Groundwater Recharge Topic Paper

Introduction

The Island County Water Resource Advisory Committee (WRAC) is tasked with developing a Watershed Plan. The goal of Watershed Planning is to determine the availability of the groundwater resources in Island County and to ensure safe and adequate water supplies. Groundwater resources throughout the county are experiencing increasing demand, and in some areas are expected to be inadequate in the future. Island County's groundwater is recharged by rainfall. This paper will focus on the importance of maintaining and managing groundwater recharge, which impacts the quantity and quality of Island County's water supplies.

The recommendations identified in this paper relate to one or both of the following inter-related aspects of groundwater recharge:

1. Quantity: Maintaining adequate groundwater recharge rates through decreasing the impacts of surface modifications (e.g., hard/impervious surface area) and encouraging activities that maintain or increase recharge (e.g., Low Impact Development); note: Groundwater availability will be addressed in the WRAC's upcoming Seawater Intrusion topic paper; and

2. Contamination: Managing surface contaminants to reduce the risk of percolation down into groundwater supplies (e.g., road runoff, septic systems, agricultural nutrient and chemical applications, residential lawn chemicals). In areas with coarse-grained surficial and sub-surface geology, surface water may percolate too rapidly for adequate "filtering out" of contaminants.

Background

Factors Affecting Groundwater Recharge Rates

Understanding groundwater recharge rates is an important aspect of managing the quality and quantity of Island County's water supplies. Groundwater recharge is freshwater that replenishes aquifers on an annual basis. In Island County, recharge is solely supplied by local rainfall.

Groundwater is "recharged" when rainwater percolates into the soil and down to underground aquifers. Percolation is the downward movement of rainwater through soil and stratigraphy (i.e., underground layers of sand, gravel, clay and rock). Some land areas have higher natural recharge rates than others based on surface soils, stratigraphy, precipitation and vegetation type. Underground stratigraphy in Island County is comprised of random unconsolidated materials deposited during glacial periods. Human activities (e.g., increase in impervious surface, loss of vegetation, grading) can greatly decrease rates of groundwater recharge.

Recharge is essential for maintaining the quantity and quality of groundwater supplies. Not all recharge is available for use, however, as some portion of the recharge must remain in the aquifer system to prevent seawater intrusion.

Natural recharge rates for Whidbey and Camano Island aquifers vary widely, due to variations in precipitation, surficial geology, soils, vegetation, etc. Recharge generally is higher in areas underlain by porous coarse-grained deposits (gravel and sand) than in areas underlain by fine-grained deposits (silt and clay), which limit water infiltration.

A recent U.S. Geological Survey (USGS) study estimated that 20-34% of the rainwater falling on Island County is available to recharge its groundwater aquifers ("Estimating Ground-Water Recharge from Precipitation on Whidbey and Camano Islands, Island County, Washington, Water Years 1998 and 1999," Sumioka and Bauer, USGS 03-4101, 2003). Remaining precipitation runs off the surface of the land, evaporates, or percolates to the root zone and is used by plants.

Human activities can significantly reduce recharge rates. As an area develops, natural rainwater percolation rates can be maintained/encouraged through using Low Impact Development (LID) methods such as:

1. Limiting the surface area of hard/impervious paved surfaces (e.g., roads, parking lots) through use of pervious concrete, pervious pavers, "grasscrete" and similar pavement materials;

2. Managing roof runoff and minimizing roof size, where possible;

3. Retaining surface water runoff in cisterns or other catchments (e.g., retention ponds, infiltration ditches, grassy swales), to return water to the soil for on-site percolation; and

4. Keeping native vegetation on-site and minimizing grading or soil compaction.

These LID methods can mitigate the effects of hard/impervious surfaces, allowing retained or collected rainwater to percolate into the ground on-site instead of running off to Puget Sound.

