS parcel map.

Septic systems can be mapped as either points for overlay maps or as systems per unit area. Ratings are based on local water quality data and analysis of population density and groundwater contamination (Eckhardt and others, 1989). Table 7 shows ratings for various septic system density categories.

Table 7. CLP Ratings for Septic System Density Categories

Septic system density	Urban/industrial rating	Agricultural/nutrient rating	General rating
More than 2 systems/acre	High	Medium	High
1 to 2 systems/acre	Medium	Low	Medium
Less than 1 system/acre	Low	Low	Low

Contaminant Loading Potential Ratings for Animal Waste Application

Animal waste and waste water from dairy facilities and confined animal operations are routinely disposed of by spraying or spreading onto fields. These wastes contain nutrients and microorganisms. Under optimal conditions nutrients are taken up by field crops and microorganisms are trapped in soil. If application rates exceed crop capacity for nutrient consumption, however, contaminants such as nitrate can move through the soil into groundwater.

Animal waste application is mapped for many of the larger livestock operations. These include dairies, beef and pork operations that generally had more than 40 head and poultry farms. Information to map waste application sites is from Clark County Conservation District staff, Washington State University Clark County Cooperative Extension staff and Lacamas Lake Restoration Program staff. The reported waste application areas were checked against 1989 infrared aerial photos to provide a first level of verification. The map is considered preliminary and may include areas where waste application does not currently occur.

The application areas were identified by parcel serial number and converted into a GIS map using the Assessor's office parcel boundary map. All sites are mapped as animal waste application sites with no discrimination in size or rate of application because complete information was not readily available. Also, it is difficult to quantify site specific contaminant loading potential because application areas and application rates change with time at each operation. Table 8 shows contaminant loading potential ratings for animal waste application.

Table 8. CLP Ratings for Animal Waste Application.

	Urban/industrial rating	Agricultural/nutrient rating	General rating
Animal Waste Application	Low	High	High

Irrigated Agriculture

There is little intensive irrigated agriculture in Clark County. As a result, no inventory exists for these areas.

POINT SOURCES

Point sources are defined here as specific sites where activities or facilities that pose a risk to groundwater quality exist or may have existed in the past. Examples include underground storage tanks, landfills and waste water lagoons. Point source locations are usually derived from site inventories for regulatory or permitting purposes. The Washington Department of Ecology underground storage tank inventory, inventories of livestock waste ponds and inventories of known sites of contamination are examples. High risk land uses can also be included as point sources by using parcel land use codes.

Point source inventories are often compiled into data bases which facilitate mapping. Location descriptors such as street address, however, are often not adequate to accurately map point sources.

Rating contaminant loading potential for point sources is complex. Most of the point source facilities are perceived to have a relatively high risk to groundwater. Point sources are usually specific sites rather than regional characteristics. Any accurate screening of individual sites should include site specific assessment. This report simply assigns ratings to entire groups of sites without using site specific information. Point source mapping can be done by using density pattern maps, with higher densities associated with increasing contaminant loading potential.

Contaminant Loading Potential Ratings for Known Sites of Contamination

Known sites are sites where documented contamination of soil or groundwater exists. The map and data tables were compiled by the Intergovernmental Resource Center from public records at the Department of Ecology, the EPA and the Southwest Washington Health District. Sites are on a map base that precedes GIS mapping of parcels and are not coded to parcels.

A simple rating scheme was devised to map known sites of contamination that have the greatest known risk to groundwater. This rating scheme is intended to group sites into relative categories. Sites with existing groundwater contamination are rated highest. These are followed by sites where soil has been contaminated and there is either potential, unknown or suspect groundwater contamination. Sites where soil has been contaminated, but groundwater has tested negative for contaminants are given the lowest risk rating among known sites.

Sites with neither confirmed soil nor groundwater contamination are not rated or mapped as known sites but are included in the database. Contamination loading potential ratings for known sites of contamination appear in Table 9.

Table 9. CLP Ratings for Known Sites of Contamination

	Urban/industrial rating	Agricultural/nutrient rating	General rating
Contaminated groundwater	High	Low	High
Potential groundwater and confirmed soil contamination	Medium	Low	Medium

Contaminant Loading Potential Ratings for Solid Waste Disposal Sites

Solid waste disposal sites pose a significant risk to groundwater. Solid waste disposal sites include existing permitted landfills, abandoned landfills, and uncontrolled dump sites. Landfills and dumps were inventoried for the Clark County Groundwater Management Program which tabulated data and described many landfills (Clark County Groundwater Advisory Committee, 1992). Sources of data include Health District records, Washington Department of Ecology records, newspaper articles and anecdotal accounts from the public. The best information generally exists for permitted landfills, with decreasing knowledge for abandoned landfills and uncontrolled dumps.

The landfill and dump sites are compiled on a GIS map, however the map is not accurate to parcel scale. Landfills were mapped as accurately as data permitted. In some cases landfill boundaries were mapped (at 1:24,000 scale mapping), but in most cases a point identifies the location of the landfill (1:48,000 scale mapping). In addition to the Groundwater Management Program map, Department of Assessment and Mapping tax parcel data include some parcels that are identified as dumps and disposal operations.

All existing permitted and abandoned landfills are generally considered to have a high risk to groundwater quality. Uncontrolled dump sites are of uncertain risk. Contaminant loading potential ratings for landfills are included in Table 10.

Table 10. CLP Ratings for Solid Waste Disposal Sites.

	Urban/industrial rating	Agricultural/nutrient rating	General rating
Existing landfills	High	High	High
Abandoned landfills	High	High	High
Uncontrolled dumps	Medium	Medium	Medium

Contaminant Loading Potential Ratings for Underground Storage Tanks

Underground storage tanks usually contain flammable fluids such as motor fuels and heating oil, or other hazardous industrial materials. Underground storage tanks that are not exempt from EPA Underground Storage Tank rules are regulated by the Department of Ecology. Most of the regulated tanks hold motor fuel. Tanks for heating oil and agricultural use under 1,100 gallons are exempt from regulation. An inventory of all non-exempt underground tanks receiving product is maintained by the Department of Ecology as a part of the regulatory and permitting process for underground storage tanks.

The underground storage tank regulatory program is predicated on the high risk that storage tank and piping leaks pose to groundwater. One rating approach is to simply identify all underground storage tank sites as having a high risk. An alternative, site specific approach would examine conditions and risk factors such as age, design and soil type to assess each system. Table 11 has contaminant potential ratings for underground storage tanks.

Table 11. CLP Ratings for Underground Storage Tanks

	Urban/industrial rating	Agricultural/nutrient rating	General rating
Underground storage tank sites	High	Low	High

TRANSPORTATION CORRIDORS

Transportation corridors, highways and rail routes pose a risk to groundwater due to normal traffic use and accidental spills. Contaminants accumulated by normal use can enter groundwater through stormwater management devices such as drywells. De-icing compounds applied to highways in areas with prolonged winter freezing can pose a threat to groundwater. Spills are infrequent events that can release large amounts of contaminants onto the ground, into stormwater management facilities and possibly into groundwater. Clandestine or inappropriate dumping or flushing of contaminants into drywells along streets and highways can also occur.

While rail accidents are rare and very difficult to predict, the occurrence of a single large spill can have catastrophic results in an area with very susceptible groundwater quality. The Vancouver rail yard is currently being investigated as a major contamination site due to maintenance and materials handling activities dating from the late 1800s.

Other transportation facilities that should be acknowledged and identified include liquid fuel pipelines and electrical transmission facilities.

Highways are mapped by state functional road classification and are at a map accuracy compatible with parcel mapping. Road right of way also appears as a category on the existing land use map. Many transportation facilities can be identified with some degree of accuracy using tax parcel land use coding. In some cases other maps are used. Examples include pipeline easements drawn on parcel survey maps, and rail routes and electrical transmission facilities in digital Census Tiger file maps.

Contaminant Loading Potential Ratings for Rail Facilities

Rail yards should have a high rating. Rail spill risk can depend on track quality and traffic volume. High volume rail corridors should be identified for spill risk. Tracks are mapped as line features and do not necessarily require a rating.

Contaminant Loading Potential Ratings for Highways and Roads

Roads can be mapped as line features or they can be incorporated into the adjacent land use. In most cases, high volume roads such as freeways, highways and major streets should be mapped. Roads in Clark County probably should receive a medium risk rating or simply be shown as line features.

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APPENDIX A. EXISTING LAND USE AND PARCEL LAND USE CODES

Existing Land use	Parcel land use codes
Forest	130 to 134, 992
Agriculture	90, 91, 160 to 175, 177 to 179, 771, 773, 779
Service commercial	74, 145, 176, 450, 451, 700 to 737, 739, 740 to 742, 744, 772, 890 to 894, 900 to 903, 911, 915, 916, 920 to 927, 932, 933, 938, 980 to 989
Retail commercial	460 to 464, 600 to 629, 640 to 682, 684 to 699, 760 to 765, 767 to 769, 790, to 792, 794 to 799
Highway commercial	630 to 639, 683, 696, 750 to 759, 766, 793
Freeway commercial (motel, hotel, rv, etc.)	50, 51, 880 to 884
Heavy industrial and mining	140, 141, 143, 144, 200, 201, 203 to 206, 208 to 212, 220 to 23, 250 to 259, 280 to 312, 320 to 322, 324 to 379, 400 to 402, 404, 425, 430 to 439, 447, 454, 520, 521, 530 to 532, 683, 774
	180 to 189
	240 to 249
	260 to 266
Light industrial	190 to 193, 202, 205, 207, 213, 270 to 279, 313 to 319, 323, 367, 380 to 399, 412 to 414, 421 to 424, 426, 441 to 444, 455, 459, 500 to 509
Public facilities	142, 194, 411, 442, 445, 465, 522, 743, 830 to 856, 910, 912, 931, 951
	403, 405, 470 to 476, 480 to 486, 490 to 497, 522
Parks/schools/recreation	820 to 827, 913, 914, 934 to 936, 940 to 950, 952 to 963, 970 to 974, 995
Institutional	42, 44, 45, 80 to 88, 800 to 813, 860 to 872
Single family residential	10 to 16, 19, 70 to 73, 92, 511
Duplex residential	20 to 29
Multi-family residential	17, 18, 30 to 39, 41
Rural residential	1 house on 1.01 to 5 acres (includes rural residential, rural estate and rural farm)
Roads and right of way	needs pt1 codes
Vacant, mixed open, open unused, open recreational and mixed recreational	photo interpretation area of parcels greater than 5 acres and/or 991, 993, 994, 996, without structures and not classified agriculture, forest or mining; and/or parcels less than 5 or 10 acres and/or 995 with structures valued less than $20,000 and not classified agriculture, forest or mining

Appendix B.

Clark County Department of Assessment And Mapping Property Type Codes

10 HOUSING UNITS, SINGLE FAMILY
11 Single family unit not sharing structure with other uses.
13 Single family unit sharing structure or premises with other major use.
14 Single family unit subsidiary to a "more important" use.
15 Non-residential structure used as a single family dwelling.
16 Mobile home converted to permanent structure.
17 Single family condominium unit.
18 Single family cooperative housing unit.
19 Single family housing not elsewhere classified.

20 HOUSING UNITS, TWO FAMILY
21 Two family units side by side (one level).
22 Two family units partly or entirely over and under(townhouse).
23 Two family units sharing structure or premises with other major use
24 Two family units subsidiary to some "more important" use in same structure
25 None-residential structure used as two family housing unit
27 Two family units converted from single family housing unit.
29 Two family units not elsewhere classified.

30 HOUSING UNITS, MULTI-FAMILY
31 Multi-family units side by side.
32 Multi-family units above one another.(most apartment houses).
33 Multi-family units sharing premises with other major use.
34 Multi-family units subsidiary to some "more important" use
35 Non-residential structure used as a multi-family dwelling.
37 Multi-family units converted from single family housing unit.
39 Multi-family units not elsewhere classified.

40 GROUP QUARTERS, NON-INSTITUTIONAL
41 Rooming house, boarding houses.
42 Mission shelters, flop houses.
44 Fraternities, Sororities, co-ops, other membership quarters.
45 Dormitories, nurses homes, nuns quarters, etc. (except barracks frats)

50 TRANSIENT FACILITIES USED AS HOUSING UNITS

51 Residential hotels and motels. Predominantly permanent guests.

70 MOBILE HOMES, HOUSEBOATS
71 One or more mobile homes not in a mobile home court.
72 Mobile home residential court.
73 One or more houseboats at private docks.
74 Houseboat moorages.
75 Hardship Mobile Homes

76 Parks
77 Mobile Home Comdominium Park

80 GROUP QUARTERS, INSTITUATIONAL
81 Home for the aged, retirement quarters.
82 Convents, monasteries, or abbeys not associated with other uses.(see 45).
83 Orphanages.
84 Sanitariums, rest homes, mental hospitals for the chronically ...
85 Jails, prisons (except [088]),detention facilities (except juvenile [086]).
86 Juvenile offenders' home, juvenile detention centers and related facilities.
87 Armed forces group quarters (barracks, etc.).
88 Military prisons, stockades, and hospitals.

90 SEASONALLY OCCUPIED QUARTERS
91 Farm labor camps.
92 Vacation cabins.

100 WATER AREAS
101 Rivers, sloughs, streams, drainage ditches, and other water courses
102 Lakes, ponds, swamps and other natural fresh water bodies.
103 Dam retention reservoirs (any use).
104 Designated navigation channels.
105 Salt water areas (oceans, lakes).
106 Waterfalls.
107 Dikes (when exclusive use).
108 Designated flood plains, flood basins (areas usually out of water)

110 STREETS, HIGHWAYS, AND BRIDGES
111 Surfaced streets with curbs and gutters.
112 Surfaced streets without curbs and gutters.
113 Passable streets with some surfacing or grading.
114 Dedicated unimproved streets.
115 Private streets.
116 Improved walkways used by the public.
117 Freeways, other access controlled roads.
118 Bridges, viaducts, bridge approach structures (pedestrian or vehicular).
119 Highway or bridge toll stations.

130 FORESTRY
131 Forestry operations
132 Cutover or burned over timber land.
133 Forestry services (fire lookouts, ranger stations, fire fighting services).
134 Farm woodlots.

140 FISHERIES, MARINE PRODUCTS EXTRACTION, HUNTING AND TRAPPING
141 Docks and related facilities of commercial fishing operations
142 Fishery services (fish hatcheries, fish preserves, fish ladders).
143 Docks and related facilities of commercial shellfish operations
144 Facilities for extraction of other marine products (kelp, sponges).
145 Professional and commercial hunting or trapping operations.

150 GAME PRESERVES
151 Game and wildlife preserves (when the exclusive use of the land).

160 AGRICULTURE CROPLAND, PASTURES, AND RANGES
161 Grain crops, cash, feed, seed, hay, alfalfa, and feed legumes.
162 Fiber crops (flax, hemp).
163 Vegetable and fruit ground crops (strawberries, lettuce, potatoes).
164 Miscellaneous specialty crops (mint, herbs, hops, sugar beets).
165 Tree fruit or nut crops.
166 Vine and bush fruit crops.
167 Ornamental shrubs, vines, trees, flowers, Christmas trees, holly.
168 Fallow or idle agricultural land.
169 Pasture and range land (if exclusive use).

170 AGRICULTURE INTENSIVE USES
171 Farm buildings, facilities, and areas used for equipment, crop etc storage
172 Farm buildings etc, used for large animal quarters, feeding and processing
173 Farm buildings etc, used for poultry or rabbit quarters, feeding, processing
174 Farm buildings etc, for fur-bearing animal quarters, feeding, processing.
175 Feedlots.
176 Dog raising kennels etc, domestic pet raising operations, aviaries
177 Apiaries and related facilities.
178 Gamebird raising facilities (pheasant, quail, pigeons).
179 Greenhouses, commercial.

180 MINING
181 Oil or natural gas wells and services.
182 Rock quarry, crushing, sand and gravel pits.
183 Top soil and fill dirt extraction operations.
184 Metal ore mines and related facilities
185 Coal mines and related facilities.
186 Dimension stone quarries (granite, marble, shale)
187 Mining services, except oil and gas(181).
188 Clay, ceramic, and refractory minerals, mines, and related facilities
189 Chemical, fertilizer, and miscellaneous non-metallic mineral mines

190 CONSTRUCTION
191 General contractors.
192 Highway construction and repair contractors.
193 Special trade contractors (plumbing, painting, heating).
194 Highway maintenance facilities (gravel piles, road equipment storage).

200 MANUFACTURING FOOD
201 Meat and poultry products (slaughtering, canning, curing, preserving).
202 Dairy products (except receiving stations of bulk milk [504]).
203 Canning and preserving fruits, vegetables, seafoods.
204 Grain mill products (flour, animal feeds, cereals.
205 Bakery products (except when part of retail store operation 621).
206 Sugar refinery.
207 Confectionery and related products (except when part of retail).
208 Beverage industries (beer, wine, liquor, soft drinks, extracts).
209 Miscellaneous food products.

210 MANUFACTURING INDUSTRIAL PARK
211 Warehousing.
212 Manufacturing.

220 MANUFACTURING TEXTILE PRODUCTS
221 Broad woven fabric mills, cotton.
222 Broad woven fabric mills, man-made fiber and silk.
223 Broad woven fabric mills, wool (includes dyeing and finishing).
224 Narrow fabrics and other smallware mills, cotton, wool, silk.
225 Knitting mills, hosiery, outwear, underwear, knit fabrics.
226 Dyeing and finishing textiles (except wool [223] and knit [225]).
227 Floor covering mills.
228 Yarn and thread mills.
229 Miscellaneous textile mills.

230 MANUFACTURING APPAREL
231 Mens, youths, and boys suits, coats, and overcoats.
232 Mens, youths, and boys furnishings, work clothing and allied garments.
233 Womens, misses, and juniors outerwear.
234 Womens, misses, and juniors undergarments.
235 Hats and millinery.
236 Girls, childrens, and infants outerwear.
237 Fur goods.
238 Miscellaneous apparel and accessories (rubber, plastic, and other).
239 Miscellaneous fabricated textile products.

240 MANUFACTURING LUMBER AND WOOD PRODUCTS
241 Logging camps and logging contractors.
242 Sawmills and planing mills, shingles, furniture blanks, flooring.
243 Millwork and prefabricated structural wood products.
244 Wooden containers.
245 Veneer or plywood mills.
246 Treated or preserved poles, posts, dimension lumber
247 Pressed wood fiber products (particle board, wood fiber molding).
248 Shake mill.
249 Miscellaneous wood products (molding, kitchen woodenware, dowels).

250 MANUFACTURING FURNITURE AND FIXTURES
251 Household furniture.
252 Office furniture.
253 Public building and related furniture.
254 Partitions, shelves, lockers, and office and store fixtures.
255 Custom cabinet shops.
259 Miscellaneous furniture and fixtures.

260 MANUFACTURING PAPER AND ALLIED PRODUCTS
261 Pulp mills.
262 Paper mills (except building paper [266]).
263 Paperboard mills.
264 Converted paper and paperboard products (except containers, boxes [265]).
265 Paperboard containers and boxes.
266 Building paper and paperboard mills.

270 MANUFACTURING PRINTING, PUBLISHING AND ALLIED INDUSTRIES
271 Newspapers, publishing and printing.
272 Periodicals, publishing and printing.
273 Books.

274 Miscellaneous publishing.
275 Commercial printing.
276 Manifold business forms manufacturing.
277 Greeting card manufacturing.
278 Bookbinding and related industries.
279 Service industries for the printing trade.

280 MANUFACTURING CHEMICALS AND ALLIED PRODUCTS
281 Industrial inorganic and organic chemicals.
282 Plastic materials and synthetic: resins, rubber, fibers (except glass[320]).
283 Drugs.
284 Soap, detergents, cleaning products, perfumes, cosmetics, toiletries.
285 Paints, varnishes, lacquers, enamels, and allied products.
286 Gum and wood chemicals.
287 Agricultural chemicals.
289 Miscellaneous chemicals.

