Herrera Environmental Consultants, Inc.

Final Memorandum

To	Kimberly Swan, Clackamas River Water Providers
From	Jennifer Schmidt, Herrera Environmental Consultants
Date	May 31, 2012
Subject	GIS Agricultural Activities Risk Analysis Results

Introduction

The Clackamas River is a source of drinking water for more than 300,000 people in Clackamas County and is an important resource for helping to meet future water demand in the region. The Clackamas River Water Providers (CRWP) represents five municipal surface water intakes on the Clackamas River: City of Estacada, Clackamas River Water, North Clackamas County Water Commission, South Fork Water Board, and City of Lake Oswego. In 2010, the CRWP developed a Drinking Water Protection Plan that outlined a series of strategies and programs to address potential threats to source water quality in the Clackamas River watershed. Herrera Environmental Consultants (Herrera) was hired to complete a series of geographic information system (GIS) analyses in order to help to identify potential pathways for pollutant export from the Clackamas River Watershed. The following major high-risk activity categories were identified in the Drinking Water Protection Plan (Clackamas River Water Providers 2010):

- Septic Systems
- Agricultural Activities
- Forestry Activities
- Vulnerable Soils
- Urban Development
- Point-Source Pollutants

The goal of these GIS analyses was to map risk factors known to have a strong negative correlation with drinking water quality in the Clackamas River watershed. Mapped risk "hot spots" for each category will provide a spatial context for both the geography and intensity of risk by activity that can be used by the CRWP help prioritize mitigation efforts. This memorandum focuses specifically on the methods and results of the GIS Agricultural Activities Risk Assessment portion of the Drinking Water Protection Plan.

Potential Threats from Agricultural Activities

The Clackamas River Water Providers (CRWP) has identified stormwater runoff from agricultural practices as being one of the most significant sources of risk to drinking water

quality in the Clackamas River watershed. The primary threats to source water from agricultural activities include (Clackamas River Water Providers 2010):

1. Non-point source pollution from sediments, nutrients, pathogens, oxygen-depleting organics, pesticides, metals and salts from irrigation and non-irrigated crop areas, plant nurseries, animal grazing areas, boarding stables, farm machinery repair shops, and chemical mixing/storing/handling areas.

2. Increased runoff of nitrates, bacteria, pharmaceuticals, and soil from Confined Animal Feed Operations (CAFOs) where large numbers of animals are confined in one location.

3. Contaminated effluent from fish hatcheries containing nutrients, biochemical oxygen demand (BOD) and antibiotics.

According to the 2000 EPA *National Water Quality Inventory,* agricultural nonpoint source pollution is "the leading source of water quality impacts on surveyed rivers and lakes, the second largest source of impairments to wetlands, and a major contributor to contamination of surveyed estuaries and ground water" (U.S. EPA 2005). Drinking water sources degraded by agricultural non-point source pollutants 1) increase water treatment costs; 2) increase the production of disinfection byproducts due to an overall increase in bacteria and organic carbon; and 2) pose a significant risk to public health (Morgenstern 2006).

GIS Agricultural Activities Risk Analysis

Herrera performed a GIS analysis mapping the extent and intensity of agricultural activities in the Clackamas River watershed to help predict the overall potential risk of stormwater runoff from these activities to source water quality. This methodology involved gathering/generating, ranking, and overlaying five agricultural practice datasets and related information in GIS:

- Recommended fertilizer and pesticide application rates by crop type for agricultural fields and nurseries

- Confined Animal Feed Operation (CAFOs) and other animal activities and impacts

- Fish hatcheries

- Proximity of agricultural activities to surface water

- Vulnerable soils and irrigated land

The following sections provide more detailed information on this risk analysis, including analysis objectives, methods for how each of the risk datasets were generated, and data sources used and limitations.

Analysis Objectives

The primary objectives of the GIS agricultural activities risk analysis were to:

1. Identify agricultural fields and nurseries and evaluate their potential impacts to surface water quality based on recommended guidelines for pesticide and fertilizer application rates for each crop type in the watershed.

2. Map the locations of CAFOs and other animal activities and impacts such as concentrated grazing areas, boarding stables, and kennels.

3. Map the locations of public and private fish hatcheries in the watershed.

4. Identify and map vulnerable soils, floodplains, and irrigated lands that could contribute to agricultural source water quality impacts.

5. Rank, weight, and overlay the agricultural activities datasets to produce maps of cumulative predicted risk to source water quality from agricultural practices in the Clackamas River watershed.

Data Sources and Limitations

The primary GIS datasets required to assess agricultural activities risk to source water quality are agricultural field locations and crop types, nurseries and greenhouses, recommended pesticide and fertilizer application rates by crop type, CAFOs and other animal activities and impacts, fish hatcheries, and irrigated land and vulnerable soils. The following sections describe these datasets in more detail, including any major data limitations that are important to keep in mind when interpreting the GIS agricultural activities risk analysis results. Documentation on all datasets used in the analyses can be found in Table 1. Herrera converted all GIS datasets used in the agricultural activities risk analysis to the Oregon State Plane North HARN 83 map projection, with both the vertical and horizontal datum measured in feet.

Crop Types

Herrera used CropScape Cropland Data Layer (CDL) grids created by the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) to identify agricultural fields and crop types in the Clackamas River watershed from 2009 to 2011. The NASS CDL is a crop-specific land cover dataset that is updated annually using several different sources of satellite imagery and remote sensing software to classify agricultural land into specific crop categories. The statistical classification accuracy of CDL datasets for dominant agricultural crop categories in the continental U.S. generally ranges from 85% to 95%; the CDL datasets obtained for the Clackamas River watershed had a classification accuracy of 81% in 2009, 82% in 2010, and 87% in 2011. Detailed accuracy reports by crop type for each year can be found at the CDL metadata link provided in Table 1.

It is important to keep in mind when interpreting the agricultural risk analysis results generated from CDL data that the pixel resolution of the grids is fairly coarse (30 meters in 2010 and 2011; 56 meters in 2009), and crop type classifications have not been field verified.

Pesticide and Fertilizer Application Rates

Herrera used crop-specific fertilizer guides and pest and weed management handbooks developed by the Oregon State University (OSU) Extension Service to determine recommended fertilizer and pesticide application ranges to apply to each mapped crop type in the Clackamas River watershed. Rather than indicating specific amounts of fertilizers and pesticides that were actually applied on the ground, these guidelines were used to estimate the average amount of fertilizers and chemicals that could possibly be applied to each field by crop type if 1) recommended application guidelines are followed and 2) all acreages are treated with each fertilizer or pesticide.

Actual applied fertilizer and pesticide rates at the individual field level are dependent on many different factors and may vary significantly from the application rates used in this analysis. Fertilizer application guidelines in particular are based in part on the results of site-specific soil testing, which was not possible to take into account in this analysis.

CAFOs and Other Animal Activities

The Oregon Department of Agriculture (ODA) and Oregon Department of Environmental Quality (DEQ) issue permits for small, medium, and large CAFOs in Oregon to "protect the quality of groundwater and surface waters of Oregon by preventing animal waste from discharging into waters of the state" (ODA and DEQ 2009). Herrera obtained the locations of three permitted CAFOs in the Clackamas River watershed from Oregon DEQ, as well as ten non-permitted locations. This data is current as of May 2008.

An additional source of CAFO and other animal activity locations came from four source water assessments completed by Oregon DEQ and the Oregon Department of Human Services (DHS) with assistance from the Clackamas Basin Watershed Council in 2002-03. The purpose of these assessments was to identify surface water areas that supply public drinking water, identify sensitive areas, and potential contaminant sources that could adversely impact that source of water (Clackamas River Water Providers 2010). Over 1,200 potential contaminant sources (PCS) were identified in the Clackamas River Source Water Assessments and mapped in a GIS dataset, including approximately 200 animal-related activities in the Clackamas River watershed indicated as being of moderate to high risk to source water quality. This included additional unpermitted CAFOs, concentrated animal grazing areas, boarding stables, large kennels, and horse camps. Herrera extracted these animal-related activity locations from the overall PCS dataset for inclusion in the risk analysis.

Nurseries and Greenhouses

Nurseries and greenhouses are not included as a specific crop land cover category in the NASS CDL dataset. To identify nursery and greenhouse locations, Herrera used two datasets. The first was the Oregon DEQ/DHS PCS dataset, which contained the approximate locations of 160

nursery and greenhouse features mapped at the state level. These features were overlaid with tax parcels and aerial photography to extract more precise nursery and greenhouse locations at the watershed scale. The second dataset used was statewide water right agricultural irrigation areas provided by Oregon DEQ and the Oregon Water Resource Division (WRD). Nursery and greenhouse irrigation uses were extracted from this dataset for inclusion in the risk analysis.

Fish Hatcheries

Herrera obtained the locations of three public and private fish hatcheries in the watershed from Oregon DEQ that are indicated as being of moderate to high risk to source water quality. This data is a subset of the Oregon DEQ/DHS PCS dataset.

Vulnerable Soils and Irrigated Land

The most prevalent source of agricultural water pollution is eroded soil and the pollutants attached to soil particles that are washed off of fields and in to nearby water bodies (U.S. EPA 2005). Oregon DEQ provided Herrera with a Highly Erodible Land (HEL) Class 1 dataset for Clackamas County that represents highly erodible soils to use in the agricultural activities risk analysis. The criteria used to determine soil erodibility is based on slope and K Factor, which is a calculated value representing both the susceptibility of soil to erosion and the rate of runoff. An HEL class of 1 represents highly erodible soils related to bare lands once crops have been harvested.

The Oregon DEQ/WRD statewide water right agricultural irrigation areas data was also used to help identify potential source water quality impacts from irrigated land in the Clackamas River watershed. Inefficient or excessive irrigation can cause erosion, increase sedimentation, and transport nutrients, pesticides, and heavy metals to water bodies (U.S. EPA 2005).

