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# Washington Nitrate Prioritization Project

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# Washington Nitrate Prioritization Project

*by*

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# Abstract

The Washington State Department of Ecology (Ecology) Water Quality Program undertook the Nitrate Prioritization Project in 2014 (Morgan, 2014) because of growing concerns about groundwater contamination by nitrates, and the inability to display and evaluate nitrate data on a statewide basis.

This report originated from the agriculture and water quality talks that took place in 2012. Participating agencies agreed that if data exists, everyone should be able to see it in one central location. Agencies that contributed included the Washington Dept. of Ecology, Washington Dept. of Health, Washington Dept. of Agriculture, U.S. Environmental Protection Agency, U.S. Natural Resource Conservation Service, U.S. Geological Survey, and the Washington Conservation Commission.

The Safe Drinking Water Act nitrate limit for delivery of water from public water systems is 10 mg/L. This limit has been exceeded in public water supplies and private wells in various areas of the state going back decades. Not only is contaminated groundwater a public health issue, treatment is also very costly to the public water supply systems and individual households who must deal with contamination on their own.

The goals of this project were to:

- Collect and organize statewide information about nitrate monitoring results, the physical factors that tend toward nitrate contamination, and United States Geological Survey (USGS) risk studies that evaluate the physical factors against monitoring results.
- Delineate areas where high nitrates in groundwater occur.
- Prioritize those areas by potential impacts to people and resources.
- Make the information available to everyone.

The inputs for developing candidate Nitrate Priority Areas include:

- A single database of nitrate sampling results for groundwater compiled from state and federal databases.
- USGS nitrate risk studies.
- Surficial geology, soil properties, topography, well locations and depths, agricultural land use, irrigated areas, annual average precipitation, nitrate concentrations, and population.

Monitoring data from the USGS and the Washington State Departments of Health and Ecology were collected and summarized. The well locations were mapped using a Geographic Information System (GIS).

Clusters of wells where a sample has exceeded 10 mg/L are a strong indicator that groundwater at that location is at high risk of, or currently is contaminated by nitrate. Other indicators include USGS nitrate risk analyses, Natural Resources Conservation Service (NRCS) soil drainage classes and travel time through the soil profile (Ksat), surficial geology, recharge and well depths.

Boundaries for candidate Nitrate Priority Areas were developed based on section lines that approximate natural boundaries. These areas will be subject to review and change where appropriate. Once the proposed Nitrate Priority Areas have been reviewed, section line-based boundaries may be replaced by natural boundaries where appropriate.

Time series plots were produced for wells with four or more sample results with at least one result over 5 mg/L. This resulted in a distribution of over 1200 graphs across the state. These are accessible through the GIS as a popup from the well location point for those who have a GIS system with this capability, and who request and receive the necessary files. A web-based application would make these graphs widely and easily available.

Challenges with databases always include checking for errors, such as the occasional locational or data entry error. Care must be used to understand the limitations of the data and the peculiarities of each data source. These issues are described more in this report.

Recommendations include developing a web application to make this information easily accessible by anyone with internet access, and automating the data downloads so they are easily updated. Management of nitrate sources to prevent groundwater contamination should be adjusted for sensitive conditions like excessively draining soils and very hydrologically conductive geologic materials. Nitrate source loading needs to be reduced in impacted areas to prevent groundwater contamination.

Results of this study can be used to protect public drinking water supplies by focusing actions on areas within the state that have the highest potential for impacts due to nitrate contamination of groundwater.

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- Washington Department of Ecology: Kirk Sinclair, Chris Martin, Llyn Doremus, Mary Shaleen-Hansen, Ron Cummings, Charles Pitz, Susan Braley, Melissa Gildersleeve, Charlie McKinney

This project would not be possible without the work and accomplishments of so many people who map and measure the environment, make data available on the web and in databases, and run the organizations that support their work.

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# Introduction

Groundwater in several areas of the state has been contaminated by nitrates above the drinking water Maximum Contaminant Limit (MCL) of 10 mg/L. This is a problem for public health, and the costs of coping with this contamination are immense.

We know about nitrate contamination of groundwater because there have been numerous studies in various areas of the state with groundwater monitoring. Federal and state agency databases house the nitrate sampling results from many of these studies and from regular public water system sampling regulated by the Washington Department of Health (WDOH).

These databases are online and freely available to anyone with an internet connection. However, the data is not easy to combine and summarize on a map. The data was therefore collected and combined into a single database with well locations and well depth, where depth was available. This way we can see where nitrates have exceeded the MCL statewide, and identify areas with a significant number of exceedences.

In addition to groundwater monitoring data, we can also look at landscape patterns of conditions that contribute to the likelihood of groundwater contamination from land use activities. These are conditions like soils and geological materials that allow water to pass through quickly, and where there is a high amount of water available from rain or irrigation. Where there are significant nitrate sources in areas with sensitive conditions, nitrate levels in groundwater tend to rise.