Sources of Potential Groundwater Contamination

This topic paper will discuss and make recommendations for mitigating potential contamination from road runoff, septic systems, agricultural nutrient and chemical applications, and residential lawn chemicals. Contaminants from each of these sources can enter groundwater supplies as rainwater percolates downward and recharges aquifers. Seawater intrusion and elevated chloride levels will be discussed in the WRAC's "Seawater Intrusion" topic paper. This topic paper will not discuss other groundwater supply contaminants such as arsenic, iron/manganese, bacteria, or pharmaceuticals. Pharmaceuticals may be introduced into aquifers through septic systems. This is an emerging issue that is

being widely researched at the national level: the widespread effect of these manmade organic compounds on ecosystems and humans is not yet understood, but current reports indicate that neither bodily biochemistry nor standard anaerobic septic systems can adequately breakdown these materials. The Island County Board of Health may want to track this emerging issue.

High recharge rate areas (areas with highly pervious soils) may be at risk for contamination. Rainwater can percolate through coarse-grained deposits so rapidly that surface contaminants are not "filtered out" before water enters the aquifer.

Shallow aquifers, "perched" aquifers, or areas with shallow soils may also be at risk for contamination. ("Perched" aquifers sit above lower aquifer levels and are kept separate by low permeability clay layers.) Where groundwater is shallow, rainwater may not move through enough sub-surface material to "filter out" contaminants before the water enters the aquifer.

Nitrates are a contaminant of concern in areas of Island County. Nitrates are not typically present in groundwater; well sample levels should be 0 mg/L. Nitrates are normally "filtered out" within the root zone of the upper soil layers. At high levels all of the nitrates present may not be taken up in the root zone, and are free to migrate downwards to aquifer supplies.

Nitrate levels of 1-3 mg/L indicate a developing problem, especially if nitrate levels are increasing over time (i.e., increasing trend shows that there is a current land use that is contaminating the groundwater supply). At nitrate levels of 5 mg/L, an action level is triggered and public water system regulations require that monitoring be increased. The maximum contaminant level (MCL) for nitrate levels is 10 mg/L. While public water systems are required to monitor nitrate levels periodically, many private domestic wells in Island County have never been tested for nitrates. Prior to 1990, there were no sampling requirements for individual wells. Since 1990, in response to Growth Management Act requirements, all individual wells must be tested for nitrate prior to building permit approval.

Drinking water with nitrate levels exceeding the 10 mg/L maximum contaminant level (MCL) may be hazardous for human consumption, especially for pregnant women (i.e., developing fetuses) and children under one year of age. Once ingested, nitrate is converted to nitrite in the stomach. The nitrite then reacts with blood hemoglobin to form methemoglobin. As a result, the capacity of the blood to carry oxygen is reduced and systems of oxygen starvation begin to occur: this condition is known as methemoglobinemia or Blue Baby Syndrome.

Nitrates will be focused on in this topic paper because the presence of nitrates indicates that other contaminants may be present in the future also, and because treatment of nitrates helps mitigate other potential contaminants. Other potential contaminants can include ammonia, total dissolved solids, nitrites, chloride, iron, lead, manganese, mercury, and fecal coliform bacteria.

A 1997 study conducted by the Island County Health Department (ICHD) identified nitrate sources and their extent, and recommended strategies for preventing further contamination. Human activities were found to directly or indirectly cause elevated nitrate concentrations. Although agricultural practices were found to be the largest contributors, densely developed residential areas using on-site wastewater treatment systems may contribute higher contaminant loads than agricultural practices. Well depth is also identified as a causal factor for nitrate contamination: "The findings of [the ICHD] study suggested a correlation between shallow aquifer depths and vulnerability to nitrate contamination… This observation is consistent with the findings of numerous other studies throughout the U.S.… These findings support the widely held theories that groundwater nitrates originate at the land surface, and that aquifers are protected from pollutants by the presence of overlying layers of semi-permeable deposits " (page 27, "Island County Groundwater Nitrate Study," Robert Hallbauer, ICHD, 1997).

Elevated nitrate levels are already observed within high susceptibility areas. Table 1 shows the current total nitrate levels in wells within Critical Aquifer Recharge Area (CARA) areas of "limited," "moderate," and "high" susceptibility. Table 1 was developed in order to validate the computer model that delineated the "limited," "moderate," and "high" susceptibility areas. This data shows that total nitrate levels are higher in areas of "high" susceptibility than in "limited" or "moderate" susceptibility areas.