290 MANUFACTURING PETROLEUM REFINING
291 Petroleum refineries.
295 Paving and roofing materials.
299 Miscellaneous products of petroleum and coal.

300 MANUFACTURING RUBBER AND MISCELLANEOUS PLASTIC PRODUCTS
301 Tires and inner tubes.
302 Rubber footwear.
303 Reclaimed rubber.
306 Fabricated rubber products not elsewhere classified.
307 Miscellaneous plastic products (plastic garments made from material produced on the premises, decorative plastic panels).
308 Injected plastic products.
309 Fabricated fiberglass products.

310 MANUFACTURING LEATHER AND LEATHER PRODUCTS
311 Leather tanning and finishing.
312 Industrial leather belting and packing.
313 Boot and shoe cut stock and findings.
314 Footwear (except rubber [302]).
315 Leather gloves and mittens.
316 Luggage.
317 Handbags and other personal leather goods.
319 Leather goods not elsewhere classified.

320 MANUFACTURING STONE, CLAY, AND GLASS PRODUCTS
321 Flat glass.
322 Glass and glassware, pressed or blown.
323 Glass products, made of purchased glass.
324 Cement, hydraulic.
325 Structural clay products.
326 Pottery and related products.
327 Concrete, gypsum, and plaster products.
328 Cut stone and stone products
329 Abrasive, asbestos, and miscellaneous non-metallic mineral products.

330 MANUFACTURING PRIMARY METALS

331 Blast furnaces, steel works, and rolling and finishing mills.
332 Iron and steel foundries.
333 Primary smelting and refining of nonferrous metals.
334 Secondary smelting and refining of nonferrous metals and alloys.
335 Rolling, drawing, and extruding of nonferrous metals.
336 Nonferrous foundries.
339 Miscellaneous primary metal industries.

340 MANUFACTURING FABRICATED METAL PRODUCTS
341 Metal cans.
342 Cutlery, hand tools, and general hardware.
343 Heating apparatus (except electric [363]) and plumbing fixtures.
344 Fabricated structural metal products.
345 Screw machine products and bolts, nuts, screws, rivets, and washers.
346 Metal stampings.
347 Coating, engraving, and allied services.
348 Ordinance and accessories
349 Miscellaneous fabricated wire or metal products.

350 MANUFACTURING MACHINERY
351 Engines and turbines.
352 Farm machinery and equipment.
353 Construction, mining, and materials handling machinery and equipment.
354 Metalworking machinery and equipment.
355 Special industry machinery, food products, printing, woodworking, looms.
356 General industrial machinery and equipment (pumps, compressors, blower).
357 Office, computing, and accounting machinery.
358 Service industry machines.
359 Miscellaneous machinery and machine shop custom products

360 ELECTRICAL MACHINERY, EQUIPMENT, AND SUPPLIES
361 Electric transmission and distribution equipment.
362 Electrical industrial apparatus.
363 Household appliances.
364 Electric lighting and wiring equipment.
365 Radio and television receiving sets (except communication types [366]).
366 Communication equipment.
367 Electronic components and accessories.
369 Miscellaneous electrical machinery, equipment, and supplies.

370 MANUFACTURING TRANSPORTATION EQUIPMENT
371 Motor vehicles and motor vehicle equipment.
372 Aircraft and parts.
373 Ship and boat building and repair of commercial and naval ships.
374 Railroad equipment.
379 Miscellaneous transportation equipment.

380 MANUFACTURING PROFESSIONAL, SCIENTIFIC, AND CONTROLLING INSTRUMENTS
381 Engineering, laboratory, scientific and research instruments
382 Instruments for measuring and controlling physicical characteristics
383 Optical instruments and lenses.
384 Surgical, medical, and dental instruments and supplies.
385 Opthalmic goods.

386 Photographic equipment and supplies.
387 Watches, clocks, clockwork operated devices, and parts.

390 MANUFACTURING MISCELLANEOUS
391 Jewelry, silverware, and plated ware.
393 Musical instruments and parts.
394 Toys, amusements, sporting and athletic goods.
395 Pens, pencils, and other office and artists materials.
396 Costume jewelry, costume novelties, buttons, and miscellaneous notions.
398 Brooms, brushes, canles, lamp shades, mortician's goods
399 Dressed and dyed furs, signs and advertising displays, umbrellas, canes etc

400 TRANSPORTATION RAILROAD
401 Railroad terminals,"piggy-back" operations, and team tracks.
402 Railroad roundhouses, switch yards, maintenance facilities, sidings.
403 Railroad right-of-way.
404 Railway express.
405 Railroad bridges and trestles.

410 TRANSPORTATION BUS, TAXI, AND OTHER MOTOR VEHICLES
411 Bus (school, charter, local, highway, etc.) terminals.
412 Bus (school, charter, local, highway, etc.) storage and maintenance.
413 Taxicab terminals, stands, maintenance and storage, dispatching centers.
414 Miscellaneous local passenger transportation (ambulance, limousine, shuttle).

420 TRANSPORTATION MOTOR FREIGHT
421 Motor freight truck terminals
422 Public warehouses, household goods storage, refrigerated warehouses
423 Freight forwarding.
424 Highway truck weighing stations.
425 Contract truck hauling (logs, fill dirt), rental of truck with driver.

430 TRANSPORTATION WATER (EXCEPT MILITARY)
431 Waterfront terminals, piers, or docks.
432 Stevedoring facilities and warehouses.
433 Towing and tugboat facilities.
434 Ferry slips, moorages, loading facilities.
435 Locks, ship canals, canal control facilities.
436 Professional marine divers, salvage operations.
437 Log raft moorages and log dumps.
438 Lighthouses, permanent bouys, channel markers.
439 Channel maintenance equipment.

440 TRANSPORTATION AIR (EXCEPT MILITARY)
441 Landing fields, runways, aprons, taxi lanes.
442 Air passenger and/or freight terminal.
443 Heliports not part of airport or flying field.
444 Hangers, fueling facilities.
445 Control towers, emergency facilities, aircraft beacons.
446 Charter air service.
447 Repair facilities.

450 TRANSPORTATION SERVICES
451 Travel and transportation ticket agencies.

454 Stockyards.
455 Packing and crating services not part of transportation company
459 Services for transportation not elsewhere classified.

460 COMMUNICATION
461 Telephone exchanges, microwave and cable stations, central offices.
462 Telegraph offices, facilities.
463 Commercial and public educational radio and television stations and studios.
464 Commercial and public educational radio and television transmitter etc
465 Post office, mail handling facilities.
467 Cable TV.

470 UTILITIES ELECTRIC, GAS, STEAM
471 Electric power boosters, transformers, sub-stations, right-of-ways.
472 Electric power operating, maintenance, and repair building.
473 Gas storage tanks, pumping, distribution, pipelines, production.
474 Steam central heating plant (may include electric generation).
475 Oil, gas or other fuel electric generation plant.
476 Hydro-electric generation facilities.

480 UTILITIES WATER
481 Domestic water supply towers and structural resevoirs.
482 Domestic water supply operating and maintenance buildings and facilities
483 Irrigation water transmission (canals, pipelines, rights-of-way).
484 Domestic water supply transmission (pipelines, rights-of-way).
485 Dams does not include the generator plants [476], fish ladders [142] etc
486 Designated and controlled water shed for domestic or irrigation water supply.

490 UTILITIES SEWAGE AND REFUSE
491 Sewage pumping stations.
492 Sewage treatment and disposal plants.
493 Sewage lagoons.
494 Sewage system operating and maintenance buildings and facilities.
495 Garbage and refuse collection.
496 Garbage and refuse dumps and disposal operations.
497 Refuse incineration.

500 WHOLESALING AND SALES TO INDUSTRIAL, COMMERCIAL, AND PROFESSIONAL USERS
501 General wholesaling.
502 Motor vehicles and/or automotive equipment.
503 Drugs, chemicals, paints, and allied products.
504 Dry goods and apparel.
506 Farm product raw materials (cotton, grain, hides, raw furs, livestock).
507 Electrical goods and appliances, hardware, plumbing, heating, refrigeration
508 Machinery (professional, industrial, farm, transportation)
509 Metals, minerals, tobacco, paper products, furniture, etc
511 Residential Use on Commercial Zone
513 Single family residence with a shared major use.
514 Single family residence subsidiary to major use (caretaker)
515 Single family residence use of non-residencial structure
516 Mobile home converted to real property
517 Condominium unit
518 Single family residence commercial not elsewhere classified

520 PETROLEUM TANK FRAMS AND PIPELINES
521 Petroleum and petroleum product tank farms and bulk terminals.
522 Petroleum pipelines.

530 SALVAGE AND JUNK
531 Salvage and junk yards (excluding refuse dumps [496]).
532 Automobile wrecking.

600 RETAIL BUILDING MATERIALS, HARDWARE, AND FARM EQUIPMENT
601 Lumber and other building material dealers.
602 Heating and plumbing equipment and electrical supply store
603 Paint, glass, and wallpaper stores.
604 Hardware
605 Farm and garden implements, tools, and equipment.
606 Heavy equipment sales/service (new)(used 695).
607 Fence.
609 Other retail building materials not elsewhere classified.

610 RETAIL GENERAL MERCHANDISE
611 Department stores.
612 Mail order houses and headquarters of door to door selling organizations.
613 General merchandise store, except department[611],
614 Dry goods stores (yardage, with or without apparel).
615 Shopping centers -three or more uses, may be retail and include services.
616 Army and navy surplus stores
617 Trading stamp redemption centers.
619 Other retail general merchandise not elsewhere classified.

620 RETAIL FOOD
621 Grocery stores and super markets (including delicatessens).
622 Meat, poultry, and sea food markets.
623 Fruit and vegetable markets.
624 Candy, nut, and confectionery store.
625 Dairy products (except ice cream [627]).
626 Retail bakeries (selling goods on the premises or delivers to house).
627 Retail ice cream stores (for consumption off the premises).
629 Other retail food not elsewhere classified.

630 RETAIL AUTOMOTIVE AND ALLIED
631 Motor vehicle dealers, new cars and small trucks,
632 Motor vehicle dealers, used cars and small trucks.
633 Tires (includes retread tires), batteries, parts and accessories dealers
634 Service stations, automotive and/or truck
635 Mobile homes, camping trailer, pick-up campers.
636 Boats and marine accessories.
637 Aircraft retail sales.
638 Motorcycle sales.
639 Other retail automotive and allied not elsewhere classified (trailers).

640 RETAIL APPAREL AND ACCESSORIES
641 Wearing apparel and accessories
642 Shoes.

643 Custom tailors (garments made to measure from material sold on premise).
644 Furriers and fur shops.
645 Uniforms, athletic or work.
646 Womens foundation garments, lingerie, hosiery.
649 Other retail apparel not elsewhere classified.

650 RETAIL FURNITURE, HOME FURNISHING, AND APPLIANCES
651 Furniture stores
652 Floor coverings (may perform incidental installation service).
653 Home furnishings (curtains, china, lamp shades, pictures, mirrors).
654 Household appliances, sewing machines.
659 Other retail furniture, furnishings, or appliances not elsewhere classified.

660 RETAIL EATING AND DRINKING PLACES
661 Eating places (except drive-in, restaurants, cafes, caterers)
662 Drive-in eating and snack facilities.
663 Taverns and bars, dine, drink, and dance establishments.

670 RETAIL PERSONAL ITEMS AND ACCESSORIES
671 Jewelry, watches, silverware.
672 Sporting goods shops, sporting supplies (bait, ammunition etc).
673 Camera stores (may do film processing).
674 Artists supplies, hobby equipment, coin and stamp shops.
675 Toy stores.
676 Optical goods and hearing equipment.
677 Orthopedic and prosthetic devices.
678 Perfumes, cosmetics, wigs.
679 Other personal items and accessories not elsewhere classified.

680 RETAIL MISCELLANEOUS
681 Florists.
682 Farm and garden supplies (except growing of nursery stock[167]).
683 Fuel, oil and ice dealers.
684 Pet stores and supplies.
685 Books, stationery, drafting supplies, office supplies (except furniture).
686 Newspapers, magazines and tobacco.
687 Gifts, novelties, etc, religious articles (except church supply), flag shops.
688 Liquors, wines.
689 Apothecaries, pharmacies

690 RETAIL USED MERCHANDISE
694 Used bookstore.
695 Used equipment sales & repair.
696 Used auto parts and accessories.
697 Antique, secondhand, and pawn shops (clothing, books, furniture, etc).
698 Auction houses or places.
699 Used building materials, plumbing fixtures etc.

700 SERVICE FINANCIAL, INSURANCE, AND REAL ESTATE
701 Banks.
702 Credit agencies other than banks (saving and loan, finance company).
703 Security and commodity brokers, dealers, exchanges and services; holdings
704 Insurance carriers and agents, brokers, and service agencies.
705 Real estate companies (selling, managing, title search, subdivision, etc)

706 Combination real estate, insurance, loan or law offices.

710 SERVICE PROFESSIONAL
711 Medical, dental, and other allied professional offices and clinics
712 Medical and dental laboratories.
713 Other health and allied servies not elsewhere classified
714 Veterinarians and small animal hospitals.

720 SERVICE PERSONAL
721 Laundries, (diaper, linen, and uniform service) dry cleaning and dyeing
722 photographic studios excluding development and printing shops [673].
723 Beauty shops.
724 Barber shops.
725 Shoe repair and shoe shine shops, hat cleaning shops.
726 Funeral services and crematories.
727 Pressing, alteration, and garment repair
728 Self service laundromats.
729 Other personal services not elsewhere classified.

730 SERVICE BUSINESS
731 Advertising agencies
732 Consumers credit reporting agencies, mercantile reporting, collection
733 Duplicating, addressing, mailing, stenographic services, blueprinting etc
734 Services to dwellings etc, exterminating, landscaping, maintenance, etc
735 News syndicates.
736 Employment agencies
737 Frozen food lockers.
739 Miscellaneous business services.

740 SERVICE PARKING
741 Open lot parking facilities, commercially operated.
742 Parking garages or other structures, commercially operated.
743 Parking facilities operated by several concerns or a municipality
744 Unimproved areas used for parking

750 SERVICE AUTOMOTIVE
751 Top, body, and fender repair shops.
752 Tire repair shops, primarily recapping and retreading.
753 Automotive paint shops.
754 Miscellaneous automotive repair shops (battery, glass, upholstery).
755 General repair shops (engine and transmission overhaul, etc)
756 Towing services.
757 Driving instruction and schools.
758 Auto laundries, washing and polishing.
759 Miscellaneous automotive services.

760 SERVICE MISCELLANEOUS REPAIR
761 Repair of non-electrical household appliances and business machines.
762 Repair of electrical equipment.
763 Repair of watches, clocks, jewelry, cameras, instruments, guns, locks, etc
764 Re-upholstery and furniture repair.
765 Small boat repair.
766 Heavy equipment, tractor, and farm equipment repair
767 Welding, blacksmithing, boiler repair, tinsmiths, and coppersmiths.

768 Cesspool, septic tank, catch basin, and furnace cleaning.
769 Repair of bicycles, motorcycles, shades, rugs, tents, awnings, knives, etc

770 SERVICE AGRICULTURAL
771 Agricultural experiment farms, experiment stations.
772 Crop dusting services, crop harvesting and planting services, tilling.
773 Animal husbandry services, poultry hatcheries.
774 Contract sorting, grading, and packing services not on farm.
779 Other agricultural services not elsewhere classified.

790 SERVICE RENTAL
791 Rental of small tools and equipment, medical and party, general rental.
792 Rental construction tools and heavy equipment (except automotive [793]).
793 Auto, truck and/or trailer rental (without drivers) fleet leasing services.
794 Sporting goods rental.
795 Clothing rental.
796 Rental of store fixtures, display material, rental of equipment to business
799 Other household or personal goods rental (furniture, musical instrument).

800 COMMUNITY SERVICES HEALTH AND MEDICAL
801 Hospitals (except those for chronically or incurably ill [84]).
803 Convalescent homes (except those taking permanent patients [80]).
804 Community insect and pest control.
805 Health inspection (food, contagious disease, public health educational)

810 COMMUNITY SERVICES RELIGIOUS
811 Churches, synagogues, temples, Sunday school buildings.
812 Other religious uses (offices, reading rooms, shrines)
813 Church camps and retreats.

820 COMMUNITY SERVICES EDUCATIONSL
821 Preschoods and nurseries.
822 Primary and elementary schools.
823 Secondary schools (junior high and high schools).
824 Accredited, degree granting colleges, community colleges, universities, etc.
825 Vocational, commercial, trade and specialized schools
826 Schools for the blind, deaf, crippled.
827 School administration and service operations.

830 COMMUNITY SERVECES CULTURAL
831 Art museums and art galleries.
832 Libraries.
834 Planetaria, natural history museums, scientific exhibit museums.
835 Historical museums, exhibits.

840 COMMUNITY SERVICES GOVERNMENTAL ADMINISTRATIVE AND PROTECTIVE SERVICES
841 Government offices and courts (exclusively the function of the government).
843 Law enforcement (except jails[085 and 086]).
844 Community fire protection facilities.

850 COMMUNITY SERVICES MILITARY
851 Military or naval bases, forts, stations, camps, training sites.
852 National guard or reserve training centers;ROTC, AFROTC.

853 Military installations (radar sites).
854 Recruiting stations.
855 Civilian defense installations.
856 Military or naval offices not on military posts.

860 COMMUNITY SERVICES SOCIAL, CHARITABLE, CIVIC AND PROFESSIONAL ORGANIZATION
861 Nonprofit business associations.
862 Nonprofit professional membership organizations.
863 Labor unions and similar labor organizations.
864 Civic, social, and fraternal organizations
865 Political organizations.
867 Charitable organizations (except business activities).
868 Humane societies and shelters.
869 Nonprofit membership clubs not elsewhere classified.

870 COMMUNITY SERVICES CEMETERIES AND MAUSOLEUMS
871 Cemeteries
872 Mausoleums, columbariums, other structures for interment.

880 COMMUNITY SERVICES TRANSIENT ACCOMMODATIONS
881 Transient hotels and motel, one or two floors
882 Transient hotels and motels, three or more floors
883 Transient tourist homes.
884 Transient trailer courts.

890 COMMUNITY SERVICES AMUSEMENT AND RECREATION PRODUCTION
891 Entertainment and sports promotion agencies, ticket offices etc
892 Motion picture and video tape distribution operations.
893 Offices of performers, actors, musicians, athletes
894 Motion picture production.

900 AMUSEMENT AND RECREATION MOTION PICTURES
902 Movie theaters.
903 Drive in theaters.

910 AMUSEMENT AND RECREATION PUBLIC ASSEMBLLY
911 Legitimate theaters.
912 Auditoriums.
913 Indoor sports arenas, coliseums.
914 Outdoor sports arenas, stadiums, coliseums.
915 Amphitheaters, and other outdoor theaters (except motion picture [903]).
916 Exhibit halls.

920 AMUSEMENT AND RECREATION MARINE
921 Marinas.
922 Pleasure boat launching facilities (ramps, hoists, ways).
923 Pleasure boat moorages (wet and dry), yacht clubs.
924 Boathouses.
925 Bathing beaches (improved beaches, with or without lifeguards).
927 Unimproved beaches.

930 AMUSEMENT AND RECREATION COMMUNITY SPORT AND RECREATION CENTERS

931 Community center building and related indoor and outdoor facilities.
932 Athletic clubs and clubhouses.
933 Gymnasiums, indoor court game facilities.
934 Indoor or covered swimming pools
935 Outdoor swimming pools
936 Outdoor court sport facilities.
938 Craft or hobby clubs and centers.

940 AMUSEMENT AND RECREATION PARKS, AND PLAY AREAS
941 Parks with and including playgrounds, ballfields, and picnic areas.
942 Parks, ornamental (traffic circles, plazas for office buildings) .
943 Botanical gardens and conservatories.
944 Arboreta.
945 Zoos, aquariums.
946 Golf courses and clubhouses.
947 Driving and archery ranges, shooting ranges, gun clubs.
949 Hunt clubs, riding academies, riding stables.