Methodology

This section describes the GIS methods used by Herrera to identify agricultural fields, nurseries, and greenhouses and apply crop-specific pesticide and fertilizer application rates; map the locations of CAFOs and other animal activities and impacts; map the locations of public and private fish hatcheries; identify and map vulnerable soils and irrigated lands; and rank, weight, and overlay the datasets based on their impact to source water quality.

Identifying Agricultural Fields and Nurseries and Greenhouses

The first step in assessing the overall risk to source water quality from agricultural activities in the Clackamas River watershed was to identify and map areas of agricultural production by crop type. To accomplish this, Herrera obtained CropScape CDL data and mapped the distribution of 47 different crop categories in the Clackamas River watershed. Next nursery and greenhouse locations were overlaid with each year of CropScape CDL data to produce comprehensive coverages of agricultural crop production in the Clackamas River watershed between 2009 and 2011.

Table 1. GIS datasets used to help assess the risk from agricultural activities to source water quality in the Clackamas River watershed.

Dataset Description	Source	Date	Online Metadata (if available)
Aerial photography	United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP)	2009	http://libweb.uoregon.edu/map/orephoto/imagery.html
Cropland Data Layers (CDL)	USDA National Agricultural Statistics Service (NASS)	2009 - 2011	http://www.nass.usda.gov/research/Cropland/metadata/meta.htm
Clackamas River watershed boundary	Oregon Metro RLIS	November 2011	http://rlismetadata.oregonmetro.gov/index.cfm?startpage=main.cfm?db_type=rlislite
Confined Animal Feed Operations (CAFOs)	Oregon DEQ & Oregon Department of Agriculture (ODA)	May 2008	None
Highly Erodible Lands (HEL) Class 1 Soils	Oregon DEQ & USDA Natural Resource Conservation Service (NRCS)	Obtained May 2011	None
Pesticide and fertilizer application rates by crop type	Oregon State University (OSU) Extension Service	Varies	See References section
Potential Contaminant Source (PCS) points	Oregon DEQ	June 2005	http://www.deq.state.or.us/wq/dwp/invresults.htm
Streams and waterbodies	Oregon Metro RLIS	November 2011	http://rlismetadata.oregonmetro.gov/index.cfm?startpage=main.cfm?db_type=rlislite
Taxlot boundaries	Oregon Metro Regional Land Information System (RLIS)	November 2011	http://rlismetadata.oregonmetro.gov/index.cfm?startpage=main.cfm?db_type=rlislite
Water rights agricultural irrigation uses	Oregon DEQ & Oregon Water Resources Department (WRD)	March 2007	None
Zoning designations	Oregon Metro RLIS	November 2011	http://rlismetadata.oregonmetro.gov/index.cfm?startpage=main.cfm?db_type=rlislite

Detailed crop type acreages by year can be found in Table 2. This data is sorted by highest percent crop cover in 2011, which is the most recent CDL data available. Detailed crop type distribution maps can be viewed online through the CropScape website at: http://nassgeodata.gmu.edu/CropScape.

Table 2. Crop cover acreages for 2009, 2010, and 2011 in the Clackamas River watershed based on USDA NASS CropScape CDL data.

Crop Type	2011	%	2010	%	2009	%
Pasture and Hay	32,195	84.1	36,720	86.5	32,579	79.3
Nurseries or Greenhouses	3,640	9.5	3,640	8.7	3,640	8.9
Cranberries	1,463	3.8	877	2.1	1,515	3.7
Other Hays	383	1	266	0.63	703	1.7
Seed and Sod Grass	245	0.64	61	0.15	679	1.7
Christmas Trees	124	0.33	172	0.41	307	0.8
Blueberries	76	0.20	10	0.02	322	0.8
Corn	28	0.07	46	0.11	17	0.04
Spring Wheat	23	0.06	23	0.05	58	0.14
Other Tree Nuts (Hazelnuts)	15	0.04	171	0.41	219	0.53
Winter Wheat	14	0.04	32	0.08	176	0.43
Cherry Orchard	13	0.04	3	0.01	80	0.19
Alfalfa	11	0.03	7	0.02	4	0.01
Other Crops	10	0.03	54	0.13	261	0.64
Clover and Wildflowers	9	0.02	21	0.05	177	0.43
Oats	8	0.02	4	0.01	31	0.08
Radish	3	0.01	0	0	0	0
Dry Beans	2	0.01	31	0.07	129	0.31
Grapes	2	0.01	15	0.04	49	0.12
Sweet Corn	2	0	19	0.04	19	0.05
Prunes	1	0	0.2	0	0	0
Onions	1	0	0	0	3	0.01
Turnips	0.5	0	0	0	4	0.01
Cabbage	0.4	0	23	0.06	0	0
Walnuts	0.4	0	0.5	0	13	0.03
Strawberries	0.2	0	6	0.01	15	0.04
Vetch	0.2	0	1	0	0	0
Rye	0.2	0	0	0	0	0
Apples	0.2	0	0	0	0.5	0
Hops	0.1	0	14	0.03	20	0.05
Barley	0.1	0	0	0	1	0
Pasture and Grass	0	0	60	0.14	17	0.04

Table 2. (continued) Crop cover acreages for 2009, 2010, and 2011 in the Clackamas River watershed based on USDA NASS CropScape CDL data.

Crop Type	2011	%	2010	%	2009	%
Squash	0	0	59	0.14	3	0.01
Cauliflower	0	0	15	0.04	8	0.02
Peppers	0	0	11	0.03	9	0.02
Beets	0	0	8	0.02	3	0.01
Peas	0	0	5	0.01	13	0.03
Canola	0	0	2	0	0.2	0
Herbs	0	0	1	0	5	0.01
Mint	0	0	0.8	0	5	0.01
Potatoes	0	0	0.7	0	2	0
Misc. Fruits and Vegetables	0	0	0.7	0	0	0
Triticale	0	0	0.7	0	0.7	0
Broccoli	0	0	0.4	0	0	0
Greens	0	0	0.2	0	1	0
Pecans	0	0	0	0	2	0.01
Garlic	0	0	0	0	1	0
Plums	0	0	0	0	1	0
Total	**38,271**	**100**	**41,932**	**100**	**41,095**	**100**

Source: USDA NASS CropScape CDL datasets (2009, 2010 and 2011); Oregon DEQ PCS (2005). See Table 1 for complete metadata.

Based on this data, the top crop items by acreage in the Clackamas River watershed between 2009 and 2011 were: 1) pastures and hay; 2) nurseries and greenhouses; 3) cranberries; 4) seed and sod grass; 5) blueberries; 6) Christmas trees; and 7) Hazelnuts (2009 and 2010 only).

Applying Crop-Specific Fertilizer and Pesticide Application Rates

After Herrera mapped crop type distributions in the Clackamas River watershed between 2009 and 2011, the next step was to determine crop-specific fertilizer and pesticide application rates to apply to each field or nursery. To accomplish this, Herrera completed a review of fertilizer guides by crop type prepared by the OSU Extension to determine the recommended amounts of nitrogen and phosphorous to apply to each field. Phosphorous and nitrogen runoff from manure and synthetic fertilizers can have significant impacts on water quality and human health; phosphorous is "often the primary concern in freshwaters (lakes and streams), while nitrogen is the main concern for coastal water (bays and oceans) and drinking water supplies" (Rutgers 2011). When manure is spread on fields as a fertilizer, it can also introduce some of the more toxic substances present in livestock excretions to source water, including pharmaceuticals and bacteria (Campagnolo et. al. 2002).

Recommended nitrogen and phosphorous application rates were frequently presented as a range that was dependent on several factors, including site-specific soil test results, previous crop

cover, and crop stage. To determine the most appropriate application rate to apply from this range to each crop type, Herrera went through the following steps:

1. The minimum and maximum recommended application rates for nitrogen and phosphorous, regardless of site-specific soil test results, were determined for each crop type from individual fertilizer guides.

2. In most cases, the average value from this range was used as the estimated fertilizer application rate for each crop type used in the GIS risk analysis. Some fertilizer guides provided more detailed information on common application rates for Western Oregon that varied from the average; in these cases, the more detailed application rates were used.

3. After the average nitrogen and phosphorous application rates were determined, Herrera joined these values to the CDL crop type grids for 2009, 2010, and 2011. The recommended nitrogen and phosphorous application rates for each CDL grid were then added together and dividied by three to produce average nitrogen and phosphorous application rates for each pixel between 2009 and 2011. The purpose of this step was to attempt to account for potential crop rotation in the watershed over time.

Detailed fertilizer application rate ranges and averages used in this analysis are provided in Table 3. This data is sorted by highest average recommended nitrogen application rates. Figures 1A and 1B show average recommended application rates of nitrogen and phosphorous by crop type in the Clackamas River between 2009 and 2011. Fertilizer guides were not readily available for nurseries and greenhouses from OSU Extension Services; for these locations, the fertilizer application rates for the underlying CDL crop types were assumed.

After average fertilizer application rates were estimated for each crop type, the next step was to identify recommended pesticide application rates. More than two hundred different herbicide and insecticides were listed for managing weeds and insects in the Clackamas River watershed based on the OSU Extension Service herbicide and insecticide handbooks. To help narrow the focus of the risk analysis efforts to the pesticides that have historically been most impactful to source water quality, Herrera reviewed 119 water quality sample results collected in the Clackamas River watershed between 2000 and 2005 to identify pesticides that 1) were detected in at least 20% of samples or 2) were detected at levels that exceeded aquatic-life benchmarks. In total, 17 pesticide compounds met one or both of these criteria; average recommended application rates were obtained for eleven herbicides and six insecticides, with the most frequent detection rates being: 3,4-Dichlorophenyl isocyanate, a degradate of diuron (100%); glyphosate (71%); simazine (52%); atrazine (47%); napropamide (44%); and diuron (44%) (Carpenter et. al. 2005).