	CARA Susceptibility		
	Limited	**Moderate**	**High**
Total Area (Square Miles)	38	141	32
Area (% of Total)	18%	67%	15%
Number of Wells with NO3 data	469	2064	568
Average NO3 (mg/L)	0.81	1.01	1.35
Percent of Wells where MaxNO3 > 1 mg/L	18%	27%	36%
Percent of Wells where MaxNO3 > 5 mg/L	3.6%	5.4%	9.7%
Percent of Wells where MaxNO3 > 10 mg/L	0.9%	1.0%	2.3%

Table 1. Critical Aquifer Recharge Area (CARA) Data from the Island County Hydrogeology Database. (Note: Nitrate levels of 5mg/L trigger additional monitoring actions; the Maximum Contaminant Level (MCL) for nitrate levels is 10mg/L.)

Source protection is the most prudent approach to prevent contamination, particularly in areas where surface water may percolate too rapidly for adequate "filtering out" of contaminants (i.e. areas with coarse-grained sub-surface geology). Source protection could include the following strategies as related to groundwater recharge:

1. Design standards for on-site wastewater treatment systems, to ensure adequate treatment and disposal of domestic wastewater;

2. Best management practices (BMPs) for agricultural nutrient and chemical applications, to protect aquifers from concentrated sources of contamination;

3. Siting appropriate land uses in areas with susceptible sub-surface geology; and

4. Retention of nonpoint pollution sources (road and lawn chemical contaminants carried by surface water runoff), particularly in areas with susceptible sub-surface geology. LID practices retain water runoff on a site so that any contaminants can be treated in the soil root zone.

Existing Policy Tools

The following policy tools protect groundwater supplies through maintaining adequate groundwater recharge rates and managing surface contaminants in susceptible aquifer recharge areas.

US-EPA Sole Source Aquifer Status

In 1982 the U.S. Environmental Protection Agency (US-EPA) designated Island County with "Sole Source Aquifer" status. This status is a legal designation, not a physical description. "Sole Source Aquifer" status can be granted when more than 50% of the county population relies on an aquifer system as their principal source of drinking water, and when contamination of the source would create a significant hazard to public health. The Board of Island County Commissioners' petition to the EPA in April 1981 was based on the aquifers' vulnerability to contamination from industrial sources, subsurface sewage disposal, and seawater intrusion (1992 Island County Groundwater Management Program, page I-1).

The designation as "Sole Source Aquifer" publicizes groundwater value and provides limited federal groundwater quality protection. Once the EPA designates an aquifer through a public process, it has the authority to apply additional review prior to approval of federally funded projects that may potentially contaminate the "Sole Source Aquifer." Examples of federally funded projects that the EPA reviews include transportation, agriculture, and construction: projects that may impact groundwater quality. This does not mean that projects cannot go forward in a sole source aquifer area, but rather that the project needs to take special measures to minimize the risk of contaminating the aquifer. (EPA website, http://yosemite.epa.gov/R10/WATER.NSF)

Congress first established the Sole Source Aquifer Protection Program in 1974 under Section 1424(e) of the Safe Drinking Water Act and reauthorized the program under the August 1996 SDWA Amendments.

Critical Aquifer Recharge Area (CARA) Protection

Island County currently has tools and policies in place to address groundwater recharge through land use protections. "Areas with a critical recharging effect on aquifers used for potable water, also referred to herein as aquifer recharge areas, are regulated pursuant to Potable Water and Supply, Chapter 8.09 IC Code, and the Land Development Standards,

Chapter 11.01 IC Code" (IC Zoning Ordinance 17.02.107). Any changes to IC Code 8.09 are approved by the Island County Board of Health.

Critical Aquifer Recharge Area (CARA) protection is part of Island County's Critical Areas Ordinance. "A hydrogeologic site evaluation shall be required prior to preliminary project approval of projects identified…as having the potential for groundwater contamination and where best management practices will not adequately prevent groundwater contamination" (IC Code 8.09.097, Critical Recharge Area Protection, 1992). "Hydrogeologic evaluations are required prior to preliminary approval of projects identified by the (Island County) Health Officer as having a potential for groundwater contamination. Appropriate mitigation measures are imposed as conditions of approval for projects with a potential for impacts to groundwater resources" (page 2-13, Water Resources Element, IC Comprehensive Plan, 1998).