950 AMUSEMENT AND RECREATION FAIRGROUNDS AND AMUSEMENT PARKS
951 Fairgrounds.
952 Race tracks.
954 Amusement parks.
956 Auto racing tracks, speedways, motorcycle courses.

960 AMUSEMENT AND RECREATION RESORTS AND VACATION FACILITIES
961 Summer recreational camps, dude ranches, etc.
962 Resorts at natural or developed scenics, geological, or other special sites
963 Improved forest or park campgrounds (tent or trailer).

970 AMUSEMENT AND RECREATION SCENERY, WILDERNESS
971 Designated and improved viewpoints, scenic lookouts.
972 Designated historical landmarks, monuments, ruins
973 Designated, developed, and preserved unique geological, topological features
974 Designated and controlled wilderness areas, primitive areas.

980 AMUSEMENT AND RECREATION MISCELLANEOUS
981 Dance halls, ballrooms.
982 Bowling alleys and billiard parlors.
983 Roller skating rinks.
984 Ice skating rinks.
985 Penny arcades.
986 Game rooms, card rooms.
987 Miniture golf courses
988 Fortune tellers.
989 Amusement and recreation facilities not elsewhere classified.

990 UNUSED
991 Unused land cleared.
992 Unused land timbered.
993 Unused buildings other than residential.
994 Unused buildings, burned out etc.
995 Unused land because of terrain.
996 Unused platted land.
999 Unidentified buildings or use.

APPENDIX D

VOLATILE ORGANIC COMPOUND DETECTIONS COMPARED TO HYDROGEOLOGIC AND LAND USE CHARACTERISTICS

By Rodney D. Swanson

Clark County Water Quality Division
Department of Community Development

CLARK COUNTY
Water Quality Division

Completed under Washington Department of Ecology
Centennial Clean Water Fund Grant TAX 91016
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PURPOSE AND SCOPE

Volatile organic compounds (VOCs) are contaminants commonly found in groundwater in urban and industrial areas. VOCs are a group of organic compounds commonly used as degreasers and solvents in industrial and commercial processes such as machine cleaning and dry cleaning. Many VOCs are mobile in groundwater and long-lived in the environment.

Groundwater in many areas of Clark County is affected to some degree by these compounds. Generally, VOC contamination occurs as very low level contamination of the shallowest aquifer; however, areas with concentrations exceeding water quality standards do exist.

This report examines relationships between mapped hydrogeologic and land use characteristics and VOCs detected in public supply wells and several wells sampled by the US Geological Survey (Turney, 1990). The results of this analysis are used to make general conclusions about the relationship between the mapped features and groundwater VOC contamination in Clark County. This report was completed as part of a state and locally funded grant to develop a method to evaluate aquifer vulnerability to contamination.

LIMITATIONS

Due to the small number of wells with VOC testing, a descriptive map-based method was used. These maps do not consider groundwater movement, showing only the mapped characteristics, sampled well locations, and well aquifer unit.

Another limitation of this small data set is that it includes chiefly public supply wells. These are often large capacity wells. Large pumping rate wells generally have larger contributing areas and may induce more rapid downward water movement through the aquifer. This increases the likelihood that contaminants may enter the well. Also, the wells in this report represent only areas and aquifers where larger public supply system wells occur and are not uniformly distributed throughout the county. In some cases, several wells may be in close proximity and represent nearly identical site conditions.

Limitations are also introduced by the accuracy and completeness of the information used to make the maps. In some cases data do not exactly reflect current conditions. Some data, such as the septic system inventory only include areas where there are large numbers of facilities. Because VOC samples are taken only from a small group of public supply wells, this report does not identify all areas where VOC contamination may be occurring.

SUMMARY OF RESULTS

An attempt was made to show the distribution of wells with VOC detections with respect to hydrogeologic and land use characteristics that could influence the likelihood of VOC contamination. This information is useful for identifying and predicting where groundwater is likely to be contaminated. VOC detections were tabulated for the five most often found compounds. Hydrogeologic factors included hydrogeologic setting, aquifer geologic unit, DRASTIC index category, and whether or not the aquifer geologic unit is exposed at land surface. Land use factors include general land use, population density, drywell density and septic system density.

The most commonly detected VOCs are tetrachloroethylene and 1,1,1-trichloroethane. This generally correlates with large scale monitoring on Long Island, New York (Eckhardt and others, 1989) which showed that 1,1,1-trichloroethane was most common (24 percent of wells), followed by tetrachloroethylene (20 percent) and trichloroethylene (18 percent). The frequency of detection for the five compiled VOCs in the 58 well sample set completed in Clark County is:

tetrachloroethylene	12 wells/58 (21 percent)
1,1,1-trichloroethane	10 wells/58 (17 percent)
1,1-dichloroethylene	3 wells/58 (5 percent)
trichloroethylene	2 wells/58
1,1-dichloroethane	1 well/58

Generally, the maps show that VOC detections are associated with more densely urbanized areas. Wells in more susceptible hydrogeologic settings more frequently test positively for VOCs. These settings are where gravel aquifers are exposed at land surface. The apparent link between susceptibility and VOC presence is somewhat qualified because much of the highest susceptibility area is located in the densest urban areas which have the greatest potential for release of VOCs. There may be a link between hydrogeologic setting and the absence of detected VOCs in the Hazel Dell area between Burnt Bridge Creek and Salmon Creek. Here, sampled wells draw water from the Troutdale Formation which is overlain by 100 to 150 feet of stratified clayey silt and sand. The overlying clayey silt makes the Troutdale Formation aquifers less susceptible to contamination.

APPLICATION TO VULNERABILITY MAPPING

There are some obvious relationships between VOC detections and map factors which can be used to identify areas where VOCs are most likely to have entered groundwater or are more likely to enter groundwater if they have not yet. Highly vulnerable areas have both a high likelihood of contaminant release (loading potential) and a high likelihood that the contaminant will enter aquifers in a short period of time (susceptibility). Lower degrees of vulnerability are associated with decreasing risk of contaminant release and slower rates at which contaminants can move into the aquifer.

Three general VOC vulnerability categories are described from the analysis in this report. These are: Areas most likely to have VOCs in groundwater now, areas that are at risk to VOC contamination in the near future, and areas where there is low risk of widespread VOCs in groundwater.

Areas at Risk for Current VOC Contamination

Areas where there are both land use and hydrogeologic factors associated with VOC detections are most likely to have groundwater contaminated by VOCs. Much of the Vancouver urban area is in this category. Other areas include Washougal and the part of Camas south of the Washougal River and the Town of Yacolt.

The specific loading risk factors are: 1) land use is industrial, urban commercial or residential with more than one family per acre, 2) population density is greater than 2.5 persons per acre, 3) drywells and french drains are common, and 4) septic systems are used at greater density than 80 per quarter section (1 system per 2 acres). A high risk that released VOCs have entered groundwater exists in areas with shallow aquifers in geologic units exposed at land surface. The greatest hydrogeologic susceptibility is for gravel or sand aquifers exposed at land surface.

Areas at Risk for Future VOC Contamination

Areas that are likely to face VOC contamination in the near future have land use factors similar to areas with VOC detections in shallow aquifers, but have deeper or less susceptible aquifers that do not yet show obvious contamination. The Hazel Dell area is an example of an area where VOCs are moving toward aquifers that are not exposed at land surface.

The principle difference between these areas and areas currently at risk is that these aquifers are in geologic units not exposed at land surface. VOCs may have entered shallower groundwater, but have not yet migrated down to the sampled aquifer. Recently detected low level TCE contamination of the Troutdale Formation gravel near the Boomsnub/Airco site east of Hazel Dell is an example of VOC migration from the upper to lower acquifer.

Areas at Low Risk for VOC Contamination

Areas without land use characteristics associated with VOC detections in groundwater are identified as having a low risk. Most of the rural and forest areas of Clark County fall into this category. These areas could have hydrogeologic characteristics associated with more vulnerable areas (shallow sand and gravel aquifers) but lack the numerous contaminant sources associated with urban areas.

MAP ANALYSIS

Wells are overlaid on hydrogeologic and contaminant loading potential factor maps to produce the maps presented in this section. Map data is summarized in tables. These tables should be used with care because of the small number of samples and the tendency of sample sites to be clustered in close proximity. Close geographic proximity of sample sites can lead to them being considered as one sample.

Data on VOCs come from Washington Department of Health (DOH) public supply well monitoring data and US Geological Survey water quality monitoring (Turney, 1990). Only wells that could be identified as field located wells in the Clark County Ground Water Management Program data base were used. This includes all 20 wells tested for VOCs by Turney (1990) and 38 of the DOH data base wells. One unlocated well with DOH data was added to the data base using a location and well construction information provided by Clark Public Utilities. All wells were sampled during 1988 through 1991.

The geologic unit of the aquifer sampled by each well was identified using well construction records, hydrogeologic interpretation of Swanson and others (1993) and Swanson and Leschuk (1992) and geologic mapping data compiled by Phillips (1987). Each well was also characterized by whether or not the sampled geologic unit was exposed at land surface.

VOC detections were tabulated for 1,1-dichloroethylene, 1,1-dichloroethane, 1,1,1-trichloroethane, trichloroethylene, and tetrachloroethylene. These are the VOCs most commonly found in Clark County groundwater.

HYDROGEOLOGIC SETTING AND AQUIFER UNIT OF SAMPLED WELLS

This map (Figure 1) shows the general aquifer type and hydrogeologic setting (from Swanson, December 1991) for each sampled well and the presence or absence of a VOC detection at each well. Hydrogeologic settings can be used to describe both general groundwater characteristics and hydrogeologic susceptibility of an area.

Clark County Hydrogeologic Settings

There are twelve hydrogeologic settings in Clark County based on the standardized settings used by the DRASTIC method (Aller and others, 1987). The settings are divided between two major groundwater regions, the Western Mountain Ranges Region and the Alluvial Basins Region.

Western Mountain Ranges Region

The Western Mountain Ranges Region includes the Cascade Mountains forming the eastern half of Clark County. This area is generally sparsely populated and has variable topography and geologic conditions. It includes steep forested bedrock mountain slopes and valley floors filled with alluvial sand and gravel. Mountain slopes are mantled with soil and glacial deposits of variable thickness.

- 1Ab Mountain Slopes - West
- 1Bb Alluvial Mountain Valleys - West
- 1Dd Glaciated Mountain Valleys - Glacial Deposits
- 1Eb Wide Alluvial Valleys (External Drainage)-West
- 1G Swamp/Marsh
- 1H Mud Flows - Mount St. Helens Deposits

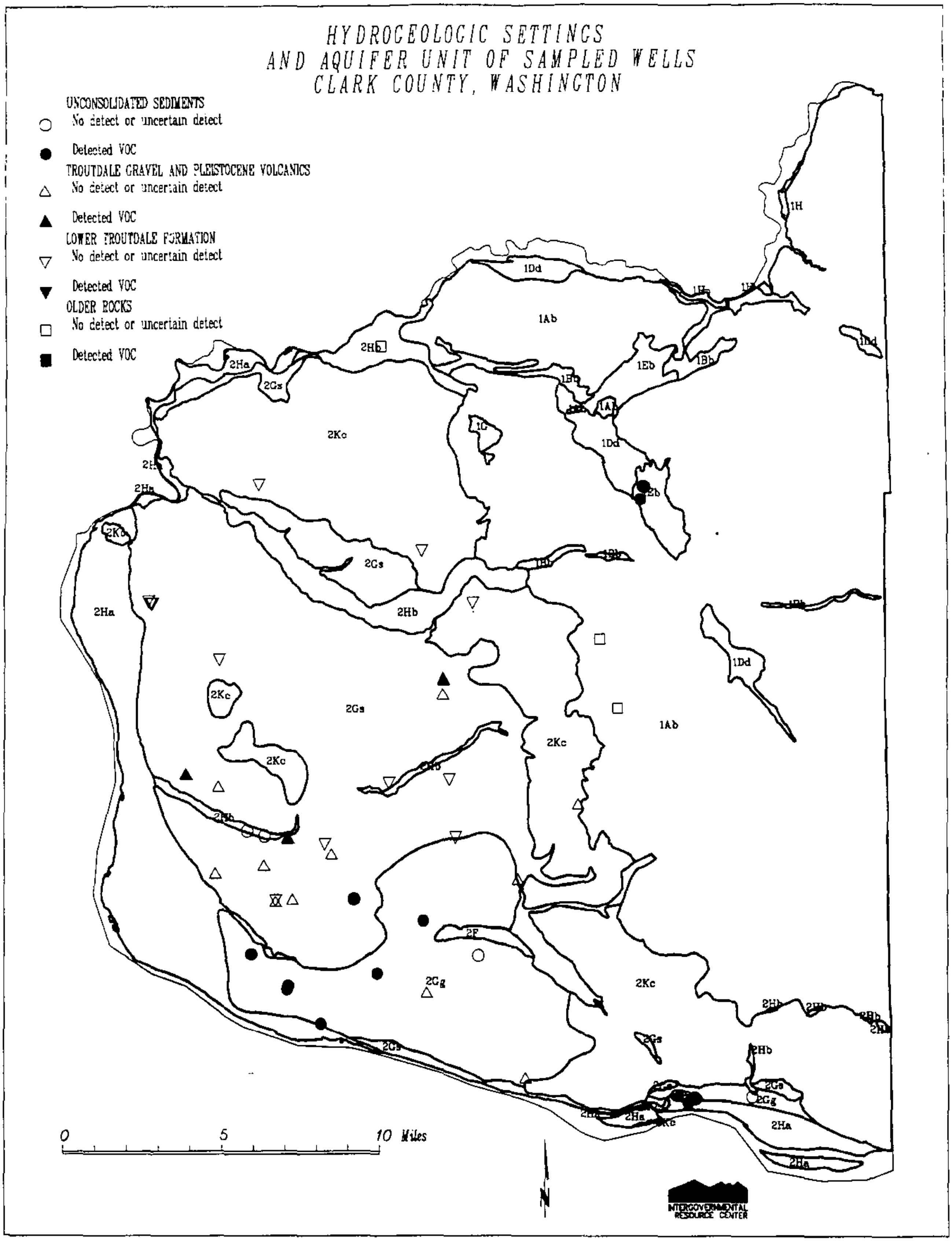

Figure 1. Hydrogeologic setting and aquifer unit.

Alluvial Basins Region

The west half of Clark County is included in the Alluvial Basins region described by the DRASTIC method. The Alluvial Basins region occupies a large area of the Western United States and is characterized by the closed basin drainage of the Great Basin and includes the Willamette Valley and Puget Sound area.

The hydrogeology is characterized by basins with several hundreds to thousands of feet of water-laid sediment filling structural basins in older rocks. In Clark County, sand and gravel layers in this setting provide almost all of the usable groundwater. Most of the recharge is by infiltration of rainfall within the basin. In urban areas, however, septic systems and stormwater disposal wells can contribute significant amounts of recharge. Recharge rates range from near zero in built up urban areas to about 40 inches per year at the margin of the Cascade Mountains. Aquifers discharge to the Columbia River and local tributaries.

The Alluvial Basins Region hydrogeologic settings are:

2F	Swamp/Marsh
2Gg	Coastal Lowlands - Unconsolidated Gravel
2Gs	Coastal Lowlands - Sand and Silt
2Ha	River Alluvium With Overbank Deposits
2Hb	River Alluvium Without Overbank Deposits
2Kc	Continental Deposits - Sediments and Volcanic Rocks

General Aquifer Units

Geologic unit names are used to define aquifer units because they are more widely understood and provide additional detail description for shallow Quaternary units. Geologic units are based largely on units compiled by Phillips (1987). Reports by Swanson and others (1993), Swanson and Leschuk (1992), Madin and Swanson (1992), Madin (1990), Mundorff (1964), and Robinson, Noble, and Carr Inc. (1980) are used to identify the geologic unit describing the aquifer at each sampled well. Preliminary aquifer descriptions in Turney (1990) were checked against more recent work to verify the preliminary aquifer choices in Turney's report.

For map presentation the units are combined into four groups that generally correspond to hydrogeologic units mapped by the US Geological Survey (Swanson and others, 1993).

Unconsolidated Quaternary Sedimentary Rocks

This unit is comprised of the youngest gravel, sand and silt deposits, and are exposed at land surface. The unit includes coarse grained quaternary catastrophic flood deposits that produce most of the groundwater used in the Vancouver area and other unconsolidated quaternary sediment aquifers. Pleistocene catastrophic flood deposits and gravel alluvium along lower Salmon Creek are prolific sand and gravel aquifers. Other units tend to be either finer grained or of very limited distribution.

Semiconsolidated Gravel Regional Aquifer and Quaternary Volcanic Rocks

This unit is the most widely used aquifer in Clark County. The unit is principally the upper Troutdale Formation of Mundorff (1964) and other poorly described gravel units. Lavas generally mapped as Boring Lavas are also included. Lithology varies from unweathered and uncemented sandy gravel to weather or cemented sandy gravel. The unit is exposed at land surface at elevations above 350 feet or is within 100 to 150 feet of land surface in all of western Clark County.

Deeper Regional Sedimentary Rocks

Aquifers in this unit are seldom used due to the presence of shallower aquifers. These are generally fine grained alluvial deposits underlying the upper Troutdale Formation. Interlayered silt and sand comprise the bulk of the unit. The unit includes the lower Troutdale Formation of Mundorff (1964) and sandstone aquifers (Swanson and others, 1993).

Older Volcanic and Sedimentary Rocks

These are dense volcanic rocks and volcaniclastic sedimentary rocks that underlie the basin sediments and form the Cascade Mountain foothills. These rocks are an aquifer in the Cascade Mountain foothills and other isolated areas where they appear at land surface.

HYDROGEOLOGIC SETTING AND AQUIFER DEPTH

This map (Figure 2) shows the hydrogeologic setting of each sampled well, whether or not the sampled aquifer is the surficial geologic unit, and presence or absence of a VOC detection at each well. A determination of whether or not the aquifer was at land surface was made by comparing aquifer units to the geologic maps of Trimble (1963), Phillips (1987), and Swanson (1993). VOC detection frequencies compared to hydrogeologic setting are summarized in Table 1.