The same steps followed for determining average recommended application rates for fertilizers by crop type were also used to determine application rates for pesticides. Recommended pesticide application rate averages (measured in pounds of active ingredients per acre) used in this analysis by crop type are provided in Table 4. Figures 2A and 2B show relative average application rates of herbicides and insecticides by crop type in the Clackamas River watershed. It is important to keep in mind when interpreting the pesticide and fertilizer application rates data

Table 3. Recommended fertilizer application rate ranges and average application rates assumed by crop type in the Clackamas River watershed.

Crop Type	Recommended Application Rates Based on Soil Test Results (lbs/acre)		Application Rates Used in the GIS Agricultural Activities Risk Analysis (lbs/acre)	
	Nitrogen	Phosphorous (P_2O_5)	Nitrogen	Phosphorous (P_2O_5)
Walnuts	0 to 15 lbs/tree	0	872	0
Broccoli	150 to 300	80 to 200	225	140
Apples	0 to 2 lbs/tree	0 to 15 lbs/tree	218	1308
Garlic	150 to 250	100 to 200	200	150
Cauliflower	150 to 250	80 to 200	200	140
Other Tree Nuts	0 to 3 lbs/tree	0	180	0
Pecans	0 to 3 lbs/tree	0	180	0
Canola	70 to 280	0 to 30	175	15
Mint	0 to 250	0 to 240	170	120
Beets	130 to 170	70 to 150	150	110
Other Hays	50 to 200	0 to 100	150	50
Seed and Sod Grass	150 to 200	0 to 60	150	30
Greens	100 to 200	100 to 150	150	125
Pasture and Grass	100 to 180	0 to 100	150	50
Pasture and Hay	100 to 180	0 to 100	150	50
Misc. Fruits and Vegetables	0	0	150	100
Onions	120 to 170	140 to 200	145	170
Potatoes	50 to 200	80 to 200	125	140
Spring Wheat	50 to 200	0 to 45	125	25
Peppers	100 to 150	100 to 150	125	125
Oats	60 to 180	0 to 60	120	30
Rye	60 to 180	0 to 60	120	30
Winter Wheat	60 to 180	0 to 60	120	30
Triticale	0	0	120	30
Herbs	75 to 150	50 to 200	115	125
Other Crops	--	--	110	60
Barley	70 to 160	0 to 60	105	30
Squash	60 to 150	0 to 150	105	75
Blueberry	30 to 165	0 to 60	100	15
Radish	50 to 150	130 to 150	100	140
Hops	100 to 150	0 to 100	100	50

Source: Oregon State Extension Fertilizer Guides. See References section for specific sources by crop type.

Table 3. (continued) Recommended fertilizer application rate ranges and average application rates assumed by crop type in the Clackamas River watershed.

Crop Type	Recommended Application Rates Based on Soil Test Results (lbs/acre)		Application Rates Used in the GIS Agricultural Activities Risk Analysis (lbs/acre)	
	Nitrogen	Phosphorous (P_2O_5)	Nitrogen	Phosphorous (P_2O_5)
Prunes	0 to 180	0 to 10 lbs/tree	90	360
Dry Beans	50 to 110	60 to 150	85	105
Corn	0 to 175	40 to 100	85	70
Cabbage	40 to 100	80 to 200	80	140
Turnips	50 to 100	80 to 150	75	105
Christmas Trees	0 to 150	0 to 180	75	180
Sweet Corn	30 to 165	0 to 150	70	75
Strawberries	40 to 70	0 to 120	60	60
Cherry Orchard	15 to 100	0 to 10 lbs/tree	60	0
Plums	15 to 100	0 to 10 lbs/tree	60	0
Cranberries	40 to 60	< 45	50	30
Grapes	20 to 30	0 to 60	25	30
Alfalfa	0	0 to 150	0	75
Clover and Wildflowers	0	0 to 80	0	40
Peas	0	0 to 80	0	40
Vetch	0	0 to 80	0	40

Source: Oregon State Extension Fertilizer Guides. See References section for specific sources by crop type.

that this information does not indicate the amount of pesticides and fertilizers physically applied on the ground. Instead, this data is intended to help compare the relative amount of fertilizers and pesticides recommended for application by crop type.

Map CAFOs and Other Animal Activities

After Herrera mapped crop distribution and estimated average recommended fertilizer and pesticide application rates for each crop type between 2009 and 2011, the next step was to map the extent and intensity of CAFOs and other animal activities in the Clackamas River watershed. The locations of three permitted CAFOs and approximately 200 other animal-related activities were mapped using the Oregon PCS dataset, including grazing areas, boarding stables, large kennels, and horse camps. Each PCS location includes a low-to-high risk ranking based on its potential impact to source water quality. Because the PCS data was mapped at the state level, the locations are approximate.

Mapped CAFOs and other animal activity locations by risk category are shown in Figure 3.

Table 4. Average annual recommended pesticide application rates by crop type in the Clackamas River watershed.

Crop Type	Herbicides (lbs/acre)											Insecticides (lbs/acre)					
	2,4-D*	Atrazine#	Dichlobenil	Dimethenamid-P	Diuron*	Glyphosate	Hexazinone	Napropamide	Simazine	Triclopyr	Trifluralin	Chlorpyrifos*+	Diazinon*	Endosulfan*^	Ethoprop+	Metalaxyl	Carbaryl*
Alfalfa	1	--	--	--	1.8	1.88	0.98	--	--	--	1.13	--	--	--	--	--	1
Apples	0.83	--	5	--	0.5	0.57	--	5	3.2	--	0.75	3	3	0.67	--	--	2.5
Barley	0.63	--	--	--	1.4	0.56	--	--	--	--	--	0.38	--	--	--	0.22	30
Beets	--	--	--	--	--	--	--	--	--	--	--	--	2.13	--	--	--	1.25
Blueberry	1.4	--	3.98	--	3	0.57	2	2	2	--	--	-	0.5	--	--	--	1.25
Broccoli	--	--	--	--	--	--	--	1.5	--	--	0.75	1.38	4	--	--	--	1.25
Cabbage	--	--	--	--	--	--	--	1.5	--	--	0.75	1.38	4	--	--	--	1.25
Canola	--	--	--	--	--	--	--	--	--	--	0.75	--	--	--	--	--	--
Cauliflower	1.5	--	--	0.77	--	--	--	--	--	--	0.75	1.38	4	--	--	--	1.25
Cherry Orchard	0.83	--	5	--	0.75	0.57	--	2.5	3.2	--	0.75	2.15	4.5	4.5	--	--	2.5
Christmas Trees	2.38	3	2.96	--	--	0.57	1.5	--	3	1.31	--	1	--	--	--	--	3
Clover and Wildflowers	--	--	--	--	1.6	--	--	--	--	--	--	--	--	--	--	--	1.25
Corn	0.85	1.8	--	0.73	--	2.25	--	--	--	--	--	0.75	0.09	--	3	0.09	1.5
Cranberries	3	--	2.1	--	--	0.57	--	6	--	--	--	1.41	2	--	--	--	1.75
Dry Beans	--	--	--	--	--	--	--	--	--	--	0.53	0.63	--	--	--	--	1.25
Garlic	--	--	--	0.77	--	--	--	--	--	--	--	--	3.5	--	--	--	1.5

Source: 2012 Pacific Northwest Weed Management and Pest Management Handbooks. See References section for more information.

*: Pesticide exceeded a U.S. EPA or non-U.S. EPA aquatic-life benchmark (Carpenter et. al. 2005)

#: Atrazine is no longer widely used in the agricultural community (Morgenstern 2006).

^: The use of endosulfan is being phased out by the U.S. EPA beginning July 31, 2012.

+: Retricted use pesticide.

Table 4. (continued) Average annual recommended pesticide application rates by crop type in the Clackamas River watershed.

Crop Type	Herbicides (lbs/acre)											Insecticides (lbs/acre)					
	2,4-D*	Atrazine#	Dichlobenil	Dimethenamid-P	Diuron*	Glyphosate	Hexazinone	Napropamide	Simazine	Triclopyr	Trifluralin	Chlorpyrifos*+	Diazinon*	Endosulfan*^	Ethoprop+	Metalaxyl	Carbaryl*
Hops	0.48	--	--	--	--	0.56	--	--	--	--	0.63	--	--	--	3	--	--
Mint	--	--	--	--	1.5	0.25	--	2	--	--	0.63	1.25	--	--	3	--	--
Misc. Fruits and Vegetables	1.76	--	3.04	0.77	2.2	0.99	2	2.64	2.82	--	0.82	1.07	2.72	1.75	--	--	1.39
Nurseries and Greenhouses	--	3	5.5	0.98	3.2	2.63	--	4.5	2.5	--	4	2	2	3	3	0.25	4
Oats	0.62	--	--	--	2	0.56	--	--	--	--	--	0.38	--	--	--	0.26	30
Onions	--	--	--	0.77	--	--	--	--	--	--	0.5	1	3	--	--	--	--
Other Crops	0.96	--	2.96	0.77	1.55	1.04	0.95	--	--	1.46	0.77	0.7	0.2	0.75	--	0.23	2
Other Hays	--	--	--	--	--	0.56	--	--	--	1.03	--	--	--	--	--	--	1
Other Tree Nuts	0.83	--	5	--	0.5	0.57	--	2.5	3.2	--	0.75	2.34	1	3	--	--	3.5
Pasture and Grass	1.36	--	--	--	--	1.97	0.66	--	--	1.75	--	--	--	--	--	--	0.88
Pasture and Hay	1.36	--	--	--	--	1.97	0.66	--	--	1.75	--	--	--	--	--	--	0.88
Peas	--	--	--	--	--	--	--	--	--	--	0.38	0.17	3	0.75	--	--	1.25
Pecans	0.83	--	5	--	0.5	0.57	--	2.5	3.2	--	0.75	1.34	1	3	--	--	3.50
Peppers	--	--	--	--	--	--	--	1.5	--	--	0.75	--	--	--	--	--	1.25
Plums	0.83	--	5	--	0.75	0.57	--	2.5	3.2	--	0.75	3	4	--	3	--	3

Source: 2012 Pacific Northwest Weed Management and Pest Management Handbooks. See References section for more information.