Two USGS groundwater nitrate risk studies compared the physical features of the landscape with nitrate monitoring data to determine where areas are at a higher or lower risk of nitrate contamination from nitrogen loading at the land surface.

Taken all together, the monitoring data, the conditions on the ground, and the USGS nitrate risk studies allow us to draft boundaries for impacted areas on a statewide basis. The results of this project can be used to visualize the extent of nitrate contamination in the state of Washington and help to reduce contamination threats to the public drinking water supply.

The goals of this project are to:

- Delineate areas where high nitrates in groundwater occur.
- Prioritize those areas by potential impact to people and resources.
- Make information available to everyone.

In order to delineate areas where high nitrates in groundwater occur, Ecology used monitoring data, USGS nitrate risk studies, and landscape patterns of contributing factors to nitrate contamination. Ecology then drafted initial boundaries to consider for Nitrate Priority Areas based on the evidence and topography. Areas were then inventoried for metrics to be used for prioritization. The following is a brief explanation of each step. More detail is provided in the remainder of this report.

- **Mapping sampling results:** Nitrate sample results from wells provide the primary indicator of where nitrate contamination is severe in Washington State. For this project, nitrate sampling results were collected from the USGS, Ecology and the WDOH.
- **USGS nitrate risk studies**: The USGS conducted two nitrate risk studies, one for Washington State, and one as a national study. Both developed GIS maps that show where the risk of nitrate contamination of shallow groundwater is higher or lower. These risk studies compared nitrate sampling results from USGS studies, with physical aspects of the landscape, and determined which combination of factors result in a higher risk.
- **Maps of physical attributes of the landscape**: Ecology also made use of GIS maps for physical attributes of the landscape that contribute to higher risk of nitrate contamination of groundwater. These include surface soils and geologic materials that transmit water rapidly. Maps show landscape patterns across the state that correspond to areas with nitrate contamination problems.
- **Topography:** Ecology used topography, along with the previously mentioned maps (e.g. sample results, USGS nitrate risk studies, landscape attributes) to produce draft boundaries of areas to consider for Nitrate Priority Areas.
- **Prioritization criteria**: Once Ecology had draft boundaries, Ecology developed metrics for each area to produce prioritization criteria. These include population and a count of wells sampled for nitrate that exceeded or approached health limits.
- **Classification**: Ecology used the previously mentioned metrics and all the information at hand to produce an initial classification into groups according to priority. Prioritization is based on the likelihood and severity of nitrate contamination of groundwater along with population.

  Some areas are very obviously candidates for prioritization as high risk. Others have evidence of risk that is not as compelling, or lack enough information to make a clear judgment. The initial classifications may be revised as more information is developed for these specific areas.

The database of monitoring results and the GIS layers are sources for a potential web application. The information developed for this project will be useful for focusing actions for nitrate abatement where it is most needed, for adjusting nitrogen loading management in view of ground conditions, and for planning where future studies and monitoring would be most useful.

# Background

Groundwater is the drinking water supply for around 60% of people who live in Washington State. This percentage is larger if you only count those who live outside of large cities like Seattle, where the drinking water is supplied from surface water.

Most groundwater in Washington is not contaminated by nitrates. However, there are several areas in the state where groundwater has been contaminated by nitrates. Nitrate contamination of groundwater has increased nationally as use of fertilizer, manure production and population have increased (Dubrovsky, 2010).

## Washington uses groundwater for drinking water

Public water supply sources may be wells, springs, or surface water sources. Some public water supply systems rely on more than one of these source types. The following maps show the distribution of public water supplies from surface water (Figure 1), springs (Figure 2), and groundwater (Figure 3) with estimates of the population that relies on these supplies for drinking water.

Figure 3 also shows the significant reliance on small public water supply systems that serve 100 people or less. The maps do not include single domestic sources unregulated by WDOH. Single residential wells are widely used in Washington to supply rural residences.