Table 1. Hydrogeologic Settings and VOC Detections

DRASTIC Setting		Number detects/number of wells
Western Mountain Ranges Region.		
1Ab	Mountain Slopes - West	0/2
1Bb	Alluvial Mountain Valleys - West	0/0
1Dd	Glaciated Mountain Valleys - Glacial Deposits	0/0
1Eb	Wide Alluvial Valleys (External Drainage) - West	2/3
1G	Swamp/Marsh	0/0
1H	Mud Flows - Mount St. Helens Deposits	0/0
Alluvial Basins Region		
2F	Swamp/Marsh	0/0
2Gg	Coastal Lowlands - Unconsolidated Gravel	8/15
2Gs	Coastal Lowlands - Sand and Silt	4/24
2Ha	River Alluvium With Overbank Deposits	2/7
2Hb	River Alluvium Without Overbank Deposits	0/3
2Kc	Continental Deposits - Sediments and Volcanic Rocks	0/4

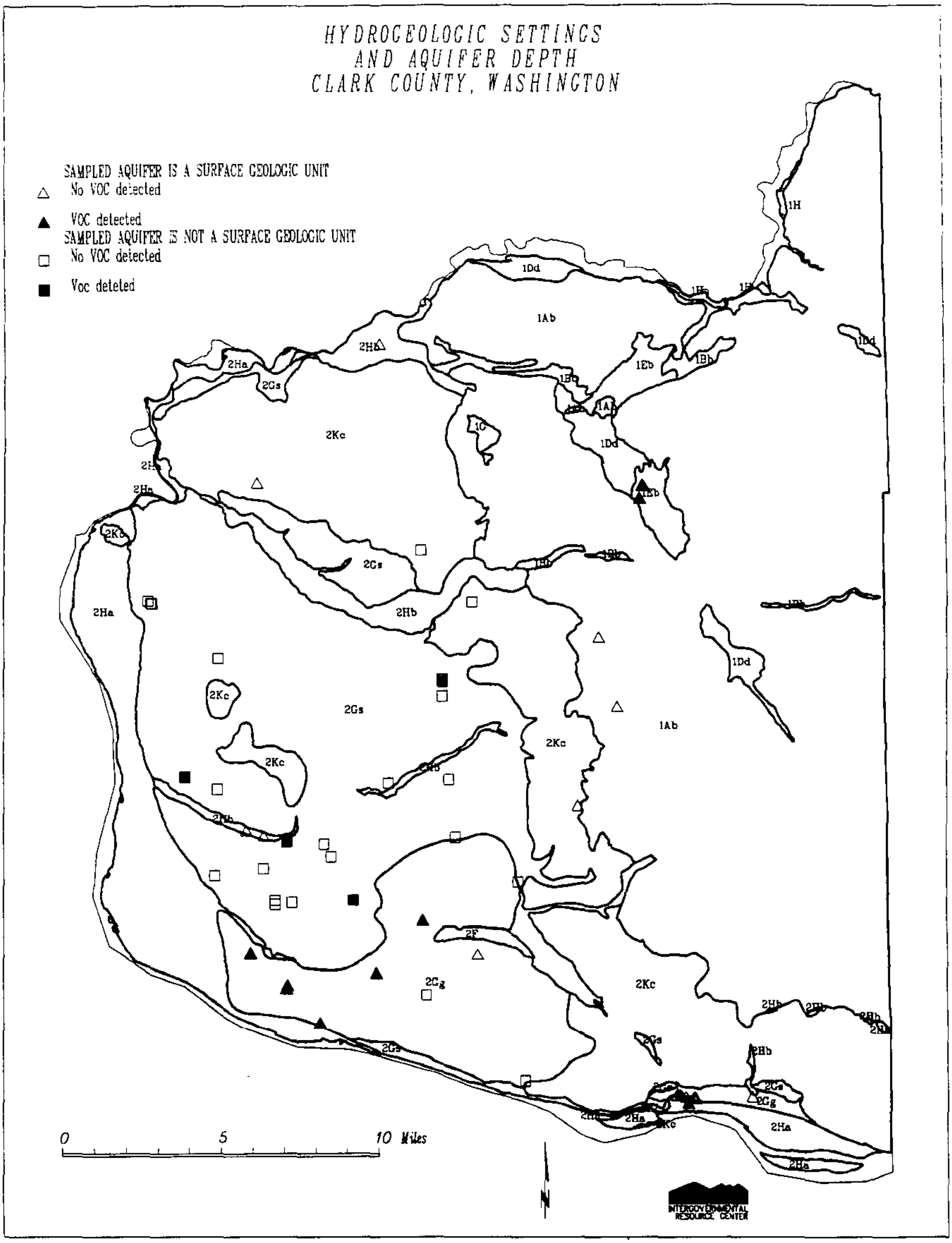

Figure 2. Hydrogeologic setting and aquifer depth.

Out of the 58 wells, 30 are in geologic units exposed at the surface and 28 are in geologic units not exposed at land surface at the well. Detect rates were 12/30 for surface units and 4/28 for deeper units.

DRASTIC INDEX

This map (Figure 3) compares the distribution of VOC detections, DRASTIC index categories and whether or not the aquifer is exposed at land surface at each well. DRASTIC index categories are modified from Swanson (December 1991) to include three DRASTIC category ranges. VOC detect frequencies by DRASTIC index category are shown in Table 2.

Table 2. DRASTIC Index and VOC Detections

DRASTIC index range		Number detects/number of wells
High	180 +	7/17 (41%)
Medium	140 to 179	7/27 (26%)
Low	100 to 139	2/14 (14%)

1974 GENERAL LAND USE

This map (Figure 4) compares general land use and VOC detections. The well symbols indicate the presence or absence of a VOC detection and whether the aquifer is exposed at land surface at the well site.

Land use was mapped by the US Geological Survey National Mapping Division using 1974 aerial photographs. Standard US Geological Survey land use categories are simplified from the original map. Table 3 includes the generalized categories and the specific land use categories mapped by the US Geological Survey. Table 4 shows VOC detect frequencies according to land use category.

Table 3. Land Use Categories According to US Geological Survey Map Categories (1974)

Combined category	US Geological Survey map categories (1974)
Forest	Deciduous forest land, evergreen forest land, mixed forest, forested wetlands, nonforested wetlands
Agriculture	Cropland and pasture, orchards, groves, vineyards, nurseries, and ornamental horticultural areas, confined feeding operations, other agricultural land, herbaceous rangeland, shrub-brushland, rangeland, mixed rangeland
Residential	Residential
Industrial	Industrial
Commercial/Urban	Commercial and services, transportation, communications and services mixed urban or built-up land, other urban or built-up land
Mining	Strip mines, quarries, and gravel pits

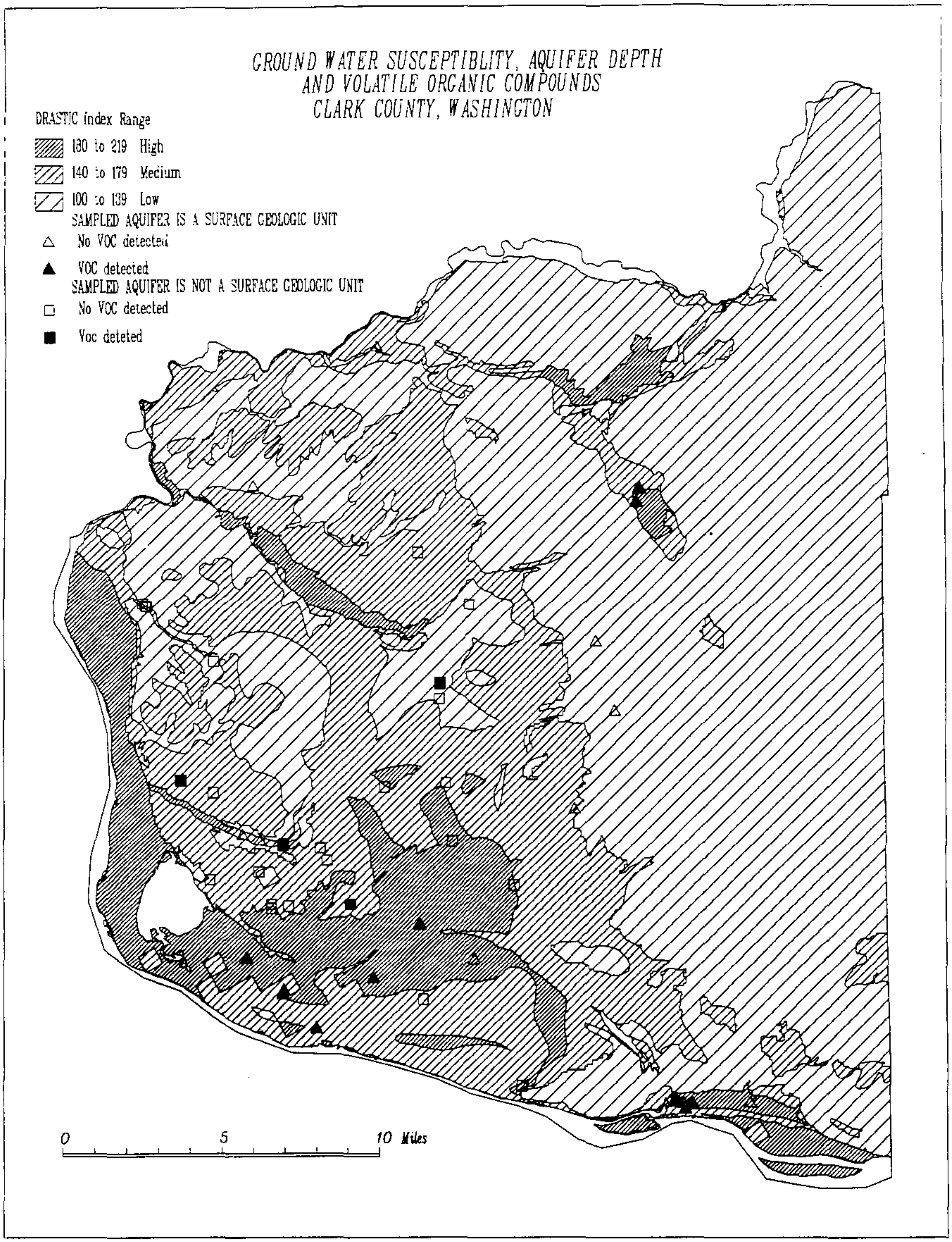

Figure 3. DRASTIC index.

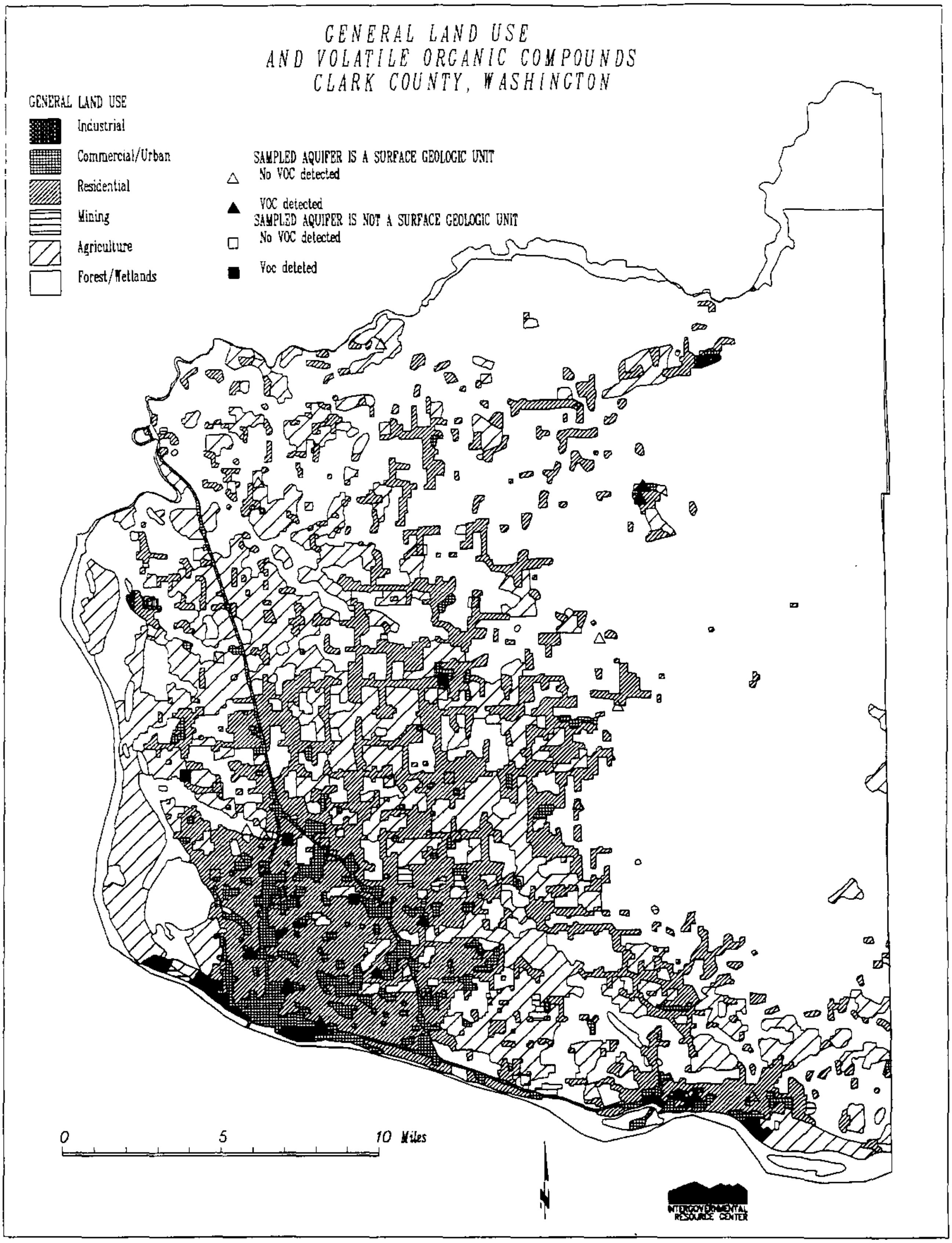

Figure 4. 1974 general land use.

Table 4. Land Use and VOC Detections

Land Use	Number detects/number of wells
Industrial	0/0
Commercial/urban	6/11 (55%)
Residential	9/29 (31%)
Mining	1/6
Agriculture	0/6
Forest	0/5
Water	0/1

Six wells are identified as being in mine areas. Five of these are in close proximity to gravel pits in the Camas/Washougal area. The sixth is in an abandoned gravel pit area along Salmon Creek, near Interstate Freeway 5. One well near the Washougal River was identified as being in water. This well is actually in an adjacent gravel pit area.

POPULATION DENSITY

This map (Figure 5) compares VOC detections to population density. Well symbols also indicate if the aquifer is at land surface. Population data are from 1990 census block data (US Bureau of the Census, 1991, US Bureau of the Census, 1989), and were aggregated into five categories. Classes for population density are based on the transition from low density to medium density residential urban land use. The great detail in census data can lead to wells in or near lower density areas such as parks and commercial centers being described as having low population density. Table 5 summarizes VOC detect frequencies compared to population density categories.

Table 5. Population Density and VOC Detections

Population density	Number detects/number of wells
Less than one person per acre	7/36
1 to 2.5 persons per acre	0/6
2.5 to 5 persons per acre	6/12
5 to 10 persons per acre	2/2
Over 10 persons per acre	1/2

DRYWELL DISTRIBUTION

This map (Figure 6) shows the distribution of drywells inventoried by the Department of Ecology (DOE) in 1986 and VOC detections. Drywells were inventoried by quarter section during a windshield survey and accuracy is deemed to be poor, with many uncounted drywells (Bowen, B, DOE, personal communication, March 1992). The Department of Ecology drywell inventory was mapped by model cell for the Portland Basin groundwater flow model (Snyder and others, 1994). The actual drywell density is probably controlled by several factors. A review of inventoried drywells, soil conditions, reported areas where drywells exist and street maps show that drywells

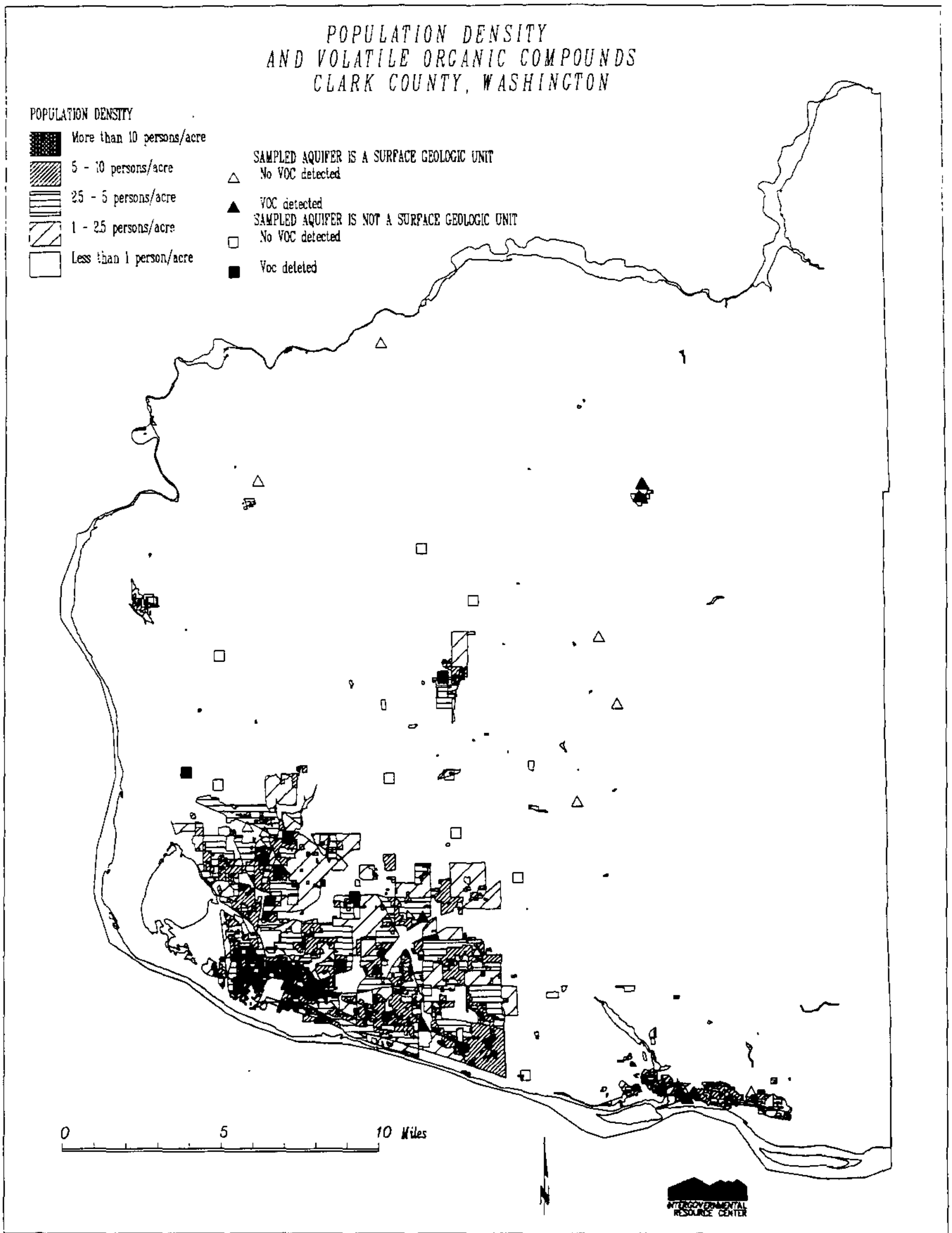

Figure 5. 1990 population density.