*: Pesticide exceeded a U.S. EPA or non-U.S. EPA aquatic-life benchmark (Carpenter et. al. 2005)

#: Atrazine is no longer widely used in the agricultural community (Morgenstern 2006).

^: The use of endosulfan is being phased out by the U.S. EPA beginning July 31, 2012.

+: Retricted use pesticide

Table 4. (continued) Average annual recommended pesticide application rates by crop type in the Clackamas River watershed.

Crop Type	Herbicides (lbs/acre)											Insecticides (lbs/acre)					
	2,4-D*	Atrazine#	Dichlobenil	Dimethenamid-P	Diuron*	Glyphosate	Hexazinone	Napropamide	Simazine	Triclopyr	Trifluralin	Chlorpyrifos*+	Diazinon*	Endosulfan*^	Ethoprop+	Metalaxyl	Carbaryl*
Potatoes	--	--	--	0.82	--	0.74	--	--	--	--	1.5	--	--	--	--	--	1.25
Prunes	0.83	--	5	--	0.5	0.57	--	2.5	3.2	--	0.75	3	4	--	--	--	3
Radish	--	--	--	0.77	--	--	--	--	--	--	--	--	3	--	--	--	1.5
Grapes	--	--	5	--	2.4	2.49	--	2	--	--	1.75	1.41	--	0.5	--	--	1.75
Greens	--	--	--	--	--	--	--	--	3	--	0.75	1.38	3	--	--	--	1.25
Herbs	--	--	--	--	--	--	--	--	--	--	0.75	1.25	--	--	3	--	1.5
Rye	0.95	--	--	--	1.2	0.57	--	--	--	--	0.75	0.38	--	--	--	0.26	30
Seed and Sod Grass	--	--	--	0.82	2	--	--	--	--	--	--	0.75	--	--	--	--	1.25
Spring Wheat	0.83	--	--	--	--	0.56	--	--	--	--	--	0.38	--	--	--	0.26	30
Squash	--	--	--	0.7	--	0.59	--	--	--	--	0.75	0.005	--	--	--	--	1
Strawberries	1.15	--	--	--	--	0.57	--	2	1	--	--	1.47	0.75	1	--	--	1.5
Sweet Corn	--	2.5	--	0.77	--	2.25	--	--	2.8	--	--	1.75	0.31	--	--	--	1.25
Triticale	0.95	--	--	--	1.2	0.57	--	--	--	--	0.75	0.38	--	--	--	0.26	30
Turnips	--	--	--	--	--	--	--	--	--	--	0.75	--	2.5	--	--	--	0.38
Vetch	--	--	--	--	1.6	--	--	--	--	--	--	--	--	--	--	--	1.25
Walnuts	0.83	--	5	--	0.75	0.57	--	2.5	2.8	--	0.75	2.6	--	4	--	--	3.75
Winter Wheat	0.95	--	--	--	1.2	0.57	--	--	--	--	0.75	0.38	--	--	--	0.26	30

Source: 2012 Pacific Northwest Weed Management and Pest Management Handbooks. See References section for more information.

*: Pesticide exceeded a U.S. EPA or non-U.S. EPA aquatic-life benchmark (Carpenter et. al. 2005)

#: Atrazine is no longer widely used in the agricultural community (Morgenstern 2006).

^: The use of endosulfan is being phased out by the U.S. EPA beginning July 31, 2012.

+: Retricted use pesticide

Mapping Public and Private Fish Hatcheries

In addition to identifying CAFOs and other animal activity locations, Herrera also mapped the locations of two public and one private fish hatchery in the watershed ranked as being of moderate to high risk to source water quality in the Clackamas River watershed. The locations of these hatcheries are shown in Figure 3.

Calculating Linear Distance to Nearest Tributary

Herrera used stream centerline data to calculate the linear distance from agricultural activities in the Clackamas River watershed to the nearest tributary to the Clackamas River. This calculation was based on surface drainage only and does not take into account existing agricultural ditches or other stormwater conveyance systems.

Mapping Vulnerable Soils

Sediment is the largest contaminant of surface water in the U.S. by weight and volume (Koltun et. al. 1997). Disturbing soil through tillage and cultivation and leaving it without vegetative cover can increase the rate of soil erosion (USDA 2006). Herrera mapped HEL Class 1 soils data obtained from Oregon DEQ representing areas of highly erodible soils with rapid runoff potential in the Clackamas River watershed. This data was then overlaid with mapped agricultural activities and irrigated land to identify areas of highly erodible soils where agricultural production is concentrated.

Calculating Aggregate Agricultural Activities Risk

After Herrera mapped crop distribution and nurseries and greenhouses locations; estimated crop-specific fertilizer and pesticide application rates to apply to each field or nursery; mapped CAFOs, other animal activities, and fish hatcheries; calculated proximity of agriculture activities to Clackamas River tributaries; and mapped vulnerable soils and irrigated land, the next step completed was to rank and overlay the datasets together to determine aggregate risk from agricultural activities to source water quality in the Clackamas River watershed. Herrera produced two separate maps showing risk from agricultural activities in the watershed: 1) aggregate risk from fertilizers; and 2) aggregate risk from pesticides. Low-to-high risk rankings were included in the Oregon PCS data for fish hatcheries and CAFOs and other animal activities and Herrera did not analyze potential risk from these locations any further; these results are shown in Figure 3. Both the fertilizer and pesticide risk analyses incorporated HEL Class 1 soil data, irrigated land, and proximity to surface water as contributing factors to aggregate risk. These risk datasets were generated using the following methodology.

First, the attributes for each individual dataset were assigned a ranking scheme on a scale of 1 to 5, with a value of 1 indicating a low risk from agricultural activities to source water quality and a value of 5 indicating high risk. The ranking scheme for each dataset was determined by computing a histogram of the data distribution in GIS and then using statistical breaks in the data to assign relative risk rankings. For example, recommended application rates of the herbicide 2,4-D ranged from 0.48 to 3 pounds per acre depending on weed type and crops being treated, with statistical breaks in the data histogram occurring at 0.85, 1, and 1.5 pounds. This

information was used to determine the 2,4-D risk factors used in the aggregate pesticide risk analysis.

Tables 5 and 6 show the detailed ranking factors applied to each dataset used in the fertilizer and pesticide aggregate risk analyses. All datasets contributing to the aggregate risk datasets were weighted equally in these analyses. After the ranking factorswere applied, the final step was to convert each dataset to a raster grid with 10-meter pixels and overlay the grids together to calculate a cumulative risk value for each pixel. These results were then mapped into low, moderate, and high risk categories. The results of the analyses showing aggregate risk from fertilizers and pesticides to source water quality in the Clackamas River watershed are shown in Figures 4A and 4B.

Table 5. Ranking, ranking criteria, and weighting factors applied to each GIS dataset to determine the risk from fertilizers to source water quality in the Clackamas River watershed.

Dataset	Ranking Factor	Ranking Criteria
HEL Class 1 Soil Designation	Yes	5
Irrigated Land	Yes	5
Proximity to Surface Water	0 to 150 feet	5
	150 to 300 feet	4
	300 to 500 feet	3
	500 to 1,000 feet	2
	> 1,000 feet	1
Fertilizers: Average Annual Recommended Application Rate of Nitrogen	None	1
	< 25 lbs	2
	25 to 75 lbs	3
	75 to 150 lbs	4
	> 150 lbs	5
Fertilizers: Average Annual Recommended Application Rate of Phosphorous	None	1
	< 25 lbs	2
	25 to 50 lbs	3
	50 to 75 lbs	4
	> 75 lbs	5

Table 6. Ranking, ranking criteria, and weighting factors applied to each GIS dataset to determine the risk from pesticides to source water quality in the Clackamas River watershed.

Dataset	Ranking Factor	Ranking Criteria
HEL Class 1 Soil Designation	Yes	5
Irrigated Land	Yes	5
Proximity to Surface Water	0 to 150 feet	5
	150 to 300 feet	4
	300 to 500 feet	3
	500 to 1,000 feet	2
	> 1,000 feet	1
Herbicides: Average Recommend Application Rates of 2,4-D (ai/acre)	0	1
	< 0.85 lbs	2
	0.85 to 1 lbs	3
	1 to 1.5 lbs	4
	> 1.5 lbs	5
Herbicides: Average Recommend Application Rates of Atrazine (ai/acre)	0	1
	< 0.85 lbs	2
	0.85 to 1 lbs	3
	1 to 1.5 lbs	4
	> 1.5 lbs	5
Herbicides: Average Recommend Application Rates of Dichlobenil (ai/acre)	0	1
	< 1 lbs	2
	1 to 1.5 lbs	3
	1.5 to 2.5 lbs	4
	> 2.5 lbs	5
Herbicides: Average Recommend Application Rates of Dimethenamid-P (ai/acre)	0	1
	< 0.25 lbs	2
	0.25 to 0.5 lbs	3
	0.5 to 0.75 lbs	4
	> 0.75 lbs	5
Herbicides: Average Recommend Application Rates of Diuron (ai/acre)	0	1
	< 0.25 lbs	2
	0.25 to 0.75 lbs	3
	0.75 to 1.25 lbs	4
	> 1.25 lbs	5

Table 6. (continued) Ranking, ranking criteria, and weighting factors applied to each GIS dataset to determine the risk from pesticides to source water quality in the Clackamas River watershed.