The purpose of Critical Aquifer Recharge Areas (CARA) protection is to protect groundwater in areas susceptible to surface contamination, through the process of groundwater recharge. CARA protection is currently a mechanism to review proposed projects that could have negative impacts on the groundwater resource (e.g., car washes, gas stations, underground storage tanks). CARA regulations include appropriate prevention, best management practices, and mitigation actions.

The Land Use Element of the 1998 IC Comprehensive Plan designates all of Island County as a CARA (page 1-108, Land Use Element). The Water Resources Element of the 1998 IC Comprehensive Plan states the following (pages 2-12, 2-13):

> "The Growth Management Act (GMA) requires the designation and protection of critical areas, such as aquifer recharge areas… All of Island County is…considered a recharge area and specific protection measures are determined at the time of application and relate to project impacts… This approach is more stringent than only applying protection measures in certain areas… Due to the complexity of the aquifer systems underlying Island County, it is difficult, if not impossible, to apply regional determinations of groundwater resource protection and water availability. Given these management limitations, site-specific and project specific evaluations are the best available option. As additional information is collected and analyzed, refinements can be made to the systems of identifying critical areas for recharge and groundwater protection."

IC Code 8.09 contains implementation activities for protecting Critical Aquifer Recharge Areas (CARA). Under IC Code 8.09, development permit applications are evaluated by the ICHD for CARA review and protection activities.

The following activities trigger CARA review and protection activities (IC Code 8.09), specifically hydrogeologic site evaluation to determine aquifer vulnerability:

1. Any land use that involves storage, use, handling or production of hazardous substances or waste products;

2. Petroleum transmission facilities and/or petroleum storage tanks;

3. Certain land and subsurface sewage disposal systems (e.g., off-site drainfields, systems serving more than two residential housing units, systems serving commercial and industrial projects, systems with design flows or more than 3,500 gallons per day); and

4. Surface mining operations requiring a permit from the State DNR.

The Critical Areas Ordinance is included within the Island County Comprehensive Plan, and will be updated by December 1, 2005. The Island County Planning Department will be responsible for recommending updates to the Critical Areas Ordinance.

Existing CARA maps are based on older, more limited information including only surficial geology (soils). Existing protection reviews or guidelines may be adequate, too restrictive, or not protective enough for quantity or contamination concerns. The WRAC and ICHD staff will use current hydrologic data to assist the Planning Department in revisiting CARA designations and protections.

Nonpoint Pollution Prevention Plans

Island County currently has recommended actions in its Nonpoint Pollution Prevention Plans that would protect and maintain groundwater supplies.

The Puget Sound Nonpoint Pollution Prevention Plan (RCW 90.71) planning activities are outlined in WAC 400-12: "reduce pollutant loading from nonpoint sources, prevent new sources from being created, enhance water quality, and protect beneficial uses." Nonpoint Pollution Prevention planning activities include water quality monitoring, nonpoint pollution source identification, and nonpoint pollution prevention recommendations.

Under WAC 400-12, Island County began its watershed ranking process in 1988. The North Whidbey Nonpoint Prevention Plan was approved in 1997, and highlighted construction BMP (best management practices) and educational (pet waste and realtor workshops) recommendations. The Central/South Whidbey Nonpoint Prevention Plan was approved in 2003 and highlighted water quality (pet waste and septic) recommendations. The Island County Implementation Actions Grant is ongoing (2000-2005), as is the Camano Nonpoint Pollution Prevention planning process (2002-2006).

Both of the North and Central/South Whidbey Nonpoint Pollution Prevention Plans describe "comprehensive sub-basin planning and analysis" recommendations that could greatly benefit groundwater recharge protection efforts. Sub-basin planning would include a comprehensive assessment of land use, hydrogeology, soils, percolation rates, geology, slope stability, and erosion. Focusing on the sub-basin scale allows making specific and effective recommendations. Island County's Critical Aquifer Recharge Area (CARA) guidelines could be considered when prioritizing sub-basin planning efforts. Highest priorities would be areas where there appears to be nonpoint pollution that could be dealt with through existing

CARA regulations. High value aquifer recharge areas should be considered when prioritizing sub-basins (i.e., not just surface water streams and wetlands).