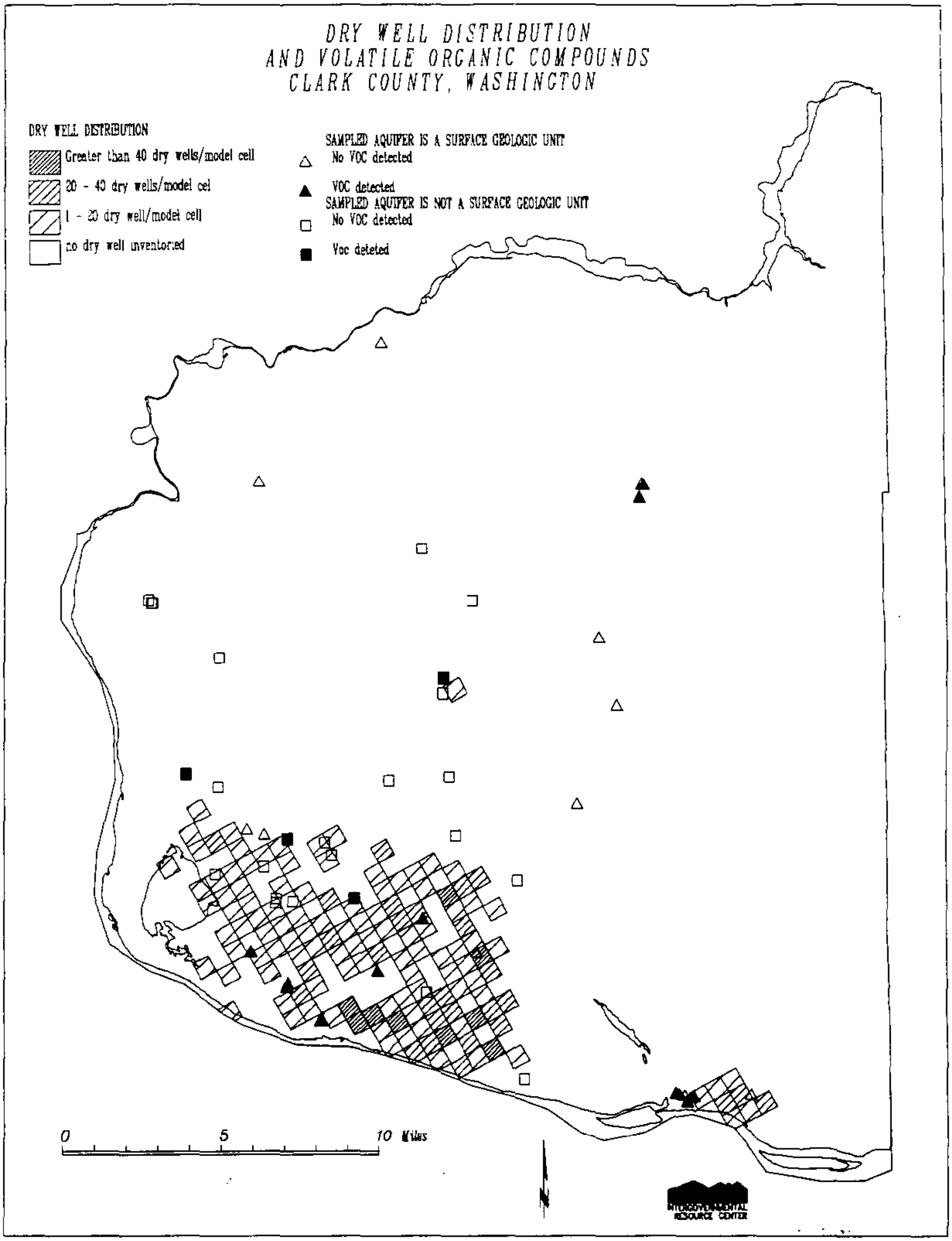

Figure 6. Dry well distribuition.

are most heavily concentrated in developed areas over gravel soils. The frequency of VOC detections in relation to drywell categories are shown in Table 6.

Table 6. Drywell Distribution and VOC Detections

Drywell categories	Number detects/number of wells
Model cells with no drywells inventoried	11/42 (26%)
Model cells with 1 to 20 wells	0/1
Model cells with 20 to 40 wells	0/1
Model cells with over 40 wells	5/14 (45%)

SEPTIC SYSTEM DISTRIBUTION

Septic systems or other on-site disposal systems can receive waste solvents which are discharged to the ground. This map (Figure 7) shows a measure of septic system distribution and VOC detections. The map symbol also shows if the aquifer is at land surface.

Septic system density was determined based upon US Geological Survey inventory (Synder and others, 1994) and Southwest Washington Health District permit files. Density categories are assigned by number of systems/acre. Results of this mapping are of somewhat limited use because the inventory is only complete in the Burnt Bridge Creek Basin where large numbers of systems contribute significantly to groundwater recharge. For example, the entire town of Yacolt, with a population of about 600 people, is on septic systems which are not inventoried. Table 7 shows the ratio of VOC detection frequencies to the number of wells sampled by category.

Table 7. Septic System Distribution and VOC Detections

Septic system density	Number detections/number of wells
Model cells with no inventory or under 40/quarter section	9/49
Model cells with 40 to 80 septic systems/quarter section	3/3
Model cells with 80 to 160 septic systems/quarter section	4/5
Model cells with 160 to 320 septic systems/quarter section	0/1

In areas with more than 40 systems per quarter section, 7 out of 9 wells have VOC detections. The total rate of wells with detections was 16 of 58 (28 percent) and the detection rate for cells with fewer than 40 systems per quarter section or no inventory was 9 of 49 (18 percent).

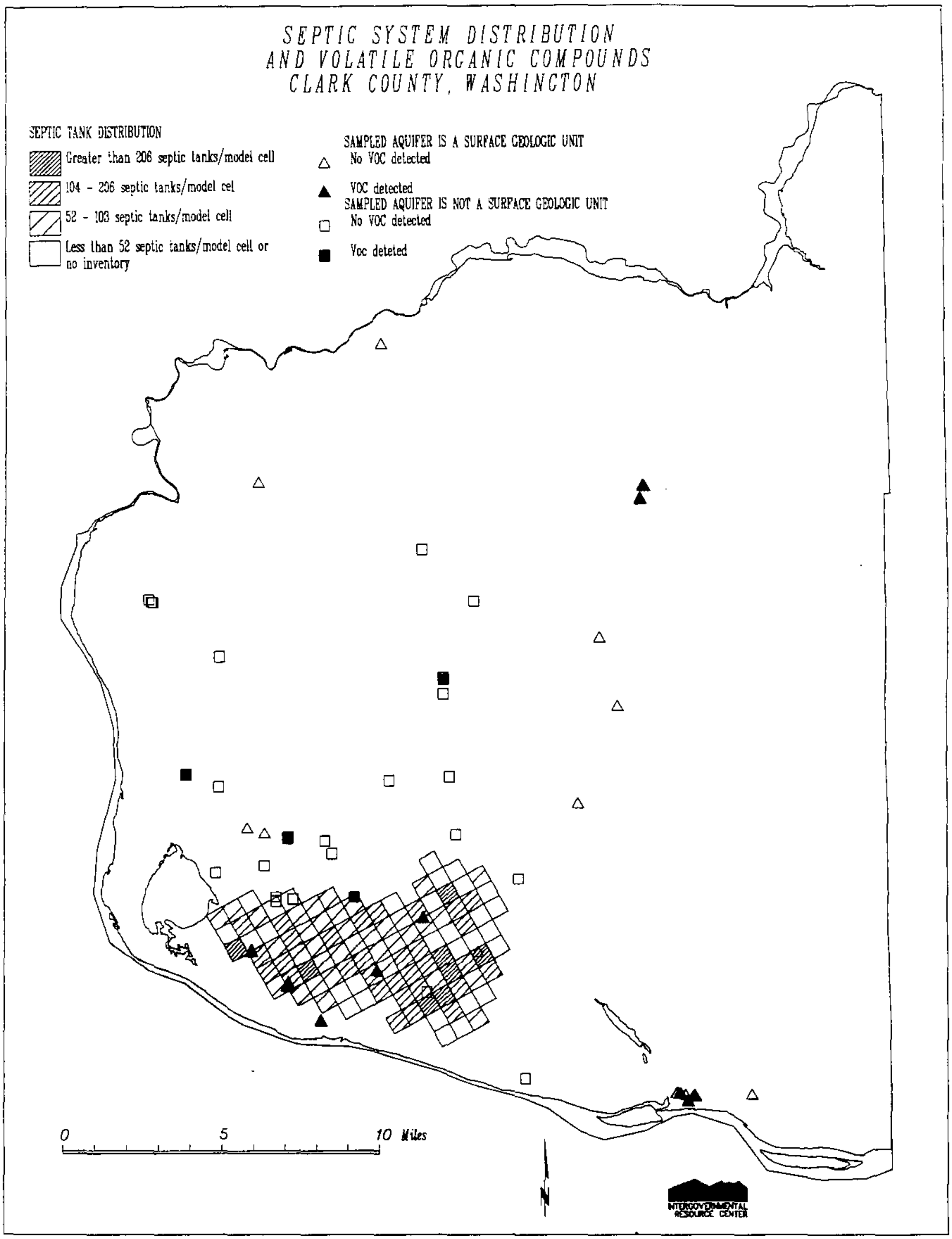

Figure 7. Burnt Bridge Creek Basin Septic System distribution.

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APPENDIX E

COMPARISON OF NITRATE DATA TO HYDROGEOLOGIC SUSCEPTIBILITY, LAND USE AND POPULATION DENSITY

By Rodney D. Swanson

Clark County Water Quality Division
Department of Community Development

CLARK COUNTY Water Quality Division

Completed under Washington Department of Ecology
Centennial Clean Water Fund Grant TAX 91016
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INTRODUCTION

Nitrate is a commonly found groundwater contaminant in urban and rural areas. Nitrate is a naturally occurring nitrogen ion that can become a contaminant when excessive amounts of nitrogen or nitrate are discharged to the ground. Nitrate concentrations in groundwater are often elevated due to disposal of nitrogen and nitrate containing water from septic systems, animal waste disposal, or use of agricultural fertilizers.

Certain hydrogeologic conditions favor nitrate formation and nitrate movement to groundwater. Nitrate forms from other nitrogen species through natural processes in the presence of oxygen. Nitrate is generally considered to be stable and mobile in groundwater. Generally, areas with sandy or gravely geology favor the formation and movement of nitrate to groundwater.

Nitrate is one of the most commonly tested groundwater constituents. Elevated nitrate concentrations may be an indication that other less commonly analyzed contaminants may be entering groundwater. For example, the presence of volatile organic compound contaminants are often associated with elevated nitrate concentrations in urban areas.

Comparison of land use, population density, and hydrogeologic factors to actual water quality data can provide a method to map areas that may have groundwater contamination due to nitrate and other untested contaminants that may be associated with nitrate contamination.

PURPOSE

This study examines the relationship of groundwater nitrate concentration with land use, population density, and hydrogeologic characteristics that generally represent influences on nitrate concentrations. Results can help to determine the relative importance of contaminant loading and hydrogeologic factors to water quality. The results should increase understanding of Clark County water quality conditions. Results from this analysis can help identify areas that may have elevated nitrate concentrations where water quality data is lacking. This report also supports development of a method to assess groundwater vulnerability in Clark County under Department of Ecology Contract TAX 91016.

METHODOLOGY

This analysis is based on the assumption that groundwater quality, and specifically nitrate concentration in shallow aquifers, is directly influenced by human activities and hydrogeologic susceptibility. Several investigations by the US Geological Survey during the 1980s compared water quality and land use for areas over shallow alluvial aquifers. The analysis in this report uses these earlier investigations, especially Eckhardt and others (1989), as a general model.

Nitrate loading potential is characterized by general land use and population density. Geologic influences are characterized by the Clark County groundwater susceptibility map utilizing the

DRASTIC method (Swanson, Dec. 1991). Susceptibility characterizes the relative ease with which a contaminant can move from land surface to groundwater. Well depths and depth to water are also examined.

Land use, population density, and hydrogeologic susceptibility were identified at each well using a computerized geographic information system (GIS). The procedure involved first overlaying well locations onto computer maps. Then the map information corresponding to each well was stored in a database for statistical analysis.

Statistical summaries were made for each factor by tabulating data for categories within each factor. Map factors that used numerical values were broken into categories using arbitrary numerical ranges. Examples of factor categories are the standard 20 point DRASTIC index ranges, land use categories such as agriculture and residential, and well depth categories of 50-foot intervals.

Statistical description of nitrate concentrations for each category or factor includes medians, quartiles, and minimums and maximums. These summary statistics are used to make some general conclusions about nitrate concentrations and the different factors.

LIMITATIONS

Analysis in this report generally examines single factors and does not attempt to characterize the interaction of more than one factor.

Factors are mapped at the sampled well location and may not accurately reflect the typical characteristics of the recharge area for each well. Land use mapping uses a 1970s older map that shows low density residential rural areas as residential and includes some presently residential areas as forest and agriculture.

Since well density is not considered, small areas with many wells can bias the sample. An example is a single subdivision where most of the nitrate concentrations over 10 mg/l occur.

Water quality often varies with aquifer and depth. The source aquifer is not known for most of the samples. Well depths are not tabulated for many wells and are not considered in the nitrate comparison. The DRASTIC susceptibility index is for the water table aquifer. In many cases the sampled well may be drawing water from a deeper, less susceptible aquifer.

Water samples were collected over a period of several months and may reflect seasonal fluctuations in water quality. Nitrate analysis results are from field methods that are accurate to about plus or minus 20 percent (Pacific Groundwater Group, March 1991).

CONCLUSIONS

Over 99 percent of the wells tested in this survey had nitrate concentrations below the 10 mg/l maximum contaminant level allowed by state and federal drinking water standards. Only 18 wells were at or exceeded the 10 mg/l maximum contaminant level. Sixty-nine wells (less than 2 percent) had concentrations equal to or greater than 5 mg/l, which is generally considered to be a significant level of contamination. Total coliform detects were found in 22 percent of the wells.

The mean nitrate concentration was 1.13 mg/l and the median was 0.8 mg/l. The minimum concentration reported was less than the method detection level of 0.01 mg/l and the maximum concentration was 16.3 mg/l. Fifteen percent of the wells had nitrate concentrations of 0.01 or less.

Map factors were categorized for analysis of nitrate concentrations. Nitrate concentrations varied in ways that would be expected based on general understanding of nitrate loading potential and hydrogeologic conditions.

Areas with DRASTIC index categories higher than 160 had higher median nitrate concentrations. Median nitrate concentrations were 1.2 to 1.75 mg/l for DRASTIC index categories of 160 or greater. Median nitrate values were 0.5 to 0.75 mg/l for DRASTIC index categories under 160.

Urban, residential, and agricultural land uses had the highest median nitrate concentrations with median values of 1.3 mg/l, 0.9 mg/l, and 0.75 mg/l, respectively. Forest land had the lowest median concentration with 0.5 mg/l.

Median nitrate concentrations increased for each of six ascending population density categories. The median nitrate concentration was 0.7 mg/l for the lowest category of 0 to 0.5 people per acre and 2.5 mg/l for the category of more than 10 persons per acre.

Analysis of nitrate loading factors and groundwater nitrate concentrations are qualified because interacting factors are not considered. Factors that are individually associated with higher nitrate concentrations also coincidentally overlap each other in south Clark County where built-up areas overlie high susceptibility areas.

Nitrate concentration values show little variation with well depth or depth to water. Conventional thought would expect decreasing nitrate concentrations with increasing well depth.

Wells having nitrate concentrations greater than 5 mg/l were compared to the total well set. Wells with greater than 5 mg/l nitrate were more likely to have high DRASTIC indexes, to be in urban, residential, or agricultural land use, and to have population densities over 1 person per acre than the total well set. Well concentrations greater than 10 mg/l probably indicate the influence of agricultural activities.

Wells with bacteria contamination had a higher median nitrate concentration. Bacteria were detected in 38 percent of the wells with 5 mg/l or greater nitrate concentrations. The presence of coliform bacteria in a well is a sign that the well bore may be open to the surface, which allows stormwater or untreated septic system effluent to enter the well bore from land surface.

ACKNOWLEDGMENTS

Water quality data collected and provided by Clark County Public Utilities and Pacific Groundwater Group made this study possible. Karl Peterson, of the former Intergovernmental Resource Center, performed geographic information system analysis.

DATA SETS

WATER QUALITY

Water quality data was collected during a large water quality monitoring survey by Clark Public Utilities during late 1990 and early 1991. Most of the samples were collected during the winter months. One sample was taken at each well. Clark Public Utilities staff collected all samples. Bacteria tests were done by the Southwest Washington Health District. Field analysis for parameters such as pH, temperature, specific conductivity, and depth to water was performed by Clark Public Utilities staff. Testing kits by Hach Inc. were used to determine nitrate, iron, and manganese concentrations to within 20 percent (Pacific Groundwater Group, March 1991). Nitrate concentrations are reported as nitrate-nitrogen in mg/l with a detection limit of 0.01 mg/l. In addition, data on iron, manganese, pH, temperature, specific conductivity, and total coliform were collected for almost every well.

WELL LOCATION AND DEPTH

A total of 4,210 wells were sampled by the survey. This is about one quarter of the estimated 17,000 household wells (US Bureau of Census, 1991) in Clark County. Wells were field located on the 1:24,000 scale Clark County Road Atlas at the time of sampling. Later, Clark Public Utilities staff digitized well locations by overlaying the road atlas pages on US Geological Survey topographic maps.

Depth to water was measured for 1,396 wells by Clark Public Utilities. Well depth was compiled for 608 wells that could be cross-referenced with the Ground Water Management Program water well data base.

HYDROGEOLOGIC SUSCEPTIBILITY

Hydrogeologic susceptibility is a general measure of the relative ease with which contaminants discharged near land surface can enter ground water. Many factors contribute to susceptibility and in most cases only general estimation of relative risk is attempted. Usually, ground water in shallow alluvial sediment aquifers is most susceptible because recharge can move quickly through overlaying sediments to the water table.

Three principle aquifers are sampled by the Clark Public Utilities survey. These are the unconsolidated sedimentary rocks, the Troutdale Formation and older volcanic rocks in the Cascade Mountains Foothills. Generally the unconsolidated sediments are most susceptible to contamination, with especially susceptible areas in southern Clark County where the aquifer is gravel and sand. The Troutdale Formation and Cascadian volcanic rocks have lower susceptibility due to their lower permeability, and in some cases, the presence of additional low permeability sediments between the aquifer and land surface.

Each well was assigned a susceptibility rating by overlaying the Clark County DRASTIC susceptibility map onto well locations. Susceptibility was mapped by the Clark County Groundwater Management Program using the DRASTIC method (Swanson, December 1991). DRASTIC is a standardized susceptibility estimation method incorporating seven mappable hydrogeologic factors. It was developed by the US Environmental Protection Agency (Aller and others, 1987).

DRASTIC indexes range from 100 to 211, with 100 the least susceptible and 211 the most susceptible. DRASTIC indexes were grouped into six categories, starting at the minimum of 100, with a 20-index point range in each category. These categories match standard DRASTIC categories in published maps by Aller and others (1987).

DRASTIC indexes assess relative susceptibility of the water table aquifer within an area. In this analysis, there was no direct way to determine if the well was sampling the water table aquifer evaluated by DRASTIC. This may lead DRASTIC to overestimate the susceptibility of wells that are in deeper aquifers. General well data, however, suggest that most of the wells in Clark County are either in the uppermost Troutdale Formation or unconsolidated sediments. Water well data collected for the Clark County Ground Water Management Program shows more than three-quarters of the wells are less than 200 feet deep.

LAND USE

Each well was assigned a land use category by intersecting the digitized well location with the digital land use map. General land use is derived from a digital land use map created by the US Geological Survey using 1974 aerial photos. The map is at an original base scale of 1:250,000. Table 1 lists the land use categories and the US Geological Survey map classes each category comprises.

The 1974 land use map, while dated, provides a good description of the areas of Clark County with residential, urban, agricultural, forest, and industrial land use. Population density data suggests that existing urban and residential areas are being filled in and that areas mapped as agricultural and forest in 1974 remain largely undeveloped or in very low density residential use. Also, areas where private wells are installed as new construction tend to be low density residential.

Table 1. Land Use Categories According to US Geological Survey Map Categories (1974)

Land use categories	US Geological Survey 1974 map categories
Forest	Deciduous forest land, evergreen forest land, mixed forest, forested wetlands, and nonforested wetlands
Agriculture	Cropland and pasture, orchards, groves, vineyards, nurseries and ornamental horticulture areas, confined feeding operations, other agricultural land, herbaceous rangeland, shrub-brush land, rangeland, and mixed rangeland.
Residential	Residential
Industrial	Industrial
Urban	Commercial and services, transportation, communications and services, mixed urban or built-up land, other urban or built-up land.
Mining	Strip mines, quarries, and gravel pits

POPULATION

Population density data were taken from 1990 census data. Population density is expressed in the number of people per acre by census block. Each well was assigned the population density for the block it was in.

Population density was categorized based on general patterns of development and previous analysis of water quality and land use. Table 2 summarizes population density categories. Lot size can also be roughly inferred using an average population per household of 2.5 persons. The lowest density category, less than 0.5 persons per acre, corresponds to about 5 acres or more for a household with 2.5 persons.

Table 2. Population Density Categories and Lot Size

Population density	Lot size
Fewer than 0.5 persons per acre	5 or more acres per house
0.5 to 1 persons per acre	2.5 to 5 acres per house
1 to 2.5 persons per acre	1 to 2.5 acres per house
2.5 to 5 persons per acre	0.5 to 1 acre per house
5 to 10 persons per acre	0.25 to 0.5 acre per house
more than 10 persons per acre	less than 0.25 acre per house

ANALYSIS

Simple statistical methods were used to characterize nitrate concentrations by DRASTIC index, land use, population density, well depth, and depth to water. These include means, medians, inter quartile values, and minimum and maximum nitrate concentrations for categories within each factor.