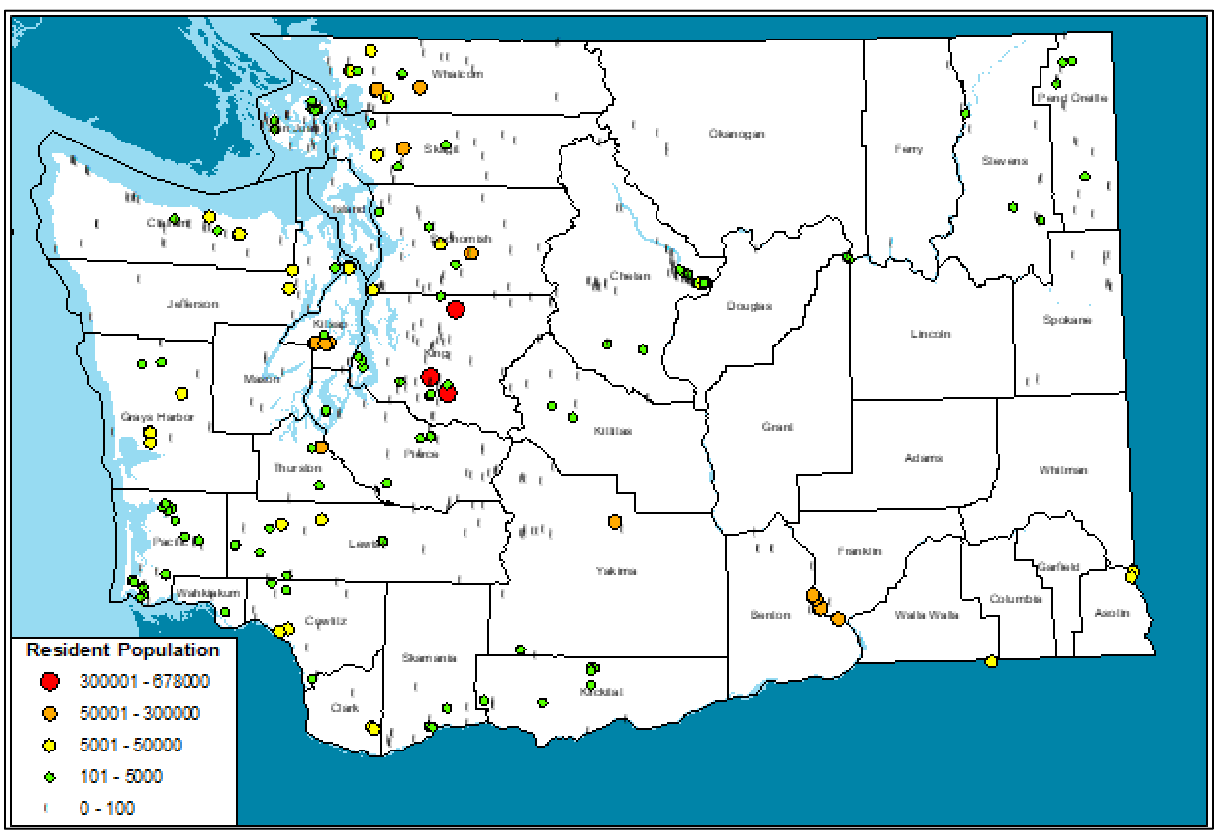

**Figure 1: Public Water Supply Systems Surface Water Sources**

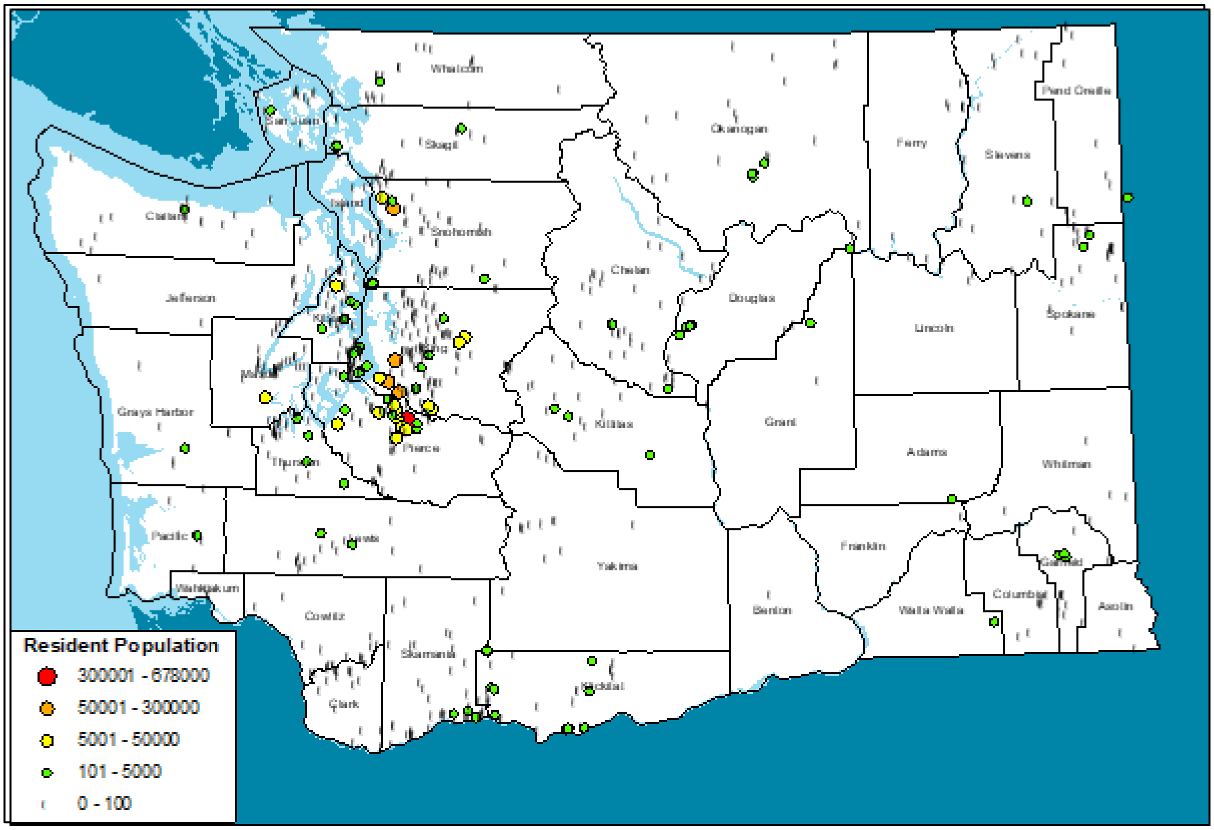