Dataset	Ranking Factor	Ranking Criteria
Herbicides: Average Recommend Application Rates of Glyphosate (ai/acre)	0	1
	< 0.25 lbs	2
	0.25 to 0.75 lbs	3
	0.75 to 2 lbs	4
	> 2 lbs	5
Herbicides: Average Recommend Application Rates of Hexazinone (ai/acre)	0	1
	< 0.5 lbs	2
	0.5 to 0.75 lbs	3
	0.75 to 1 lbs	4
	> 1 lbs	5
Herbicides: Average Recommend Application Rates of Napropamide (ai/acre)	0	1
	< 1 lbs	2
	1 to 2 lbs	3
	2 to 3 lbs	4
	> 3 lbs	5
Herbicides: Average Recommend Application Rates of Simazine (ai/acre)	0	1
	< 0.5 lbs	2
	0.5 to 1 lbs	3
	1 to 2 lbs	4
	> 2 lbs	5
Herbicides: Average Recommend Application Rates of Triclopyr (ai/acre)	0	1
	< 0.75 lbs	2
	0.75 to 1 lbs	3
	1 to 1.5 lbs	4
	> 1.5 lbs	5
Herbicides: Average Recommend Application Rates of Trifluralin (ai/acre)	0	1
	< 0.25 lbs	2
	0.25 to 0.5 lbs	3
	0.5 to 0.75 lbs	4
	> 0.75 lbs	5
Insecticides: Average Recommend Application Rates of Chlorpyrifos (ai/acre)	0	1
	< 0.25 lbs	2
	0.25 to 0.75 lbs	3
	0.75 to 1.5 lbs	4
	> 1.5 lbs	5

Table 6. (continued) Ranking, ranking criteria, and weighting factors applied to each GIS dataset to determine the risk from pesticides to source water quality in the Clackamas River watershed.

Dataset	Ranking Factor	Ranking Criteria
Insecticides: Average Recommend Application Rates of Diazinon (ai/acre)	0	1
	< 0.5 lbs	2
	0.5 to 1 lbs	3
	1 to 2 lbs	4
	> 2 lbs	5
Insecticides: Average Recommend Application Rates of Endosulfan (ai/acre)	0	1
	< 0.5 lbs	2
	0.5 to 1 lbs	3
	1 to 2 lbs	5
	> 2 lbs	5
Insecticides: Average Recommend Application Rates of Ethoprop (ai/acre)	0	1
	< 1 lbs	2
	1 to 2 lbs	3
	2 to 3 lbs	4
	> 3 lbs	5
Insecticides: Average Recommend Application Rates of Metalaxyl (ai/acre)	0	1
	< 0.1 lbs	2
	0.1 to 0.15 lbs	3
	0.15 to 0.2 lbs	4
	> 0.2 lbs	5
Insecticides: Average Recommend Application Rates of Carbaryl (ai/acre)	0	1
	< 1 lbs	2
	1 to 1.5 lbs	3
	1.5 to 2 lbs	4
	> 2 lbs	5

Results and Recommendations

Based on the results of this analysis, the top crops growns by acreage in the Clackamas River watershed between 2009 and 2011 were: 1) pastures and hay; 2) nurseries and greenhouses; 3) cranberries; 4) seed and sod grass; 5) blueberries; 6) Christmas trees; and 7) Hazelnuts (2009 and 2010 only). Of these crops, the highest average rates of herbicides recommended for use are for nurseries and greenhouses, Christmas trees, blueberries, and cranberries; for insecticides, nurseries and greenhouses, cranberries, and Christmas trees; for nitrogen, hazelnuts, pastures and hay, and seed and sod grass; and for phosphorous, Christmas trees and pastures and hay. It is important to keep in mind when interpreting the pesticide and fertilizer application rates data that this information does not indicate the amount of pesticides and fertilizers physically applied on

the ground. Instead, this data is intended to help compare the relative amount of average fertilizers and pesticides recommended for application by crop type.

As indicated in Figure 4A there are several regions with high potential aggregate risk to source water quality from fertilizer use in the Clackamas River watershed based on the GIS predictive modeling, including: 1) northwest of the City of Sandy, near the HWY 212/26 junction and 2) south of Clackamas River Road near the surface water intakes. The largest high potential aggregate risk "hot spot" from pesticide uses as indicated in Figure 4B is the area northwest of the City of Sandy, primarily due to the concentration of nurseries and greenhouses located in this area. The most appropriate method for analyzing the risk analyses output maps is to focus on overall geographic risk trends rather than field-level results due to the many assumptions applied to the risk analyses input data and the coarse resolution of the CDL crop type data. It is important to keep in mind that the agricultural activities risk estimates are predicted values only and do not necessarily reflect agricultural practices on the ground. If a modeling effort is developed in the future to help to quanitfy pollutant loading from various sources, the GIS crop type and application rates data will serve as valuable model input.

Herrera recommends that this GIS analysis be repeated every three to five years to account for changes in crop cover and the potential decommissioning of pesticides by U.S. EPA. An exact timeline for repeating this analysis should be determined based on the availability of updated pesticide detection data from water quality sampling in the watershed. The following adjustments could also be made when the analysis is repeated to help refine the results:

1. Organic farming techniques and the use of agricultural best management practices (BMPs) were not taken into account in this analysis and could have a significant impact on the overall distribution of agricultural activities risk in the watershed.

2. If particular areas of interest are identified for further analysis either based on the results of this work or future pollutant load modeling, a more precise application rate analysis could be performed on a smaller portion of the watershed through detailed aerial photography interpretation and consultation with local farmers.

3. The USDA completes a census of agriculture every five years; the next census is being conducted in 2012, and data will be released beginning in February 2014. Information collected in this census might provide helpful statistics that could be used to refine the agricultural activities analysis.

References

Campagnolo, Enzo R., Kammy R. Johnson, Adam Karpati, Carol S. Rubin, Dana W. Kolpin, Michael T. Meyer, J. Emilio Esteban, Russell W. Currier, Kathleen Smith, Kendall M. Thu, and Michael McGeehin. "Antimicrobial Residues in Animal Waste and Water Resources Proximal to Large-Scale Swine and Poultry Feeding Operations." *The Science of the Total Environment*. Vol. 299(1-3). pp. 89-95. November 2002: 90.

Carpenter, K.D., 2004. *Pesticides in the lower Clackamas River Basin, Oregon, 2000-01*. U.S. Geological Survey Water-Resources Investigations Report 03-04145. Obtained March 2, 2012 from agency website: http://pubs.usgs.gov/wri/wri034145/

Carpenter, K.D., S. Sobieszczyk, A.J. Arnsberg, and F.A. Rinella. 2005. *Pesticide Occurrence and Distribution in the Lower Clackamas River Basin, Oregon, 2000 – 2005*. U.S. Geological Survey Scientific Investigations Report 2008-5027. Obtained March 2, 2012 from agency website: http://pubs.usgs.gov/sir/2008/5027/pdf/sir20085027.pdf

Clackamas River Water Providers. 2010. *Drinking Water Protection Plan for the Clackamas River.* September 2010. Obtained December 20, 2010, from agency website: http://www.clackamasproviders.org/contacts/7.html.

U.S. Environmental Protection Agency (U.S. EPA). 2005. *Protecting Water Quality from Agricultural Runoff.* Revised March 2005. Publication No. EPA 841-F-05-001. Obtained May 28, 2012 from agency website: http://water.epa.gov/polwaste/nps/upload/2005_4_29_nps_Ag_Runoff_Fact_Sheet.pdf

Gardner, E.H., T.A. Doerge, D.B. Hannaway, H. Youngberg, and W.S. McGuire. 2000a. *Crimson clover, vetch, field peas: Western Oregon – West of Cascades.* January 2000. Fertilizer Guide 30. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 15, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20637/fg30-e.pdf

Gardner, E.H., D.B. Hannaway, T.L. Jackson, and W.S. McGuire. 2000b. *Alfalfa – Willamette Valley and Northwest Oregon.* January 2000b. Fertilizer Guide 18. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 15, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20629/fg18-e.pdf

Geosyntec Consultants. 2011. Review of GIS Risk Analysis Approach Outlines from Herrera Environmental Consultants, Inc., Seattle, Washington, memorandum to Kim Swan, Clackamas River Water Providers. December 16, 2011.

Gingrich, C., J. Hart, and N. Christensen. 2000. *Hops.* January 2010. Fertilizer Guide 79. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 15, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20648/fg79-e.pdf

Hart, J., D.M. Sullivan, J.R. Myers, and R.E. Peachey. 2010a. *Sweet Corn: Western Oregon.* October 2010. Nutrient Management Guide EM 9010-E. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 15, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/19064/em9010.pdf

Hart, J., D.M. Sullivan, M. Gamroth, T. Downing, and A. Peters. 2009. *Silage Corn: Western Oregon.* June 2009. Nutrient Management Guide EM 8978-E. Extension Services of Oregon State University, Corvallis, Oregon. Obtained March 14, 2012 from agency website: http://extension.oregonstate.edu/catalog/pdf/em/em8978-e.pdf

Hart, J., D.M. Sullivan, M.E. Mellbye, A.G. Hulting, N.W. Christensen, and G.A. Gingrish. 2010b. *Peppermint – Western Oregon.* December 2010. Nutrient Management Guide EM 9018-E. Extension Services of Oregon State University, Corvallis, Oregon. Obtained March 2, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/19693/em9018.pdf

Hart, J., G. Pirelli, L. Cannon, and S. Fransen. 2000a. *Pastures: Western Oregon and Western Washington.* January 2000. Fertilizer Guide 63. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 15, 2012 from agency website: http://extension.oregonstate.edu/catalog/pdf/fg/fg63-e.pdf

Hart, J., N.S. Mansour, D.D. Hemphill, and H.J. Mack. 2000b. *Vine crops: Cucumbers, melons, squash, pumpkins.* January 2000. Fertilizer Guide 68. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 15, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20639/fg68-e.pdf

Hart, J., N.W. Christensen, T.L. Jackson, R. Karow, and W.E. Kronstad. 2000c. *Winter Wheat: Western Oregon – West of Cascades.* January 2000. Fertilizer Guide 9. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 20, 2012 from agency website: http://www.oregon.gov/ODA/PEST/docs/pdf/97_07_fg9.pdf?ga=t

Hart, J., T. Righetti, A. Sheets, and L.W. Martin. 2000c. *Strawberries: Western Oregon – West of Cascades.* January 2000. Fertilizer Guide 14. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 20, 2012 from agency website: < Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 20, 2012 from agency website: http://www.oregon-strawberries.org/attachments/strawberry_fertilizer_guide14-e.pdf

Hart, J., B. Strik, L. White, and W. Yang. 2006. *Nutrient Management Guide for Blueberries in Oregon.* November 2006. Nutrient Management Guide EM 8918. Extensions Services of Oregon State University, Corvallis, Oregon. Obtained February 20, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20444/em8918.pdf

Hart, J., C. Landgren, R. Fletcher, M. Bondi, B. Withrow-Robinson, and G. Chastagner. 2009. *Christmas Tree Nutrient Management Guide: Western Oregon and Washington.* September 2009. Publication EM 8865-E. Extension Services of Oregon State University, Corvallis,

Oregon. Obtained February 15, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/12863/EM8856.pdf?sequence=3

Koltun, G.F, M.N. Landers, K.M. Nolan, and R.S. Parker. 1997. *Sediment Transport and Geomorphology Issues in the Water Resources Division.* Proceeding of the U.S. Geological Survey Sediment Workshop, February 4-7, 1997.