Wells with high nitrate concentrations (greater than 5 mg/l) were examined to determine if there were any obvious distinguishing characteristics for these wells. Most of the samples have nitrate concentrations less than 2 mg/l.

The Clark Public Utilities water quality data set consists of 4,210 wells with corresponding analysis. Several wells were removed because they had location data that gave no match to one or more of the analyzed maps. This left 4,182 wells.

Wells with possible direct contamination from septic systems, animal waste, or stormwater were removed by eliminating all wells in which bacteria had been detected. Nitrate concentration medians, inter quartile values, and ranges are summarized in Table 3 for the entire 4,182 well set, the 3,343 wells without detected bacteria, and the wells removed due to bacteria contamination.

Table 3. Nitrate Concentrations for all Wells

	All wells	Wells without bacteria	Wells with bacteria
mean (mg/l)	1.13	1.05	1.44
standard deviation (mg/l)	1.34	1.20	1.75
median (mg/l)	0.80	0.75	1.00
1st quartile (mg/l)	0.40	0.30	0.50
3rd quartile (mg/l)	1.60	1.50	1.90
minimum (mg/l)	0.01	0.01	0.01
maximum (mg/l)	16.30	16.30	16.00
total number of wells	4,182	3343	839

NITRATE CONCENTRATION AND DRASTIC INDEX

It appears that DRASTIC index categories can be separated into two groups according to nitrate concentration. Wells with DRASTIC indexes over 160 have median nitrate concentrations between 1.2 and 1.75 mg/l, while wells with DRASTIC index categories below 160 have median nitrate concentrations between 0.5 and 0.75 mg/l. Table 4 summarizes nitrate concentrations by DRASTIC index category.

Table 4. Nitrate Concentration by DRASTIC Index Category

DRASTIC index	100-119	120-139	140-159	160-179	180-199	> 200
median (mg/l)	0.05	0.75	0.5	1.2	1.5	1.75
1st quartile (mg/l)	0.25	0.3	0.2	0.5	0.6	0.8
3rd quartile (mg/l)	1	1.1	1	2.1	2.25	2.6
minimum (mg/l)	0.01	0.01	0.01	0.01	0.01	0.01
maximum (mg/l)	4	14	16.3	11	11.5	7
number of wells	432	732	1287	451	360	81

The increase in nitrate concentration with increased susceptibility could be explained in part by how DRASTIC indexes relate to conditions promoting the formation of nitrate. Nitrates form in oxidizing unsaturated conditions. These conditions are often associated with the sand and gravel geology that produces high DRASTIC indexes.

The correlation between higher susceptibility and nitrate concentration is qualified because much of the area with higher susceptibility also has more intensive land use and higher population density. Areas with high DRASTIC indexes coincidentally correspond to areas with higher population density in south Clark County. Relatively higher DRASTIC indexes coincidentally correspond to agriculture, residential, and urban land uses. The most densely populated parts of the County are in areas with DRASTIC indexes generally above 160.

NITRATE CONCENTRATION AND LAND USE

The total number of wells varies greatly for different land use categories. Almost all the sample wells are categorized as having residential, forest, and agricultural land use. No wells were in industrial areas. Table 5 summarizes statistical data for nitrate concentrations by land use category.

Table 5. Nitrate Concentration by Land Use Categories

Land use	Forest	Agriculture	Residential	Mining	Urban
median (mg/l)	0.5	0.75	0.9	1.25	1.3
1st quartile (mg/l)	0.2	0.25	0.5	0.25	0.75
3rd quartile (mg/l)	1	1.5	1.8	2.25	2.1
minimum (mg/l)	0.01	0.01	0.01	0.2	0.01
maximum (mg/l)	6.5	16.3	14	2.5	5.05
number of wells	1,109	548	1,599	7	80

Nitrate concentrations increase with urbanization and agricultural use. Urban areas have the highest nitrate concentrations with a median of 1.3 mg/l. Forest areas have the lowest nitrate concentrations. Agriculture has the highest individual well concentrations.

It should be noted that the areas sampled are generally low density residential and rural. The average population density for forest, agricultural, and mining is approximately 0.5 persons per acre. The average population density for residential is about 1 person per acre, while the density for urban land use is about 1.5 persons per acre.

NITRATE CONCENTRATION AND POPULATION DENSITY

Over one half of the sample wells are from areas with 0.5 or fewer persons per acre. Areas with the largest numbers of private wells are generally developed areas at the margins of urban service areas. Normal urban densities are not well represented in this sample. Only 5 percent of the wells in Table 6 are from areas with more than 2.5 persons per acre, or about one household per acre. Table 6 summarizes statistical data for nitrate concentrations by 1990 census block population per acre categories.

Table 6. Nitrate Concentrations by Population Density Categories

People per acre	0 - 0.5	0.5 - 1	1 - 2.5	2.5 - 5	5 - 10	> 10
median (mg/l)	0.7	0.75	1.5	2	2.1	2.5
1st quartile (mg/l)	0.25	0.4	0.75	1.2	1.5	2
3rd quartile (mg/l)	1	1.6	2.25	2.6	2.5	3
minimum (mg/l)	0.01	0.01	0.01	0.01	0.3	1.75
maximum (mg/l)	16.3	11	9	9.5	8.5	4.5
number of wells	2,305	605	268	118	38	8

There are increasing nitrate concentrations with greater population density. Median and first quartile nitrate values increase for each increased population density category. Third quartile nitrate concentration values increase for each category with the exception of 5-10 people per acre, where there is a 0.1 decrease. Increasing nitrate concentrations with greater population density could be due to greater numbers of septic systems and application of fertilizers to lawns and gardens.

NITRATE CONCENTRATION AND WELL FACTORS

Well depth was compiled for 608 of the wells that could be cross-referenced with Groundwater Management Program well data base (Pacific Groundwater Group, March 1991). Depth to water was measured at the time of water quality sample collection for 1,396 wells. Well factors are evaluated for wells without detected bacteria.

Nitrate Concentration and Well Depth

Well depth is a function of depth to water and depth to the target aquifer. Generally, depth to water is between 30 and 125 feet in the built-up area of the basin floor. Depth to the target aquifer, usually the upper part of the Troutdale Formation or the lower part of Pleistocene alluvial deposits, is usually between land surface and 150 feet (Swanson and others, 1993). About 80 percent of the wells are less than 200 feet deep and about 60 percent are less than 150 feet deep. Very shallow wells, less than 50 feet deep, account for a small fraction of the wells.

Table 7 shows nitrate concentration statistics for well depth categories. This data set includes 608 wells with no detected bacteria that were correlated to the US Geological Survey Ground Water Management Program well data base.

Table 7. Nitrate Concentration and Well Depth

Well depth (feet)	Less than 50	50-100	100-150	150-200	More than 200
median (mg/l)	0.6	0.75	0.6	0.5	0.5
1st quartile (mg/l)	0.25	0.5	0.25	0.1	0.1
3rd quartile (mg/l)	1.1	1.75	1	1	1
minimum (mg/l)	0.01	0.01	0.01	0.01	0.01
maximum (mg/l)	3.5	3.5	4.95	2.5	3.5
number of wells	19	171	169	117	132

There appears to be a slight decrease in nitrate concentrations with increasing well depth. However, little obvious difference in nitrate concentration exists between well depth categories. A physical model for predicting nitrate concentration by depth to water would expect that nitrate concentrations would decrease with increasing well depth because deeper wells generally receive older, less contaminated water. The general lack of change in nitrate concentration with well depth could be due to the relatively uniform well depths throughout the area.

Nitrate Concentration and Depth to Water

Water levels are recorded as depth to water below a measuring point near land surface. None of the wells had water levels above measuring point. Table 8 summarizes statistical data for nitrate concentration by depth to water. The depth to water in a well reflects depth to water in the aquifer. Generally in Clark County, increasingly deeper aquifers have increasingly deeper depth to water (McFarland and Morgan, 1994). Consequently, deeper wells tend to have deeper depth to water. About 75 percent of the water levels are less than 100 feet, about 40 percent are less than 50 feet, and about 18 percent of the water levels are less than 25 feet.

Table 8. Nitrate Concentration and Depth to Water

Depth to water (feet)	1-25	25-75	75-150	More than 150
median (mg/l)	0.75	0.8	0.8	0.75
1st quartile (mg/l)	0.35	0.3	0.3	0.2
3rd quartile (mg/l)	1.6	1.75	1.5	1
minimum (mg/l)	0.01	0.01	0.01	0.01
maximum (mg/l)	11.5	16.3	11	14
number of wells	253	572	471	100

There is not much difference in nitrate concentration with depth to water. However, wells with depth to water measuring more than 150 feet appear to have slightly lower nitrate concentrations based on quartile values. Factors that influence nitrate concentration and well depth also apply to depth to water.

HIGH NITRATE WELLS

Of the 4,182 wells in the complete set, 69 had concentrations greater than 5 mg/l. Fifteen of these wells were in a housing subdivision with shallow private wells constructed in an area with previous intensive fertilizer applications (verbal communication, John Louderback, Southwest Washington Health District). A tabulation of category counts for population density, land use, and DRASTIC index was made to compare the high nitrate wells to the complete 4,182 well data set. In addition, the number of wells with detected bacteria was tabulated.

Bacteria Detections and High Nitrate Wells

Bacteria were found in 38 percent of the samples with nitrate-nitrogen concentrations over 5 mg/l. The total set of 4,182 samples had bacteria detections in 22 percent of the wells. Poor well surface seals may contribute to nitrate contamination by allowing surface water into the well bore.

DRASTIC Index and High Nitrate Wells

The percentage of wells in each DRASTIC index category is tabulated in Table 9 for high nitrate wells and all wells. There are 15 high nitrate wells in one-square-mile section with a DRASTIC index category of 140 to 159.

Table 9. Percentage of High Nitrate Wells by DRASTIC Index

DRASTIC index	100-119	120-139	140-159	160-179	180-200	> 200
Percent of high nitrate wells	0	5	39	10	36	10
Percent of all wells	14	22	38	13	11	2

High nitrate wells have proportionally greater DRASTIC indexes than the total well set. This could be due to increased nitrification and ease of nitrate migration in more susceptible areas. Also, areas with higher DRASTIC indexes tend to also be areas with higher population density and septic system density.

Land Use and High Nitrate Wells

Percentage of wells in each land use category is tabulated in Table 10 for land use categories.

Table 10. Percentage of High Nitrate Wells by Land Use

Land use	Mining	Forest	Urban	Agriculture	Residential
Percent of high nitrate wells	0	3	6	31	60
Percent of all wells	< 1	34	2	16	48

The high nitrate wells are predominantly agricultural and residential land uses. These uses total 91 percent of the high nitrate wells. Forest land use is only three percent of the high nitrate set versus 34 percent of all wells. It should be noted that 13 percent of the 21 high nitrate samples mapped as agricultural are from a housing development in areas mapped as agricultural land use. However, the source of nitrate loading was agricultural.

Population Density and High Nitrate Wells

Percent of wells for each population density class is tabulated in Table 11 for high nitrate wells and the complete data set.

Table 11. Percentage of High Nitrate Wells by Population Density

People per acre	0 - 0.5	0.5 - 1	1 - 2.5	2.5 - 5	5 - 10	> 10
Percent of high nitrate wells	44	16	20	12	7	1
Percent of all wells	69	17	8	1	1	< 1

Almost one-half of the high nitrate wells are from areas with fewer than 0.5 persons per acre. However, high nitrate wells generally had higher population density than the total well set. The high nitrate wells have a smaller proportion of wells in the 0 to 0.5 person per acre category, an equal proportion in the 0.5 to 1 person per acre category, and larger proportions in all categories over 1 person per acre.

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APPENDIX F

WELLHEAD PROTECTION AREA INVENTORY USING A GEOGRAPHIC INFORMATION SYSTEM

By Rodney Swanson and Clifton McCarley

Clark County Water Quality Division and
Clark County Department of Assessment and GIS

CLARK COUNTY Water Quality Division

Completed under Washington Department of Ecology
Centennial Clean Water Fund Grant TAX 91075
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DISCLAIMER

The maps and tables in this report are intended for the purpose of presenting the results of a computerized data inventory. The results of this report are initial inventories that require field verification for much of the information. The maps and tables presented in this report are derived from data compiled from many sources. Some map information is less accurate than parcel base maps upon which it is presented, resulting in facilities such as underground storage tanks and water wells being mapped in the incorrect parcel. Some information may contain errors or not represent current conditions at a site.

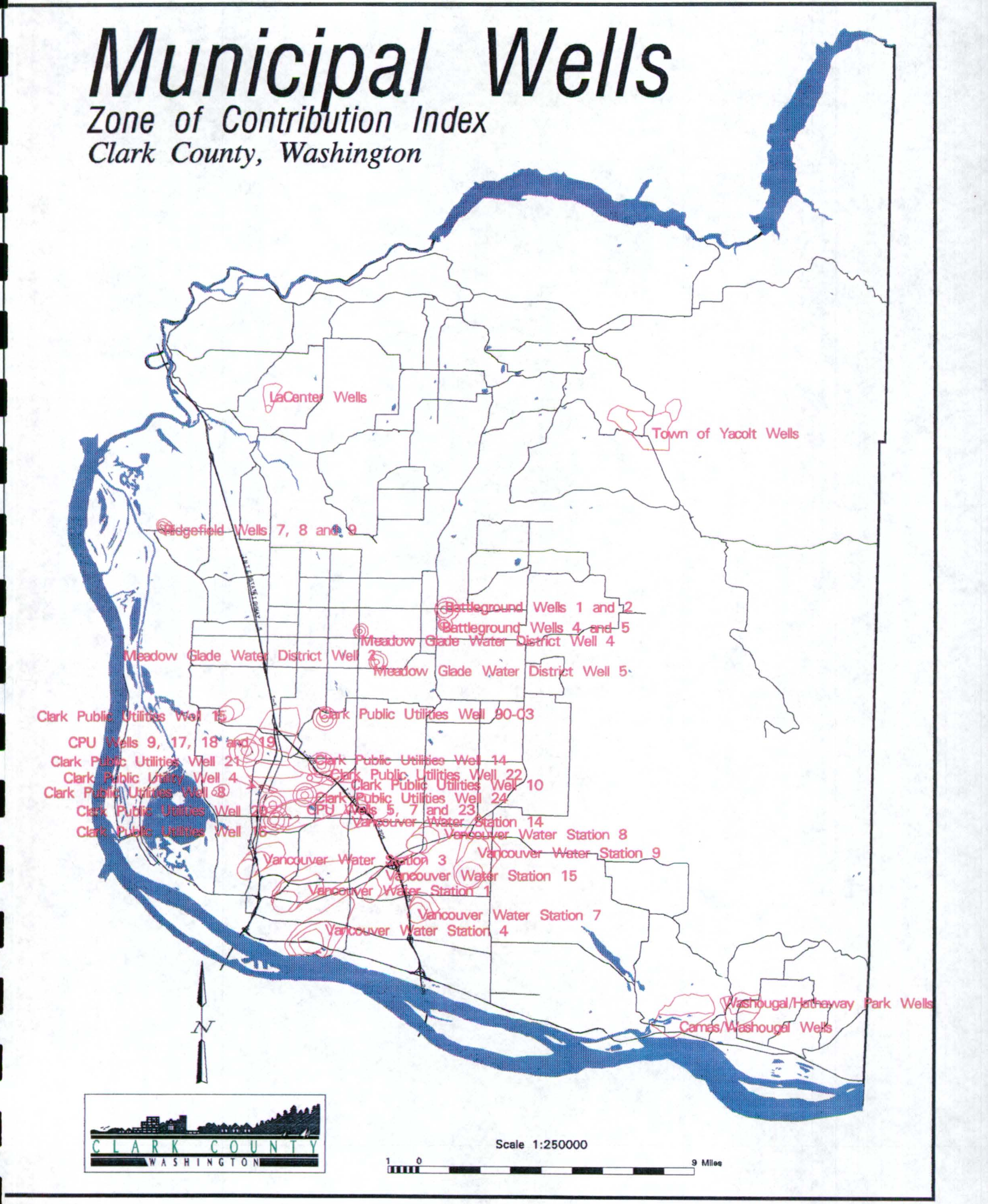
INTRODUCTION

An inventory of potential sources of groundwater contamination is a required component of local wellhead protection areas under the Washington State Wellhead Protection Program (Washington Department of Health, December 1993). The inventory is intended to identify past, present, and future activities that may pose a risk to regulated public water supply wells. This document describes a method to perform wellhead protection area inventories for a pilot wellhead protection program. The program was completed by the Clark County Water Quality Division and the Clark County Department of Assessment and GIS (geographic information systems) with funding from the Washington Department of Ecology Centennial Clean Water Fund and the City of Vancouver. Under the Washington Wellhead Protection Program, public water systems have the primary responsibility for implementing wellhead protection, including inventory requirements. The inventory conducted for the project may be sufficient to meet minimum requirements of the Washington Wellhead Program. Results of the inventory analysis were transmitted to water utilities and municipalities for their use.

This report describes a public supply system wellhead protection area inventory using a geographic information system, commonly called a GIS. Wellhead protection areas are areas managed to protect wells from contamination. The wellhead protection area is the land area that overlies the zone of an aquifer that contributes water to a well. In Clark County, the wellhead protection areas are divided into zones that correspond to the estimated time required for water to travel from a point in the aquifer to the well. A GIS is a computerized system for storing, analyzing, and mapping data that describes areas of the earth.

The GIS is used to compile and map computerized data within wellhead protection areas. The inventory includes many potential contamination sources that are commonly inventoried and managed in wellhead protection areas. Land use is inventoried for each parcel using tax assessor parcel data. Potential sources of contamination are inventoried using a series of computer maps compiled by Clark County agencies and the US Geological Survey since the late 1980s. The one-year, five-year, and ten-year zones of contribution for wells supplying major water systems were inventoried. Figure 1 shows the wellhead protection areas inventoried for this project.

The GIS inventory provides an initial screening that can help identify objectives for wellhead protection by showing existing land use and waste disposal patterns. The inventory is considered preliminary because data is not specifically field checked for the wellhead protection program. Areas or sites where field inspections are critical to protecting drinking water quality can be identified. The inventory is also valuable for identifying types of information that are lacking or not adequate for implementing wellhead protection measures.



ıre 1. Wellhead Protection Area Locations

wellhead protection area. Summary tables list totals for each inventoried characteristic within each wellhead protection area. Complete data bases are stored as GIS maps and tables and can be transferred to water utilities for use during inventory work. Informational inventory maps showing land use, zoning, and potential sources of contamination within wellhead protection areas were prepared.

In addition to preliminary mapping, the use of GIS can facilitate ongoing wellhead protection area management. A GIS provides a framework for compiling field inventory results in a system that can facilitate analysis and graphic presentation. Geographic information systems are especially useful where management programs require compiling and managing site specific information.

METHODOLOGY

The concept behind the GIS inventory methodology is relatively simple. A GIS is used to overlay wellhead protection area delineations and maps of each inventoried feature to identify the individual sites that fall within each wellhead area. Within each wellhead protection area, separate zones are identified for one-year, five-year, and ten-year time-related contributing areas. This allows more detailed summary of inventory data in areas where management options may vary depending on the distance from the well.

The Clark County Department of Assessment and GIS performed the GIS analysis using the ARC\INFO software package by Environmental Systems Research Institute, Inc. on Hewlett Packard UNIX workstations.

The first step in the analysis was to compile data maps for all inventoried features. Overlaying wellhead protection areas on inventory feature maps created a set of maps for each wellhead protection area that can be stored in GIS and used to create maps and data tables. Each wellhead protection area was assigned a unique identification number to simplify identification.