Options

The WRAC recommends that Island County implement the following options. Implementation of these options is vital for the management of the quality and quantity of Island County's water supplies.

Option #1

The WRAC recommends the use of the newly developed "Combined CARA Scoring" map as a tool to show "limited," "moderate" and "high" susceptibility areas (i.e., areas susceptible to surface contamination through the process of groundwater recharge). Appendix 1 contains the "Combined CARA Scoring" map.

The "Combined CARA Scoring" map was developed by the WRAC and ICHD staff as an update to Island County's Critical Aquifer Recharge Area (CARA) map. "Limited," "moderate" and "high" susceptibility areas have been delineated using the DOE "Guidance Document for the Establishment of CARA Ordinances" (2000) as well as "Best Available Science" developed through the county's hydrogeology database. Use of the DOE Guidance Document raises the confidence level of the final scores for the CARA map.

The following four criteria were used to assess aquifer vulnerability, and maps of each parameter were developed (see Appendix 1, "Derivation of the CARA Susceptibility Map," for maps and a further description of how each was developed):

1. Depth-to-Water parameter was used to develop the "Depth to Water Susceptibility Rating" map, using data from the Island County hydrogeology database;

2. Recharge parameter was used to develop the "Groundwater Recharge Rate" map, using information from the USGS Deep Percolation Model and DOE Scoring Options;

3. Soil Permeability parameter was used to develop the "Soil Percolation Rate" map, using information from the Island County Soil Survey; and

4. Surficial Geology parameter was used to develop the "Surficial Geology Susceptibility Rating" map, using data from the Island County hydrogeology database.

The "Combined CARA Scoring" map shows the sum of the scores from the four individual maps and ranks the county into one of three zones: "limited," "moderate," and "high" risk

susceptibility to groundwater contamination. This new CARA map would be a useful tool for the groundwater protection review process, and would accomplish the following:

1. Identify the "high" susceptibility areas in Island County. Within these areas, Island County would continue to provide its current level of groundwater protection review for highly susceptible areas;

2. Remove some areas ("limited" or "moderate" susceptibility) from unneeded groundwater protection review; and

3. Inform the public of review requirement differences between "limited," "moderate," or "high" susceptibility areas. This would enable applicants to make informed development decisions prior to the application process.

The process of review and required performance standards could be publicized, allowing applicants to either follow county regulations or pay for private engineering review. All permit applications undergo additional review by county hydrogeologist staff; putting this process into writing would be helpful to applicants.

The WRAC recommends that Island County Health Department hydrogeology staff provide technical assistance to the Planning Department during future updates to the county's Critical Area Ordinance and Comprehensive Plan.

The WRAC also recommends that the IC Planning and Health Departments should use this same map to show CARA designations. A new CARA map would be a starting point for determining whether additional site review was needed (based on IC Code 8.09 requirements); site conditions would prevail.

Option #2

The WRAC recommends that Island County encourage, but not require, Low Impact Development practices (LID) that would help maintain groundwater recharge rates. LID could be encouraged and emphasized in recharge areas important for maintaining groundwater quantity. LID practices can contribute to increased groundwater recharge rates (as well as treating/reducing groundwater contamination sources – see option #3).

LID practices include keeping water on-site, reducing land clearing and grading, and limiting effective hard/impervious surfaces. Island County Nonpoint Pollution Prevention plans have recommended LID practices for protection of groundwater supplies. (Note: LID practices for groundwater recharge purposes would be needed for moderately susceptible areas only, because highly pervious areas would not benefit significantly from LID practices.)

Option #3

The WRAC recommends that Island County continue its current level of review for groundwater protection efforts. The WRAC also recommends that Island County focus this review on the "high" susceptibility areas identified on the newly developed CARA map (i.e. aquifer areas susceptible to surface contamination through the process of groundwater recharge). The WRAC recommends that, at the beginning of the permitting process, applicants should be provided with the groundwater protection process and the newly developed CARA map. (Note: The WRAC does not recommend that the county develop new regulations for groundwater protection.)