Mack, H.J., E.H. Gardner, and T.L. Jackson. 2000. *Table beets: Western Oregon – West of Cascades.* January 2000. Fertilizer Guide 13. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 24, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20624/fg13-e.pdf

Mahler, R.L. 2007. *Northern Idaho Fertilizer Guide: Oats.* July 2007. Publication No. CIS 1135. University of Idaho College of Agricultural and Life Sciences, Moscow, Idaho. Obtained February 15, 2012 from agency website: http://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1135.pdf

Mansour, N.S., H.J. Mack, E.H. Gardner, and T.L. Jackson. 2000. *Bush Beans: Western Oregon – West of Cascades.* January 2000. Fertilizer Guide 28. Extension Services of Oregon State University, Corvallis, Oregon. Obtained March 24, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20632/fg28-e.pdf/

McDole, R.E., and Mahler, R.L. 2002. *Northern Idaho Fertilizer Guide: Feed Barley.* January 3, 2002. University of Idaho College of Agricultural and Life Sciences, Moscow, Idaho. Obtained February 15, 2012 from agency website: http://www.uiweb.uidaho.edu/wq/wqfert/cis758.html

Morgenstern, K.A. 2006. *Nonpoint Source Pollution Assessment and Evaluation Results for the McKenzie River Watershed, Oregon.* April 2006. Eugene Water and Electric Board. Obtained January 5, 2012 from agency website: http://www.eweb.org/public/documents/water/NPSassessment.pdf

Hellman, E. 1997. *Winegrape Fertilization Practices for Oregon.* February 9, 1997. Northwest Berry and Grape Information Network. Obtained March 1, 2012 from agency website: http://berrygrape.org/winegrape-fertilization-practices-for-oregon/

Olsen, J. 2006. *Growing Walnuts in Oregon.* June 2006. Publication No. EM 8907. Extension Services of Oregon State University, Corvallis, Oregon. Extension Services of Oregon State University, Corvallis, Oregon. Obtained March 24, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20433/em8907.pdf

Olsen, J. 2001. *Hazelnuts.* August 2001. Nutrient Management Guide EM 8786. Extension Services of Oregon State University, Corvallis, Oregon. Obtained February 1, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20209/em8786-e.pdf

Oregon Department of Agriculture Natural Resources Division (ODA), Oregon Department of Environmental Quality Water Quality Division (DEQ). 2009. *Oregon Confined Animal Feeding*

Operation National Pollutant Discharge Elimination System General Permit Number 01-2009. June 29, 2009

Oregon State University (OSU). 2002. *Commercial Vegetable Production Guides: Arugula.* April 2, 2002. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/arug.html

Oregon State University (OSU). 2004a. *Commercial Vegetable Production Guides: Broccoli.* August 6, 2004. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/broc-pr.html

Oregon State University (OSU). 2004b. *Commercial Vegetable Production Guides: Cabbage.* August 6, 2004. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/cabb.html

Oregon State University (OSU). 2002. *Commercial Vegetable Production Guides: Cauliflower.* August 6, 2004. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/cauliflower.html

Oregon State University (OSU). 2004c. *Commercial Vegetable Production Guides: Dry Bulb Onions – Western Oregon.* August 6, 2004. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/onionb-w.html

Oregon State University (OSU). 2004d. *Commercial Vegetable Production Guides: Garlics.* August 6, 2004. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/garlic.html

Oregon State University (OSU). 2004e. *Commercial Vegetable Production Guides: Herbs and Spices.* April 2, 2002. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/herbs.html

Oregon State University (OSU). 2004f. *Commercial Vegetable Production Guides: Pepper.* August 6, 2004. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/pepper.html

Oregon State University (OSU). 2003. *Commercial Vegetable Production Guides: Radish.* January 3, 2003. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/radish.html

Oregon State University (OSU). 2004g. *Commercial Vegetable Production Guides: Rutabaga (Swede) and Turnip.* August 6, 2004. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://nwrec.hort.oregonstate.edu/rutabaga.html

Oregon State University (OSU). 2012. *2012 Pacific Northwest Insect Management Handbook.* Extension Services of University of Idaho, Oregon State University, and Washington State University. Obtained April 1, 2012 from agency website: http://pnwpest.org/pnw/insects?00INTR03.dat

Oregon State University (OSU). 2012. *2012 Pacific Northwest Weed Management Handbook.* Extension Services of University of Idaho, Oregon State University, and Washington State University. Obtained April 1, 2012 from agency website: http://pnwhandbooks.org/weed/

Pacific Northwest Extension. 2001. *Nutrient Management for Onions in the Pacific Northwest.* Publication No. PNW 546. February 2001. Extension Services of University of Idaho, Oregon State University, and Washington State University. Obtained March 24, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20755/pnw546.pdf

Pacific Northwest Extension. 2010. *Pasture and Grazing Management in the Northwest.* Publication No. PNW 614. Extension Services of University of Idaho, Oregon State University, and Washington State University. Obtained March 24, 2012 from agency website: http://www.cals.uidaho.edu/edComm/pdf/PNW/PNW0614.pdf

Righetti, T., K. Wilder, R. Stebbins, D. Burkhart, and J. Hart. 1998. *Apples.* June 1998. Nutrient Management Guide EM 8712. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20034/em8712-e.pdf

Roper, T., J. Davenport, C. DeMoranville, S. Marchand, A. Poole, J. Hart, and K. Patten. 2000. *Nitrogen for Bearing Cranberries in North America.* June 2000. Publication No. EM 8741 Extension Services of University of Wisconsin, University of Massachusetts, Oregon State University, Washington State University Cooperative, and the U.S. Department of Agriculture cooperating. Obtained February 15, 2012 from agency website: http://extension.oregonstate.edu/catalog/pdf/em/em8741.pdf

Roper, T., J. Davenport, C. DeMoranville, S. Marchand, A. Poole, J. Hart, and K. Patten. 2004. *Phosphorus for Bearing Cranberries in North America.* November 2004. Extension Services of University of Wisconsin, University of Massachusetts, Oregon State University, Washington State University Cooperative, and the U.S. Department of Agriculture cooperating. Obtained February 15, 2012 from agency website: http://longbeach.wsu.edu/cranberries/documents/phosphorusforbearingcranberriesinnorthamerica.pdf

Roper, T., Donaldson, B., Hart.J., Davenport, J., and White, L. 2011. *Answers to common cranberry questions: Oregon Cranberry School.* February 19, 2011. Extension Services of Oregon State University, Corvallis, Oregon.

Rutgers New Jersey Agricultural Experiment Station (Rutgers). 2011. *Certified Fertilizer Application Training Manual.* Obtained May 15, 2012 from agency website: http://profact.rutgers.edu/Pages/toc.aspx

Stebbins, R.L, M.H. Chaplin, E.H. Gardner, and T.A. Doerge. 1982. *Prunes (Oregon).* February 1982. Fertilizer Guide 24. Extension Services of Oregon State University, Corvallis, Oregon. Obtained January 24, 2012 from agency website: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/23762/FGNO024.pdf?sequence=1

Sullivan, D.M., B.D. Brown, C.C. Shock, D.A. Horneck, R.G. Stevens, G.Q. Pelter, and E.B.G. Feibert. 2001. *Nutrient Management for Onions in the Pacific Northwest.* February 2001. Publication No. PNW 546. Extension Services of Oregon State University, Washington State University, and University of Idaho. Obtained March 24, 2012 from agency website at: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20755/pnw546.pdf

United States Department of Agriculture (USDA). 2006. *Agricultural Resources and Environmental Indicators, 2006 Edition.* July 2006. Economic Information Bulletin 16. Obtained May 24, 2012 from agency website: http://www.ers.usda.gov/publications/arei/eib16/eib16fm.pdf

Wysocki, D.J., M. Corp, D.A. Horneck, and L.K. Lutcher. 2007. *Irrigated and Dryland Canola.* November 2007. Nutrient Management Guide EM 8943-E. Extension Services of Oregon State University, Corvallis, Oregon. Obtained May 12, 2012 from agency website at: http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20480/em8943-e.pdf