Examples of maps and tables summarizing original inventory data are presented in this report. Tables for each wellhead protection area summarize the inventory results. Two sets of maps were made for each wellhead protection area. One map set shows existing land use, parcels with septic systems and sanitary sewer lines, and animal waste application areas. The second map set shows land use zoning, water wells, and potential sources of contamination including landfills, underground storage tanks, and known contamination sites. Complete data sets are available to transfer to public supply systems.

Each wellhead protection area may contain one or several water supply wells. A wellhead protection area can be for a single well or closely spaced wells which are treated as a single well. In other cases, wells in close proximity and a single hydrogeologic setting are combined into a single delineation. Examples of wells grouped into a single delineation include the numerous wells in the gravel aquifer in the Camas/Washougal area, closely grouped wells operated by Clark Public Utilities, and the wells in Yacolt basin.

ACKNOWLEDGMENTS

This project used data from many sources, each listed in the following section. The cooperation of these organizations is greatly appreciated.

INVENTORY DATA

The following section describes maps or data tables used to map wellhead protection areas, parcel land use, and potential contaminant sources.

WELLHEAD PROTECTION AREA DELINEATIONS

Wellhead protection areas are defined using hydrogeologic models to estimate the area of the groundwater flow system that contributes water to a well. These hydrologically defined areas can also be referred to as contributing areas in order to distinguish hydrogeologic analysis results from wellhead protection area boundaries which are jurisdictional or administrative. The terms wellhead protection area and zone of contribution, however, are often used interchangeably. Generally, time intervals are used to define these contributing areas. In Clark County, one-year, five-year, and ten-year zones of contribution define and map areas where water is estimated to travel to a well within the specified time interval.

Contributing area delineations were done by several organizations. In some cases several delineations exist for individual wells. The most accurate and technically defensible contributing area delineation was selected as the wellhead protection area for each well. The US Geological Survey Portland Basin groundwater flow model and a particle-tracking model were used to define contributing areas for City of Vancouver water supply wells (Orzol and Truini, written communication, 1992). US Geological Survey modeling results were modified slightly by the Clark County Water Quality Division to transfer results from the Portland Basin model grid to actual well locations. Contributing areas for Clark Public Utilities supply wells were delineated using a combination of semi-analytical models and hydrogeologic mapping (Pacific Groundwater Group, written communication, March 1993). Calculated fixed radius delineations were done for Clark Public Utilities deep wells (Pacific Groundwater Group, written communication, March 1993). Yacolt, Washougal, and Camas wells were delineated using hydrogeologic mapping (Swanson and Leschuk, 1992, modified by Clark County Water Quality Division). The remaining delineations are by the Water Quality Division using semi-analytical models or a combination of semi-analytical modeling and hydrogeologic mapping.

Delineations by the Clark County Water Quality Division, the Intergovernmental Resource Center, and the US Geological Survey (Orzol and Truini, written communication, 1992) were transferred from original base maps to 1:24,000 scale County parcel maps and digitized by the Department of Assessment and GIS. Pacific Groundwater Group delineations were transferred to the County as a digital map using the Department of Assessment and GIS tax parcel boundary map as a base. The Department of Assessment and GIS converted the various delineation maps into GIS maps.

EXISTING LAND USE (1993)

Existing land use provides a general description of the types of activities that occur within the wellhead protection area delineations. Particular types of land use, such as industrial, have posed a greater risk of contaminating groundwater. The high degree of detail in this map makes it usable at a local scale.

The Department of Assessment and GIS created and maintains the existing land use map. The map was made by integrating aerial photography and GIS parcel land use codes and boundaries from the Assessor's files. Aerial photography identifies areas of used and unused land, and different types of agricultural and forestry uses in rural areas and for residential parcels larger than five acres. Parcel boundaries and land use codes identify specific categories of land use in built-up areas and parcels less than five acres in size. Table 1 shows each land use type and associated assessor parcel land use codes.

Table 1. Existing Land Use Categories and Parcel Land Use Codes

LAND USE	PARCEL LAND USE CODES
FOREST	130 to 134, 992
AGRICULTURE	90, 91, 160 to 175, 177 to 179, 771, 773, 779
COMMERCIAL	
Service	74, 145, 176, 450, 451, 700 to 737, 739, 740 to 742, 744, 772, 890 to 894, 900 to 903, 911, 915, 916, 920 to 927, 932, 933, 938, 980 to 989
Retail	460 to 464, 600 to 629, 640 to 682, 684 to 699, 760 to 765, 767 to 769, 790, to 792, 794 to 799
Highway	630 to 639, 683, 696, 750 to 759, 766, 793
Freeway (motel, hotel, RV, etc.)	50, 51, 880 to 884
HEAVY INDUSTRIAL AND MINING	
	140, 141, 143, 144, 200, 201, 203 to 206, 208 to 212, 220 to 23, 250 to 259, 280 to 312, 320 to 322, 324 to 379, 400 to 402, 404, 425, 430 to 439, 447, 454, 520, 521, 530 to 532, 683, 774, 180-189, 240-249, and 260-266
LIGHT INDUSTRIAL	190 to 193, 202, 205, 207, 213, 270 to 279, 313 to 319, 323, 367, 380 to 399, 412 to 414, 421 to 424, 426, 441 to 444, 455, 459, 500 to 509
PUBLIC FACILITIES	142, 194, 411, 442, 445, 465, 522, 743, 830 to 856, 910, 912, 931, 951
	403, 405, 470 to 476, 480 to 486, 490 to 497, 522
PARKS, SCHOOLS, RECREATION, AND INSTITUTIONAL	42, 44, 45, 80-88, 800-813, 820 to 827, 860-872, 913, 914, 934 to 936, 940 to 950, 952 to 963, 970 to 974, 995
RESIDENTIAL	
Single Family	10 to 16, 19, 70 to 73, 92, 511
Duplex	20 to 29
Multi-family	17, 18, 30 to 39, 41
Rural Residential	1 house on 1.01 to 5 acres (includes rural residential, rural estate, and rural farm)
ROADS AND RIGHT-OF-WAYS	110-119
Vacant, Mixed Open, Open Unused, Open Recreational, and Mixed Recreational	Photo interpretation area of parcels greater than 5 acres and/or 991, 993, 994, 996, without structures and not classified agriculture, forest, or mining; and/or parcels less than 5 or 10 acres and/or 995 with structures valued less than $20,000 and not classified agriculture, forest, or mining

PARCEL BOUNDARIES AND PARCEL LAND USE

The Clark County Department of Assessment and GIS has digital mapping for tax parcel boundaries and associated Assessor's files. Parcel boundaries are from survey plats. Land use is one of many attributes that are entered into the Assessor's data base for each parcel. Each parcel is coded with a serial number that is a unique identification code for that parcel. Tax parcel mapping can facilitate the use of GIS for compiling information for each site.

The most useful attribute for inventory purposes is probably the property type code describing the current land use at each parcel. The property type is similar to the Office of Management and Budget SIC (Standard Industrial Classification) code and is used to describe the type of use at each parcel. A review of all parcel property type codes showed that there are 433 different codes currently in use. Of these, the great majority are in one of the twenty most numerous property type codes. A complete listing of property codes and associated land use is included as a part of Method to Estimate Contaminant Loading Potential Ratings, Appendix C, Method to Evaluate Aquifer Vulnerability Through Conjunctive Use of A Ground Water Model and Geographic Information System (Swanson, 1994).

ZONING

Land use zoning provides a good description of the types of land uses that should be expected to be built within a wellhead protection area. Mapping zoning and the wellhead protection area produces a simple method to evaluate the potential for a high-risk land use to locate within the area.

A zoning map is maintained by the Department of Assessment and GIS that matches parcel boundary mapping. The parcel data base also includes the zoning designation for each parcel. Because of the multiplicity of zoning designations existing for the municipalities in the county, the zoning maps show generalized zoning groupings and letter codes.

WATER WELLS

Water wells are direct conduits through overlying rock to groundwater. In areas where contamination of groundwater exists, wells can provide conduits for contaminated water to move vertically from shallow groundwater to deeper aquifers used for public supplies.

The total number of active and unused wells in Clark County is unknown. The 1990 housing census estimated that there are about 17,000 households that derive water from private wells. Well inventories are large but not complete. About 10,500 wells are included in the well data base compiled by the Water Quality Division and the Department of Assessment and GIS. This includes about 7,000 wells inventoried by the Ground Water Management Program and an additional 4,200 wells from field inventories conducted by Clark Public Utilities (Pacific Groundwater Group, March 1991). The Ground Water Management Program inventory includes all Washington Department of Ecology's water well reports on file in 1988 and field records from previous US Geological Survey investigations. Clark Public Utilities has a water quality monitoring data base with about 4,200 wells. About 700 of the wells in the Clark Public Utilities well set are also included in the Ground Water Management Program well data base. The Southwest Washington Health District started permitting wells under requirements of the State Growth Management Act in 1991. This information is in a data base at the Health District.

About 5,000 wells have digital map locations that are transferred from field mapped locations on 1:24,000 scale maps. The remaining 5,500 wells have digital map locations calculated from quarter-section descriptions on driller reports. Ecology driller report data is compiled for most of the 7,000 wells inventoried by the US Geological Survey in 1988. Data for the other wells are less complete.

The total number of unused wells in Clark County is unknown and no inventory or data exists describing unused wells. In some areas of the United States there are as many as one unused well for every active well (Zimmerman and others, 1989). The only way that an unused well is identified in the Ecology well data base is through a proper abandonment record. Some abandoned wells are identified by County building inspectors, but this rarely occurs and no compiled list exists. Also, the Health District has recently begun to require abandonment of wells within 100 feet of septic systems and abandonment of unused wells outside the 100-foot septic setback.

UNDERGROUND STORAGE TANKS

Underground storage tanks (USTs) usually contain flammable fluids such as motor fuels, heating oil, or other hazardous industrial materials. Underground storage tanks are not exempt by EPA. UST rules are regulated by the Washington Department of Ecology. Most of the regulated tanks hold petroleum products. Exempt tanks include heating oil tanks and agricultural use tanks under 1,100 gallons.

An inventory of all non-exempt underground tanks receiving fluids is completed by Ecology as a part of the UST regulatory and permitting process which began in 1986. Ecology maintains a data base of UST sites from the Underground Storage Tank Notification Form List. A digital map of UST sites was created by the Intergovernmental Resource Center using address and business name to map each site on 1:48,000 or 1:24,000 scale base to digitize site locations. The map is accurate to about one city block. The last update of the Intergovernmental Resource Center UST maps was in March 1991. In addition to tank sites that are inventoried by Ecology, land uses that are likely to use significant amounts of petroleum products can be mapped using tax parcel land use.

DRYWELLS

Drywells are large-diameter shallow disposal wells that are widely used in Clark County to dispose of stormwater. Stormwater entering drywells can contain many urban contaminants including metals and petroleum products. In addition, drywells can receive contaminants from drains routed from indoor and outdoor vehicle maintenance areas, materials handling areas, and other commercial and industrial facilities. Rainfall routed to drywells from pavement and roofs contributes large amounts of water to aquifers in urbanized Clark County. In some areas, over one-half of groundwater recharge is due to drywells (Snyder and others, 1994).

At this time no complete digital drywell inventory exists for Clark County. The current digital inventory is compiled from an inventory by the Washington Department of Ecology in 1986. The Ecology inventory counted drywells in a windshield survey and totaled them by quarter sections.

Accuracy of this survey is deemed to be poor, with many uncounted drywells (B. Bowen, Washington Department of Ecology, personal communication, March 1992). The Ecology inventory was compiled into GIS format by the US Geological Survey. The survey does not include any updates since 1986. The map can be used to determine if drywells are routinely used in an area. County and City of Vancouver's records map many of the drywells.

ON-SITE WASTE DISPOSAL

Septic systems and other forms of on-site waste disposal are common in rural areas or areas where development preceded installation of sanitary sewer. Properly designed and constructed septic systems remove pathogens and some inorganic constituents such as phosphorus from domestic wastewater. However, septic systems are not capable of treating many household contaminants such as paint materials, cleaning solvents, and automotive products. These contaminants can be discharged to groundwater if they are dumped into drains that discharge to septic systems. Most of the septic systems in Clark County are permitted by the Southwest Washington Health District under authority of the State Department of Health. Larger septic systems, over 3,500 gallons per day, are regulated directly by the Washington Department of Health.

The Health District maintains a digital data base for all septic system permitting actions in the County after 1985 and contains over 6,000 records. Two exhaustive sewer connection inventories by the City of Vancouver and the Burnt Bridge Creek Stormwater Utility are the source for much of the septic system data. The inventories conducted a building permit and sanitary sewer record search for each developed parcel. In cases where there was an uncertain record of sewer connection a dye test was performed to test connection to sanitary sewer.

A digital parcel based septic system map was compiled by the Water Quality Division and the Department of Assessment and GIS using three local septic system and sewer connection data bases. Each septic system site or sewer hookup inventory is coded by parcel serial number, facilitating GIS mapping. The mapping is very good in areas where inventories were done by the Burnt Bridge Creek Utility and the City of Vancouver. Outside these areas, septic system inventory is not complete because digital Health District records exist only after 1985.

SANITARY SEWER LINES

Maps of sanitary sewer lines show sewer availability. The Department of Assessment and GIS digitized sewer lines from records provided by utilities as a part of analysis for compliance with the State Growth Management Act. The amount of detail varies with each system. The Hazel Dell system map includes laterals to buildings, while the other sewer system maps include only main lines.

ANIMAL WASTE APPLICATION SITES

Animal waste and wastewater from dairy facilities are routinely disposed of by spraying or spreading onto fields. Other types of livestock waste are both disposed of on field and used as fertilizer for crops. These wastes contain nutrients and microorganisms that can contaminate surface and groundwater. Under optimal conditions nutrients are taken up by field crops and microorganisms are trapped in soil. However, if application rates exceed crop capacity for nutrient consumption, contaminants such as nitrate can move through the soil into groundwater.

Animal waste application is mapped for many of the larger livestock operations. These include dairies, beef, and pork operations that generally had more than 40 head and poultry farms. Information to map waste application sites was provided by Clark County Conservation District's staff; Washington State University, Clark County Cooperative Extension's staff; and Lacamas Lake Restoration Program's staff. The map is considered preliminary. The reported waste application areas were checked against 1989 infrared aerial photos to provide some verification that the site was a farm area with fields where application could occur. It includes areas where application was done in the past, but is not currently being applied. Also, some small non-farm parcels are included with larger tracks that are identified as application areas.

The animal waste application areas were identified by tax parcel and converted into a GIS map using the Assessor's Office parcel boundary map. All sites are mapped as animal waste application sites with no discrimination in size or rate of application because complete information was not readily available.

TRANSPORTATION ROUTES

Highway corridors are mapped by the Regional Transportation Council and the County. Roads are classified by state functional class. Street and highway right-of-way is also identified by parcel mapping.

Rail lines are identified by Department of Assessment and GIS Mapping.

PIPELINES

One major petroleum product pipeline crosses Clark County. The pipeline enters the County near Woodland, passes through Ridgefield, and then continues south and west passing along the west side of Vancouver Lake. The pipeline easement is marked on County parcel plat maps, but is not in a digital format. No pipelines are included on inventory maps.

A major natural gas pipeline also passes across Clark County from north to south.

LANDFILLS AND DUMPS

Inventoried solid waste disposal sites include existing permitted landfills, abandoned landfills, and uncontrolled dump sites. The sites were inventoried for the Ground Water Management Program and mapped by the Intergovernmental Resource Center. The best information generally exists for permitted landfills, with decreasing knowledge for abandoned landfills and uncontrolled dumps. In some cases abandoned landfills and uncontrolled dumps are very poorly documented.

Sources of data include Health District records, Ecology records, newspaper articles, and anecdotal reports from the public. The Clark County Ground Water Management Program (1992) contains tabulated data and a description for individual landfills. Landfills were mapped as accurately as data permitted. In some cases landfill boundaries were mapped (at 1:24,000 scale mapping), but in most cases a point identifies the location of the landfill (1:48,000 scale mapping). The map is not accurate to parcel scale.

In addition to the Ground Water Management Program map, the Assessment and GIS tax parcel land use data base includes some parcels that are identified as dumps and disposal operations.

KNOWN SITES OF CONTAMINATION

Known sites of contamination are sites where regulatory agencies have determined that contamination of soil or groundwater has occurred. The Intergovernmental Resource Center compiled Ecology's Toxics Cleanup Program Affected Media and Contaminants Report and EPA's Comprehensive Environmental Response, Compensation, and Liability Information System (CECRLIS) site records into a GIS map of known and suspected contamination sites. The data tables and map were periodically updated, with the last update in September 1991. Site locations were placed on 1:24,000 scale US Geological Survey Quadrangles and digitized. The table and maps are currently being updated by the Clark County Hazardous Waste Citizens Task Force.

WASTEWATER DISCHARGE PERMITS

Washington Department of Ecology requires wastewater discharge permits for all waste that is discharged to surface or groundwater. A listing of the 18 sites with wastewater discharge permits was obtained from Ecology to identify permitted waste discharges within any wellhead zones of contribution. This information is not in GIS.

AIR DISCHARGE PERMITS

Southwest Washington Air Pollution Control Authority and the Department of Ecology issues permits to sites that discharge pollutants into the air. These can provide a good inventory of sites that handle materials that may contaminate groundwater. No air discharge permits are used for the GIS inventory.

GIS INVENTORY RESULTS

Examples of the GIS inventory summary tables and wellhead area maps are included in this report. The wellhead inventory maps can be obtained as a set or individually from the Clark County Water Quality Division. Complete GIS inventory data bases are stored as GIS maps at the Department of Assessment and GIS.

INVENTORY SUMMARY TABLES

Wellhead protection area inventories were conducted and summarized through the use of GIS. Summary tables include separate categories for the one-, five-, and ten-year zones of contribution. The summary table gives a summary of land use, zoning and potential contamination sources within each zone of contribution. Table 2 is an example for Map 21, Vancouver Water Station 8 wellhead protection area.

INVENTORY MAPS

A set of maps was made showing inventory results for each wellhead area. One set shows land use, on-site disposal facilities, and sanitary sewer. The other shows zoning and a number of inventoried point sources. The maps are used to inform water system operators and the public about the size of the wellhead protection area and the potential water quality risks within the area contributing water to their wells. These maps also serve as an introduction for training field inspection and inventory crews.

Land Use and On-Site Waste Disposal

Figure 2 shows a land use and waste discharge map for Map 21, Vancouver Water Station 8. The purpose of the maps is to show the distribution of inventoried septic systems and areas where sanitary sewer is absent. Land use gives a general description of the likelihood that a particular parcel may be handling potential contaminants. Land use is colored as background and other data is overlaid lines and points. Data layers for Figure 2 are:

- One-, five-, and ten-year zones of contribution
- General land use from parcel groupings made by Clark County Mapping
- Parcel boundaries
- Rail corridors
- Septic system parcel points
- Sanitary sewer lines
- Animal waste application sites
- Public supply wells inventoried by the US Geological Survey

Table 2. Summary Table for Water Station 8.