The WRAC recommends that Island County include, within ICC Chapter 8.09, examples of projects/activities that would receive review in "high" susceptibility areas. The WRAC has consulted the DOE "Guidance Document for the Establishment of CARA Ordinances" (2000) for these examples (see Table 2). These example projects/activities could be included under Chapter 8.09.097, under heading H, "The following are subject to the foregoing requirements of 8.09.097, A, B, C, D, E, F, and G." Single family residences would not be included within this list. The WRAC recommends that these activities should be reviewed within "high" susceptibility areas, with the exception of "Landfills," which are prohibited by RCW 70.95.060 based on Island County's Sole Source Aquifer designation.

Examples of Projects/Activities Receiving Review in "High" Susceptibility Areas

Above Ground Storage Tanks	Animal Feedlots
Automobile Washers	Below Ground Storage Tanks
Chemical Treatment Storage & Disposal	Hazardous Waste Generators
Injection Wells	Junk & Salvage Yards
Landfills*	Mining
Oil & Gas Drilling	Onsite Sewage Systems (>14,500gal/day)
Pesticide Storage & Use	Recycling Facilities
Sawmills	Solid Waste Handling Facilities
Surface Mining (including Sand & Gravel)	Underground Injection Wells
Waste Water Application to Land Surface	Wood Treatment Facilities

*Note: Landfills are prohibited in Island County by RCW 70.95.060

Table 2. Adopted from the DOE "Guidance Document for the Establishment of CARA Ordinances" (2000).

Island County will develop specific implementation tools for recommendations made in the Watershed Plan during "implementation" of the Island County Watershed Plan (Phase 4 of 2514 Watershed Planning). At that time, the WRAC recommends that the Island County Health Department forward the above recommendations related to ICC 8.09 to the Island County Board of Health.

For road and residential contaminant sources (e.g., lawn chemicals and fertilizers), contaminants could be mitigated through encouraging Low Impact Development (LID) practices. Residential LID practices include keeping water on-site, reducing land clearing and grading, and limiting effective hard/impervious surfaces. Island County Nonpoint Pollution Prevention plans have recommended LID practices for mitigating surface water

contamination. Island County is in process of adopting sections of the WA Department of Transportation Highway Runoff Manual (Flow Control and Water Quality) and the DOE Stormwater Management Manual; implemented actions will help to mitigate road runoff contamination.

Agricultural nitrate contaminant sources could be mitigated through working with the agricultural community on a voluntary basis, to ensure that farm plans and best management practices (BMPs) are followed. The Snohomish Conservation District and the Whidbey Island Conservation District fully approve of the concepts and strategies discussed in this topic paper, and anticipate using the newly developed CARA maps to focus their farm plan and BMP efforts.

Biosolids are an end-product of the wastewater treatment process, and are an excellent fertilizer containing organic material, nitrogen, and phosphorus. Island County could work with the regulatory agencies involved with biosolid applications to determine the most appropriate locations and timing of applications, and to closely monitor nitrate levels in susceptible groundwater recharge areas.

The WRAC is aware of the threat of nitrate contamination from onsite sewage treatment systems. Elevated nitrate levels are already observed within high susceptibility areas, as discussed in the Background of this paper ("Sources of Potential Groundwater Contamination, pages 2-5).

The WRAC recommends that the Island County Board of Health and the Board of Island County Commissioners be involved in the current State DOH process of setting new onsite sewage treatment rules. This recommendation in no way suggests that the WRAC holds a position on the proposed onsite rule changes.

Groundwater Recharge Topic Paper Appendix: Derivation of the CARA Susceptibility Map

DOE Guidance Document

The Washington Department of Ecology (DOE) document entitled "Guidance Document for the Establishment of Critical Aquifer Recharge Area Ordinances" (2000) was utilized to provide the methodology for creation of the CARA Susceptibility Map. This document outlined a rating system, which could be used for evaluating aquifer susceptibility. The rating system focuses on three factors which should be considered, these being:

1. Overall permeability of vadose zone material (this includes both the permeability of the soil and permeability of material underlying);

2. Thickness of the vadose zone (this may also be considered as the depth to water in unconfined conditions); and,

3. Amount of recharge available (either natural precipitation or artificial irrigation).

Each parameter is considered critical in determining susceptibility of underlying aquifers. The DOE Guidance Document provides procedures, based upon data available to most jurisdictions, which can be used to evaluate each of these factors. In general the procedures and methodologies outlined in the DOE Guidance Document were followed in the creation of the Island County CARA Susceptibility Map.