FIGURES

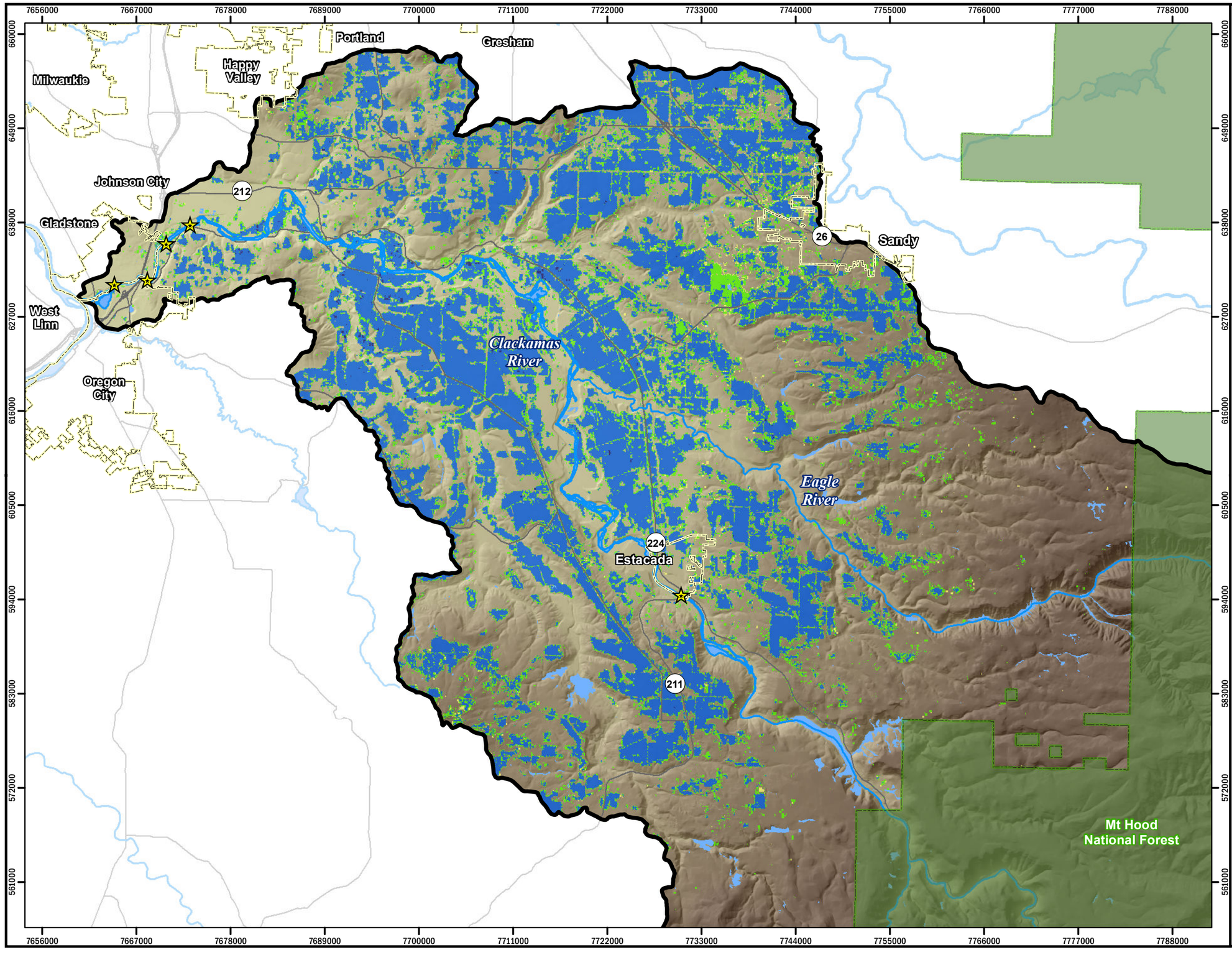

Figure 1A.
Distribution of average relative nitrogen application rates in the Clackamas River watershed between 2009 and 2011 based on recommended fertilizer application guidelines.

Legend

Relative nitrogen application rates

- None
- Low
- Moderate
- High
- Very high
- Clackamas River Watershed boundary
- National Forest boundary
- Surface water intake
- City limits

N

0 5,500 11,000 22,000

feet

Clackamas River Water Providers
Working together to protect and conserve our drinking water.

HERRERA

Coordinates: Oregon State Plane North
HARN NAD83 (feet)

Produced By: GIS (JAS)
Project: K:\Projects\10-04900-001\Project\Result_Maps\Agricultural_Activities_Results_Extent.mxd (6/6/2012)

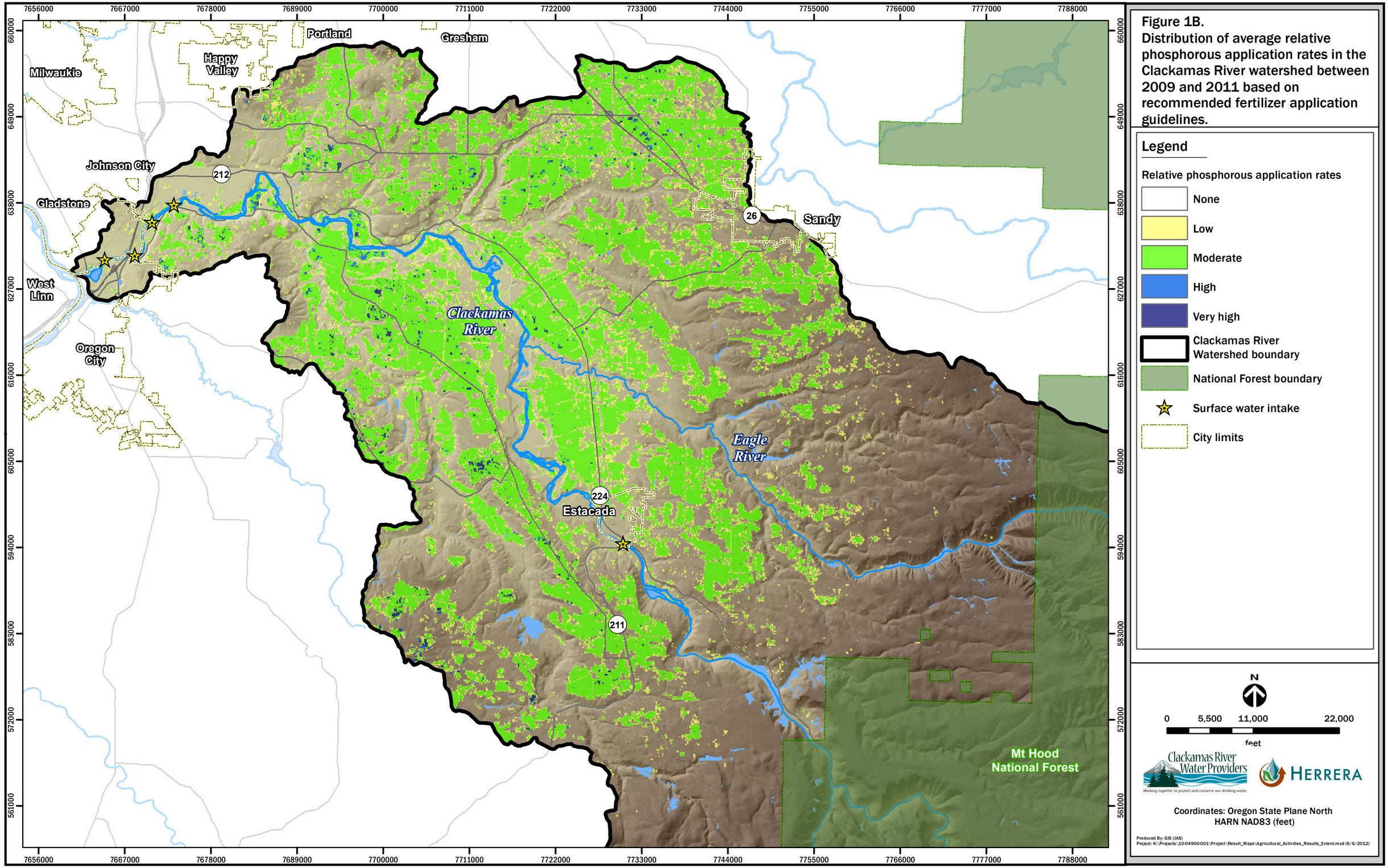

Figure 1B.
Distribution of average relative phosphorous application rates in the Clackamas River watershed between 2009 and 2011 based on recommended fertilizer application guidelines.

Legend

Relative phosphorous application rates

- None
- Low
- Moderate
- High
- Very high
- Clackamas River Watershed boundary
- National Forest boundary
- Surface water intake
- City limits

N

0 5,500 11,000 22,000

feet

Clackamas River Water Providers
Working together to protect and conserve our drinking water.

HERRERA

Coordinates: Oregon State Plane North
HARN NAD83 (feet)

Produced By: GIS (JAS)
Project: K:\Projects\10-04900-001\Project\Result_Maps\Agricultural_Activities_Results_Extent.mxd (6/6/2012)

Figure 2A.
Distribution of average relative herbicide application rates in the Clackamas River watershed between 2009 and 2011 based on recommended pesticide application guidelines.

Legend

Relative herbicide application rates

- None
- Low
- Moderate
- High
- Very High
- Clackamas River Watershed boundary
- National Forest boundary
- Surface water intake
- City limits

N

0 5,500 11,000 22,000

feet

Clackamas River Water Providers
Working together to protect and conserve our drinking water.

HERRERA

Coordinates: Oregon State Plane North
HARN NAD83 (feet)

Produced By: GIS (JAS)
Project: K:\Projects\10-04900-001\Project\Result_Maps\Agricultural_Activities_Results_Extent.mxd (6/6/2012)

Portland
Gresham
Happy Valley
Milwaukie
Johnson City
Gladstone
West Linn
Oregon City
Sandy
Estacada
Clackamas River
Eagle River
Mt Hood National Forest
212
26
224
211

7656000 7667000 7678000 7689000 7700000 7711000 7722000 7733000 7744000 7755000 7766000 7777000 7788000

660000 649000 638000 627000 616000 605000 594000 583000 572000 561000

Figure 2B.
Distribution of average relative insecticide application rates in the Clackamas River watershed between 2009 and 2011 based on recommended pesticide application guidelines.

Legend

Relative insecticide application rates

- None
- Low
- Moderate
- High
- Very High
- Clackamas River Watershed boundary
- National Forest boundary
- Surface water intake
- City limits

N

0 5,500 11,000 22,000

feet

Clackamas River Water Providers
Working together to protect and conserve our drinking water.

HERRERA

Coordinates: Oregon State Plane North
HARN NAD83 (feet)

Produced By: GIS (JAS)
Project: K:\Projects\10-04900-001\Project\Result_Maps\Agricultural_Activities_Results_Extent.mxd (6/6/2012)

Figure 3.
Potential risk from fish hatcheries, Confined Animal Feed Operations (CAFOs) and other animal activities in the Clackamas River watershed based on Oregon DEQ Potential Contaminant Source (PCS) data.