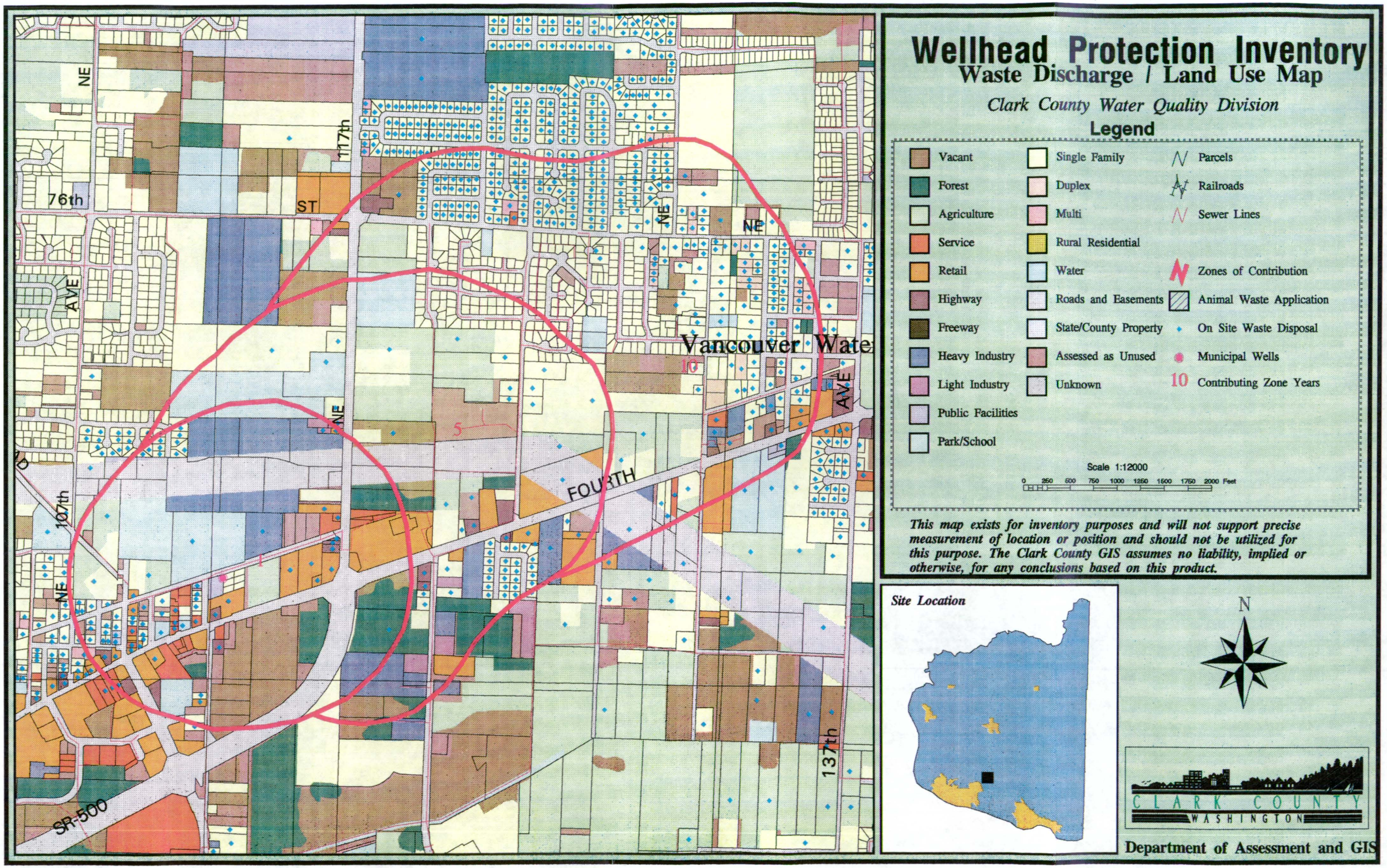
Vancouver Water Station 8	1 year	1-5 year	5-10 year	Total	
Zone R1-6	0	0	16.84	16.84	Acres
Zone R1-7.5	43.62	38.56	165.24	247.42	Acres
Zone A2	17.53	69.93	22.43	109.88	Acres
Zone A1	0.33	0	0	0.33	Acres
Zone C3	0	8.15	0.57	8.72	Acres
Zone CL	106.01	24.38	46.51	176.89	Acres
Zone CH	0	16.23	15.34	31.58	Acres
Zone CG	3.14	1.86	1.39	6.39	Acres
Zone ML	49.56	76.28	7.3	133.14	Acres
Single family unit not sharing structure with other uses	16.92	36.94	124.44	178.3	Acres
Mobile home converted to permanent structure	0.22	0	3.14	3.36	Acres
Two family units side by side (one level)	0	0	7.82	7.82	Acres
Multi-family units side by side	0	0	0.53	0.53	Acres
Multi-family units above one another(most apartment houses)	0.22	0	0	0.22	Acres
One or more mobile homes not in a mobile home court	0.29	0	0.73	1.01	Acres
Mobile home residential court	1.59	24.28	9.97	35.84	Acres
Passable streets with some surfacing or grading	0.11	0	0	0.11	Acres
Private streets	0	0	0.05	0.05	Acres
Farm buildings, facilities, and areas used for equipment, crop, etc., storage	0	0	0.65	0.65	Acres
Oil or natural gas wells and services	0	0.76	0.18	0.94	Acres
Rock quarry, crushing, sand and gravel pits	33.65	0.01	0	33.67	Acres
General contractors	0.72	0.33	0	1.05	Acres
Special trade contractors (plumbing, painting, heating)	0	0.99	0	0.99	Acres
Warehousing	7.26	11.35	2.18	20.79	Acres
Household furniture	0	0	6.96	6.96	Acres
Industrial inorganic and organic chemicals	0	0.35	0	0.35	Acres
Flat glass	0	1.2	0	1.2	Acres
Miscellaneous fabricated wire or metal products	0	0	0.45	0.45	Acres
Jewelry, silverware, and plated ware	0	0.67	0	0.67	Acres
Bus (school, charter, local, highway, etc.) terminals	0.14	0	0	0.14	Acres
Services for transportation not elsewhere classified	0	0	0.74	0.74	Acres
Telephone exchanges, microwave and cable stations, central offices	4.37	0	0	4.37	Acres
Post office, mail handling facilities	0.33	0	0	0.33	Acres
Electric power boosters, transformers, sub-stations, right-of-ways	2.55	0	0	2.55	Acres

Table 2. Summary Table for Water Station 8.

Domestic water supply towers and structural reservoirs	0.77	0	0	0.77	Acres
Electrical goods and appliances, hardware, plumbing, heating, refrigeration	0	0.08	0	0.08	Acres
Metals, minerals, tobacco, paper products, furniture, etc.	0	1.12	0	1.12	Acres
Residential Use on Commercial Zone	11.54	42.86	25.67	80.07	Acres
Lumber and other building material dealers	0	1.86	4	5.86	Acres
Paint, glass, and wallpaper stores	0.27	0	0	0.27	Acres
Shopping centers -three or more uses, may be retail and include services	8.73	3.77	0.9	13.4	Acres
Grocery stores and supermarkets (including delicatessens)	0.99	0.33	0.07	1.38	Acres
Service stations, automotive and/or truck	0.33	0	1.24	1.57	Acres
Mobile homes, camping trailer, pick-up campers	2.2	0	0	2.2	Acres
Other retail automotive and allied not elsewhere classified (trailers)	0.43	0.88	0	1.32	Acres
Furniture stores	0	0	0.06	0.06	Acres
Floor coverings (may perform incidental installation service)	0.95	0	0	0.95	Acres
Eating places (except drive-in, restaurants, cafes, caterers)	1.4	1.68	0	3.08	Acres
Drive-in eating and snack facilities	1.88	0	0	1.88	Acres
Other personal items and accessories not elsewhere classified	0.31	0	0	0.31	Acres
Florists	0.12	0	0	0.12	Acres
Farm and garden supplies (except growing of nursery stock167)	0.2	0	0	0.2	Acres
Gifts, novelties, etc., religious articles (except church supplies), flag shops	0.29	0.05	0	0.34	Acres
Used auto parts and accessories	0	9.46	0	9.46	Acres
Used building materials, plumbing fixtures, etc.	0	0	1.07	1.07	Acres
Banks	3.22	0	0	3.22	Acres
Credit agencies other than banks (saving and loan, finance company)	2.17	0	0	2.17	Acres
Real estate companies (selling, managing, title search, subdivision, etc.)	0	0	0.28	0.28	Acres
Medical, dental, and other allied professional offices and clinics	1.51	0	0	1.51	Acres
Other health and allied services not elsewhere classified	0.24	0	0	0.24	Acres
Accounting, auditing, bookkeeping	0	0	0.68	0.68	Acres
photographic studios excluding development and printing shops 673.	0.13	0	0	0.13	Acres
Beauty shops	0.35	0	0	0.35	Acres
Miscellaneous business services	0.24	0	0	0.24	Acres
Automotive paint shops	0	0.97	0.35	1.32	Acres
Miscellaneous automotive repair shops (battery, glass, upholstery)	1.03	0.26	0	1.29	Acres
General repair shops (engine and transmission overhaul, etc.)	0.42	0.57	0.62	1.61	Acres
Auto laundries, washing and polishing	0.61	0	0	0.61	Acres
Repair of electrical equipment	0.08	0	0	0.08	Acres
Rental of small tools and equipment, medical and party, general rental	0.25	1.27	0	1.52	Acres

Table 2. Summary Table for Water Station 8.

Churches, synagogues, temples, Sunday school buildings	3.39	0	1.16	4.55	Acres
Preschools and nurseries.	13.82	16.56	0	30.38	Acres
Primary and elementary schools.	11.16	0	0	11.16	Acres
Vocational, commercial, trade and specialized schools	0.44	0	0	0.44	Acres
Community fire protection facilities.	0	0	0.57	0.57	Acres
Cemeteries	0	0	2.31	2.31	Acres
Parks with and including playgrounds, ballfields, and picnic areas.	0	0	3.1	3.1	Acres
Driving and archery ranges, shooting ranges, gun clubs.	0	0	0.78	0.78	Acres
Summer recreational camps, dude ranches, etc.	0	7.55	0.5	8.05	Acres
UNUSED	0	5.02	3.11	8.13	Acres
Unused land cleared.	47.65	43.65	21.68	112.98	Acres
Unused land timbered.	0	0	0.44	0.44	Acres
Unused buildings, burned out etc.	0	0	0.94	0.94	Acres
Unused platted land.	0.32	0.04	0.49	0.85	Acres
Roads	34.36	20.54	47.76	102.66	Acres
Wells Mapped by Clark Public Utilities	0	2	4	6	Total
Regulated Underground Storage Tanks	5	3	3	11	Total
On-Site Waste Disposal	76	59	291	426	Total
Wells Mapped by the USGS	5	4	7	16	Total
Drywell Inventory quarter sections	220.18	235.39	275.62	731.19	Acres



MAP 21 : City of Vancouver Water Station 8.

Figure 2

Zoning, Point Sources, and Water Wells

The purpose of Figure 3 is to show possible future land use based on current zoning and to display a series of potential sources of contamination. Zoning is shown as the background color with the inventoried potential sites overlaid as points. Data layers for Figure 3 are:

- One-, five-, and 10-year zones of contribution
- Zoning
- Parcel boundaries
- Rail corridors
- Underground storage tank sites
- Landfills and dumps
- Known sites of contamination
- Water wells
- Public supply wells inventoried by the US Geological Survey

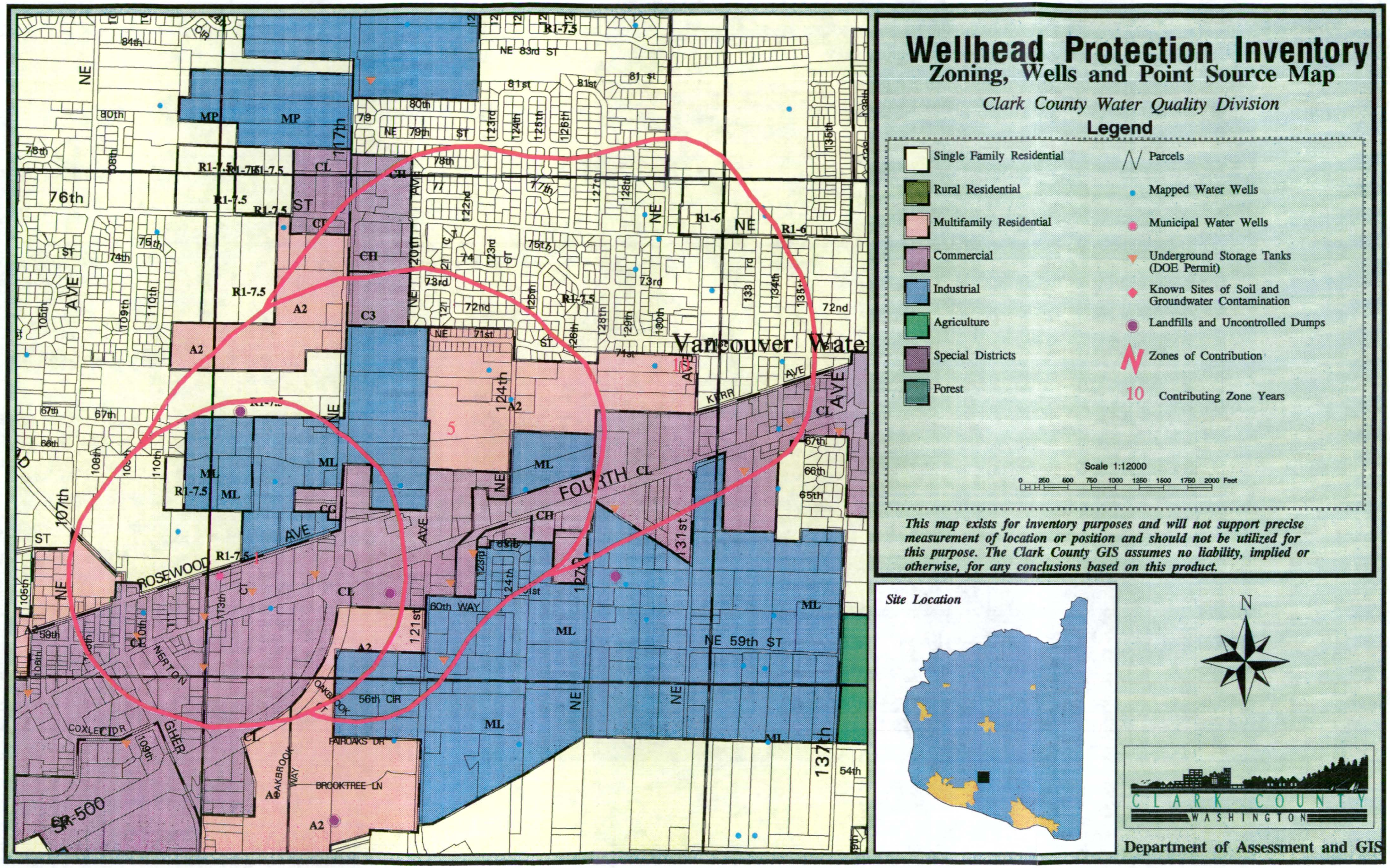
Drywells

A single map is made showing wellhead protection areas and quarter sections that have drywells (Figure 4). The quarter sections with drywells had drywells at the time of an inventory by the Department of Ecology in 1986.

FIELD INVENTORY

The objective of the GIS inventory is to provide a preliminary screening of the wellhead protection area for potential contamination sources. The results can be used by water systems to begin site-by-site management. At the least, a site land use verification should be made for each parcel in the wellhead protection area. Additional site inspection and management should be done at sites that are likely or known to be handling hazardous materials.

Field inventories could use existing quarter-section plat maps or computer generated maps if appropriate. Existing quarter-section maps are easy to reproduce and work well for field use. Computer generated parcel maps could be used for data compilation for digitizing or in cases where a larger scale field map is required.



MAP 21 : City of Vancouver Water Station 8.

Figure 3

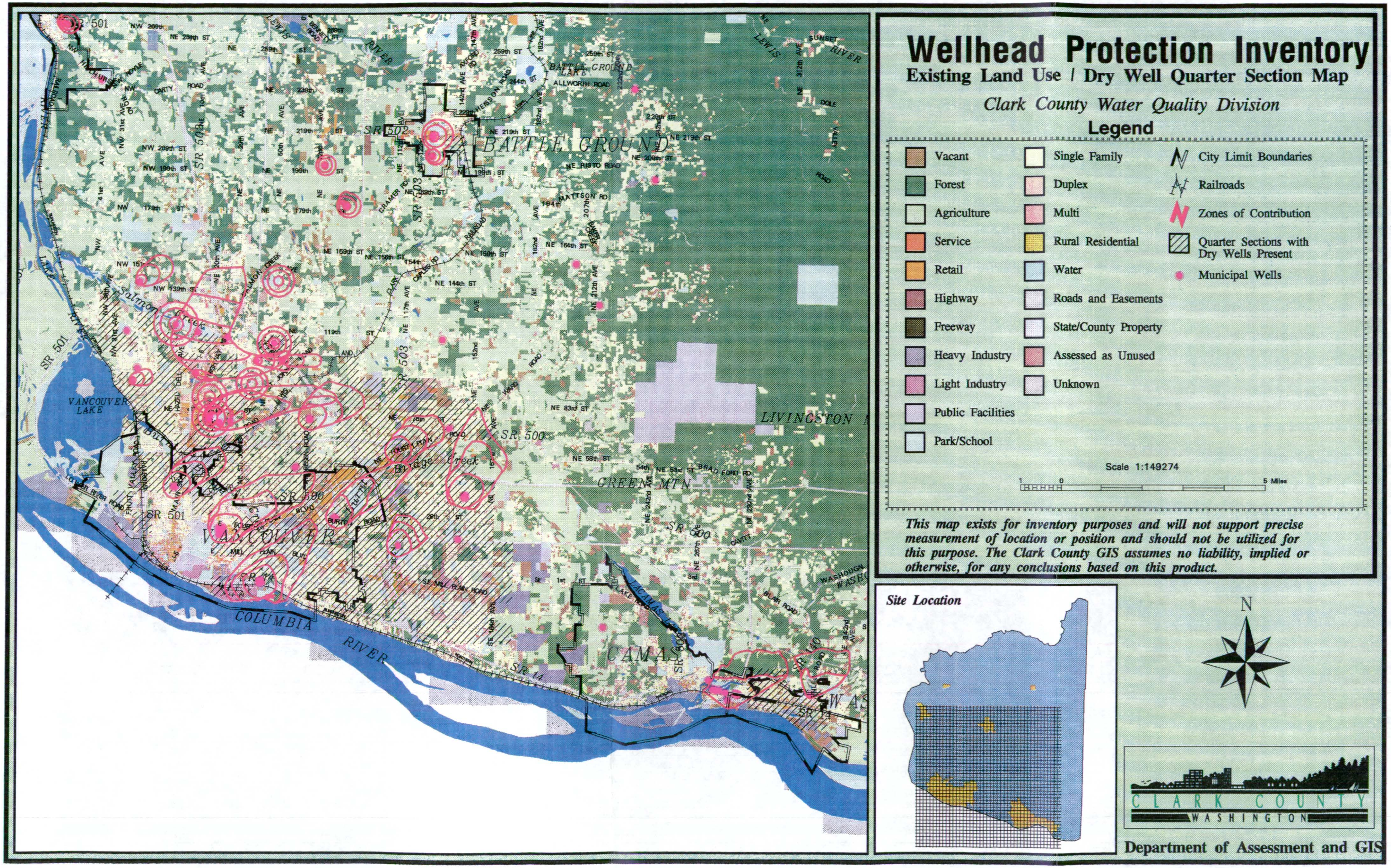

Wellhead Protection Inventory
Existing Land Use / Dry Well Quarter Section Map
Clark County Water Quality Division
Legend
Vacant
Forest
Agriculture
Service
Retail
Highway
Freeway
Heavy Industry
Light Industry
Public Facilities
Park/School
Single Family
Duplex
Multi
Rural Residential
Water
Roads and Easements
State/County Property
Assessed as Unused
Unknown
City Limit Boundaries
Railroads
Zones of Contribution
Quarter Sections with Dry Wells Present
Municipal Wells
Scale 1:149274
5 Miles
This map exists for inventory purposes and will not support precise measurement of location or position and should not be utilized for this purpose. The Clark County GIS assumes no liability, implied or otherwise, for any conclusions based on this product.
Site Location
N
CLARK COUNTY
WASHINGTON
Department of Assessment and GIS
BATTLE GROUND
VANCOUVER
CAMAS
VANCOUVER LAKE
COLUMBIA RIVER
LIVINGSTON
GREEN MTN

Figure 4

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