For several of the factors considered, Island County has data available that was considered of higher quality or accuracy than the data utilized in the DOE Guidance Document. In cases where Island County had access to data that was considered more accurate than the data utilized in the DOE Guidance Document, this data was utilized. For example, the DOE Guidance Document utilizes a rather simple method for estimating the amount of recharge available, based on average precipitation and potential evapo-transpiration (PET). The USGS recently completed a four-year study in Island County, designed to estimate groundwater recharge. This study utilized a deep percolation model (DPM) which calculates recharge based on the following factors:

1. daily values of precipitation,
2. precipitation throughfall (rain that reaches land surface beneath vegetation),
3. air temperature,
4. shortwave solar radiation,
5. land-surface altitude,
6. properties of soils and land cover (vegetation type, surface water, or impervious surfaces), and
7. "direct runoff."

The methodology for application of the data was derived from the DOE Guidance Document. Specific procedures utilized to evaluate each parameter are discussed below.

Soil Permeability Rate

Data pertaining to the permeability of soils was derived from the 1958 Soil Survey of Island County. Geographic Information System (GIS) data was obtained from the Natural Resources Conservation Service (NRCS) web site, including a map of soil type distribution and a table of parameters for each soil type. Soil type information included soil percolation rates. Soil percolation rates were scored based on the scoring system recommended in the DOE Guidance Document resulting in the "Soil Permeability Rate" map.

Surficial Geology Susceptibility Rating

Island County Health has a database containing well log data for wells within the county. This data includes stratigraphic descriptions which are geo-coded to allow for automated evaluation of stratigraphy. Also included in the digital well data are depth to water measurements and estimations of land-surface altitude.

A short Visual Basic (VBA) program was developed within the database to spatially evaluate surficial geology. The program evaluated surficial geology in a 1000-foot grid across the spatial extents of the county. For each grid cell, the following method was used to derive a grade for surficial geology:

1. Search grid cell for wells that have depth to water and stratigraphy data, wells should be accurately located (at least to a parcel) so that elevation estimates can be reasonably close;

2. If less that three wells (meeting above criteria) are found, expand search area until at least three are found;

3. Find the Maximum Water Level Elevation (MaxWLE) of the selected wells and use that as the top of the aquifer (conservative);

4. Evaluate the stratigraphy above MaxWLE for each well, picking the lowest conductivity unit from each well that is at least five feet thick;

5. Find the highest conductivity section from the list of wells (provides the least protection) and use that to score Surficial Geology. Scoring is based on the system defined in the DOE Guidance Document.

The above procedure yields a grid of scores, which was imported into ArcGIS to create the "Surficial Geology Susceptibility Rating" map.

Depth to Water Susceptibility Rating

The water well database was also used to evaluate depth to water spatially across Island County. The VBA code described previously was modified to extract the minimum depth to water for each 1000-foot cell in the grid. Gridded depth to water values were graded using the DOE Guidance Document scoring system, yielding the "Depth to Water Susceptibility Rating" map.

Groundwater Recharge Rate

The results of the 2003 USGS report estimating groundwater recharge across Island County were utilized in the evaluation and scoring of the recharge parameter. Spatial distribution of recharge was derived from the DPM model output, recharge values were graded using the DOE Guidance Document system yielding the "Groundwater Recharge Rate" map.

Summary of Aquifer Susceptibility: Combined CARA Scoring

The procedures described above resulted in four maps, consisting of GIS polygons defining scoring of each of the parameters. GIS was then utilized to perform an addition of all four maps, summing the individual scores into a spatially varying summary score. The ranking of the summary score into limited, moderate and high susceptibility areas was accomplished using the DOE Guidance Document scoring system, resulting in the "Combined CARA Scoring" map.