Legend

- Confined Animal Feeding Operation (CAFO) - Oregon DEQ/ODA

Animal activities (Oregon PCS)

- Boarding stable
- Confined Animal Feed Operation (CAFO)
- Grazing animals (> 5 large animals or equivalent/acre)
- Kennels (> 20 pens)
- Other - horse camp
- Fish hatchery

Potential Contaminant Source (PCS) risk

- Lower
- Moderate
- Higher
- Clackamas River Watershed boundary
- National Forest boundary
- Surface water intake
- City limits

N

0 5,500 11,000 22,000

feet

Clackamas River Water Providers
Working together to protect and conserve our drinking water.

HERRERA

Coordinates: Oregon State Plane North
HARN NAD83 (feet)

Produced By: GIS (JAS)
Project: K:\Projects\10-04900-001\Project\Result_Maps\Agricultural_Activities_Results_Extent.mxd (6/6/2012)

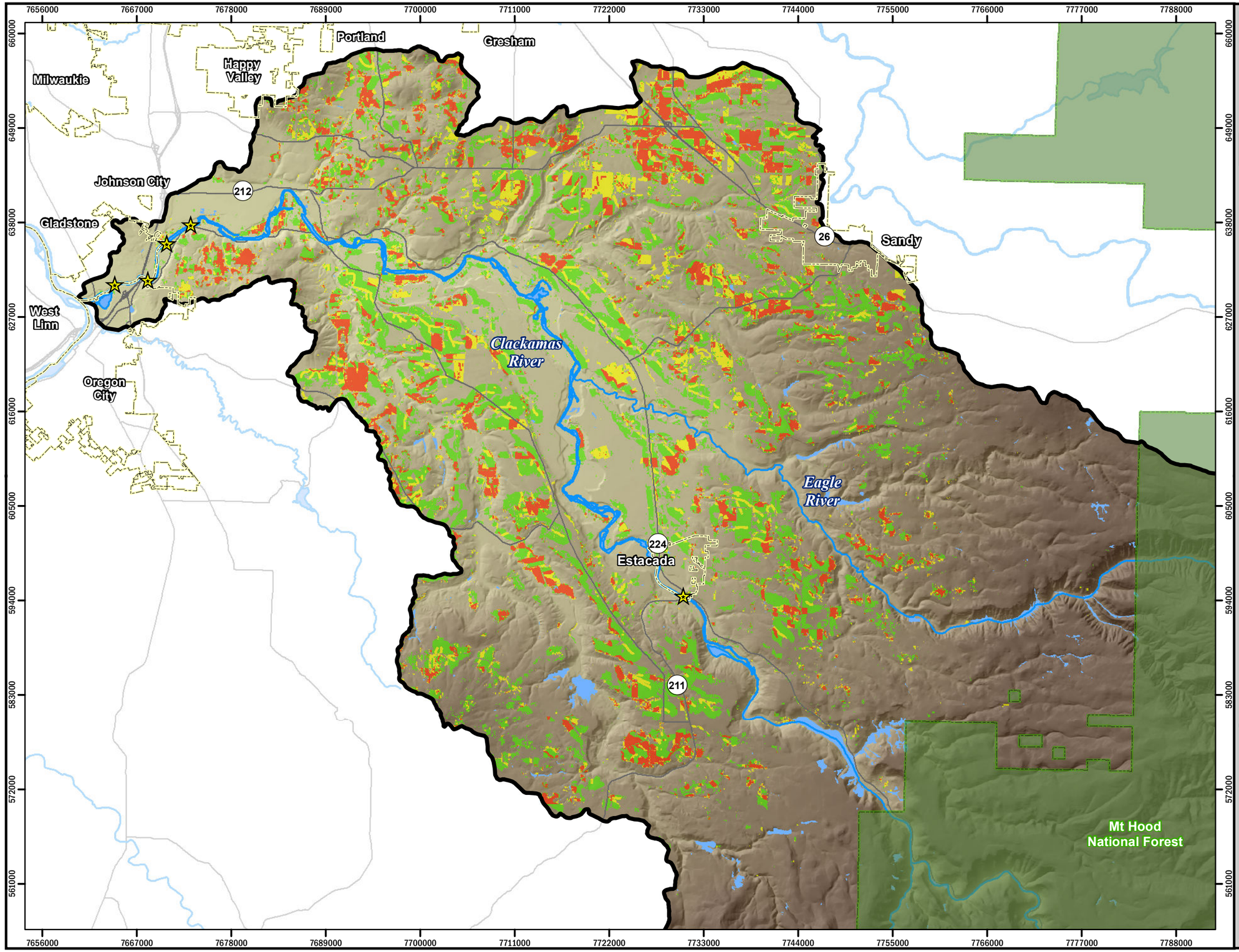

Figure 4A.
Potential cumulative risk from fertilizers to drinking water quality in the Clackamas River watershed based on GIS predictive modeling.

Legend

Cumulative predicted risk

- Very low
- Low
- Moderate
- High
- Surface water intake
- City limits
- Clackamas River Watershed boundary
- National Forest boundary

N

0 5,500 11,000 22,000

feet

Clackamas River Water Providers
Working together to protect and conserve our drinking water.

HERRERA

Coordinates: Oregon State Plane North
HARN NAD83 (feet)

Produced By: GIS (JAS)
Project:
K:\Projects\10-04900-001\Project\Result_Maps\Agricultural_Activities_Results_Extent_vers2.mxd (6/7/2012)

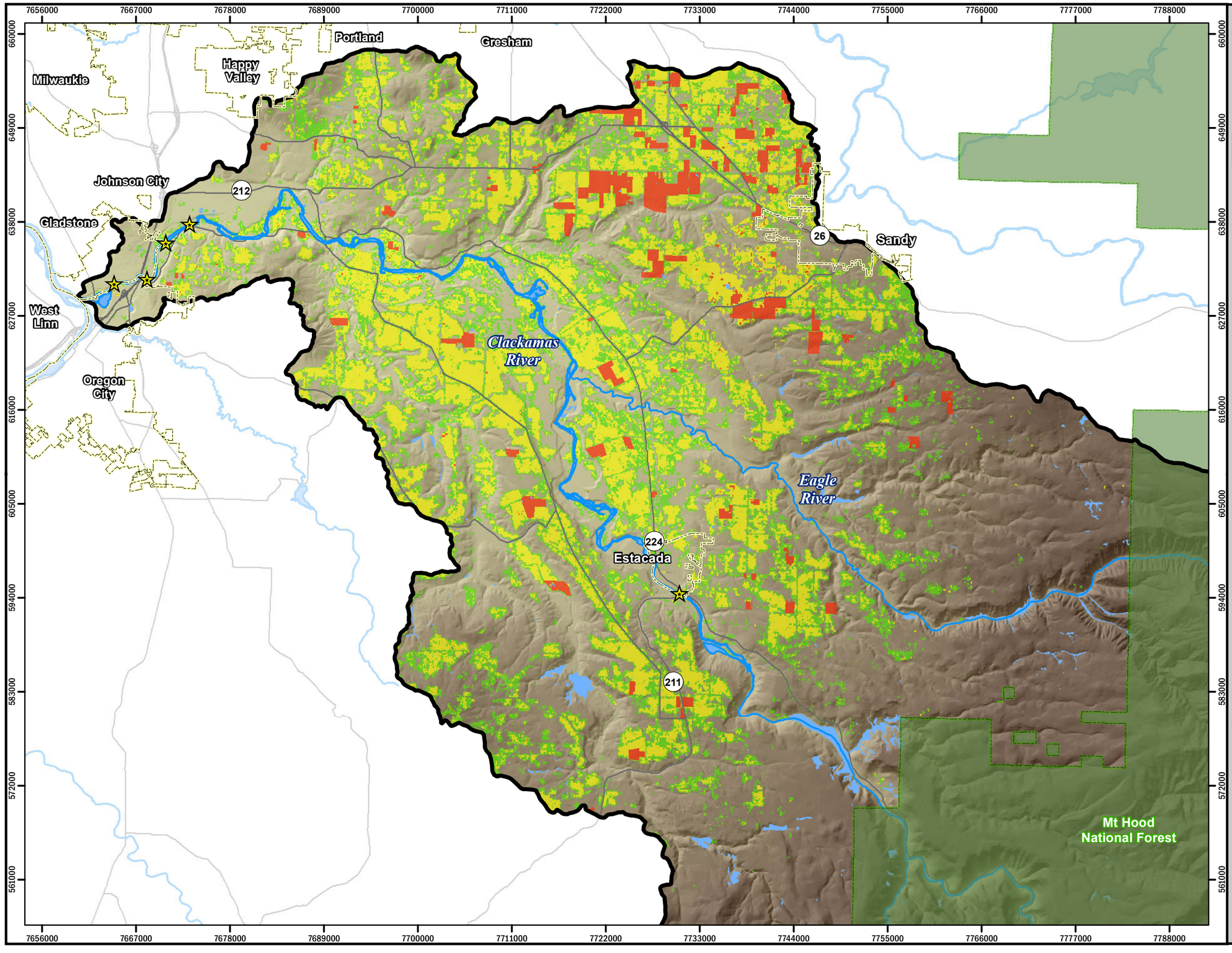

Figure 4B.
Potential cumulative risk from pesticides to drinking water quality in the Clackamas River watershed based on GIS predictive modeling.

Legend

Cumulative predicted risk

- Very low
- Low
- Moderate
- High
- Surface water intake
- City limits
- Clackamas River Watershed boundary
- National Forest boundary

N

0 5,500 11,000 22,000

feet

Clackamas River Water Providers
Working together to protect and conserve our drinking water.

HERRERA

Coordinates: Oregon State Plane North
HARN NAD83 (feet)

Produced By: GIS (JAS)
Project:
K:\Projects\10-04900-001\Project\Result_Maps\Agricultural_Activities_Results_Extent_vers2.mxd (6/7/2012)