**Figure 2: Public Water Supply Systems Spring Sources**

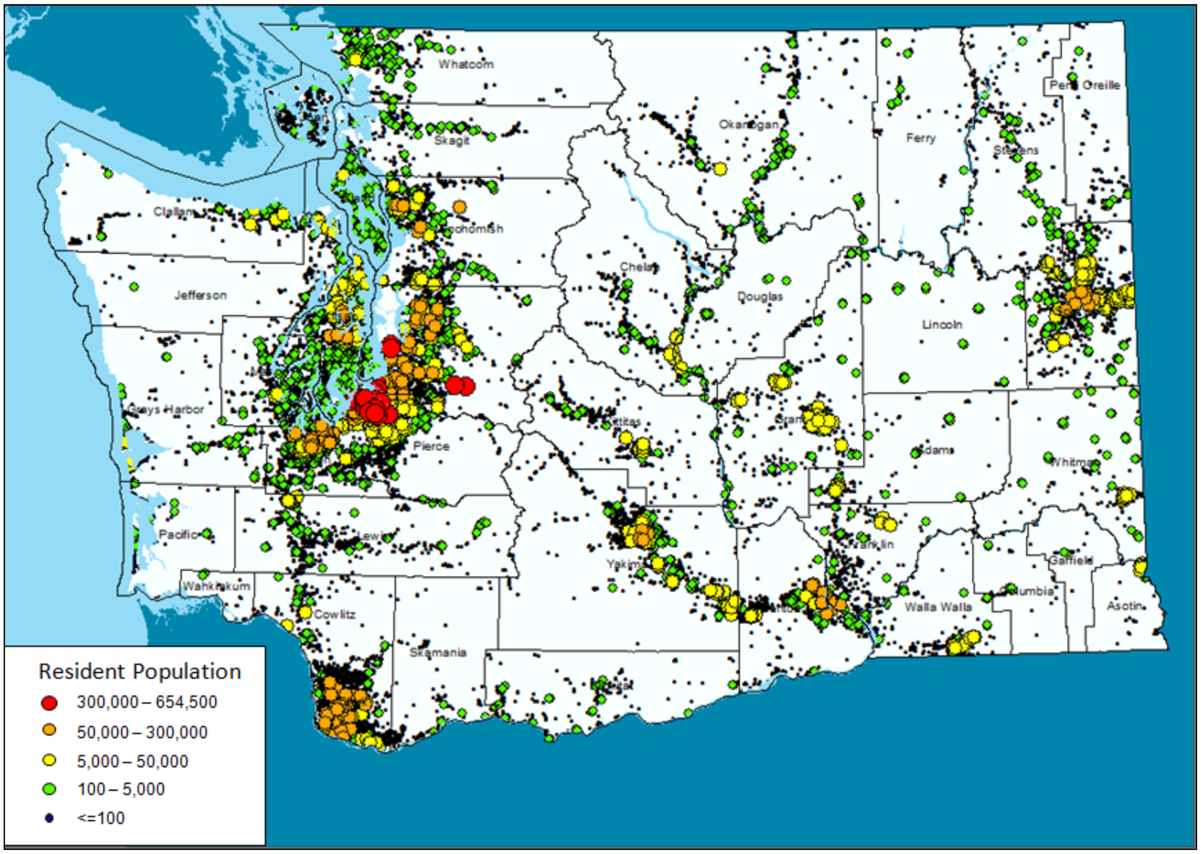


**Figure 3: Public Water Supply System Groundwater Sources**

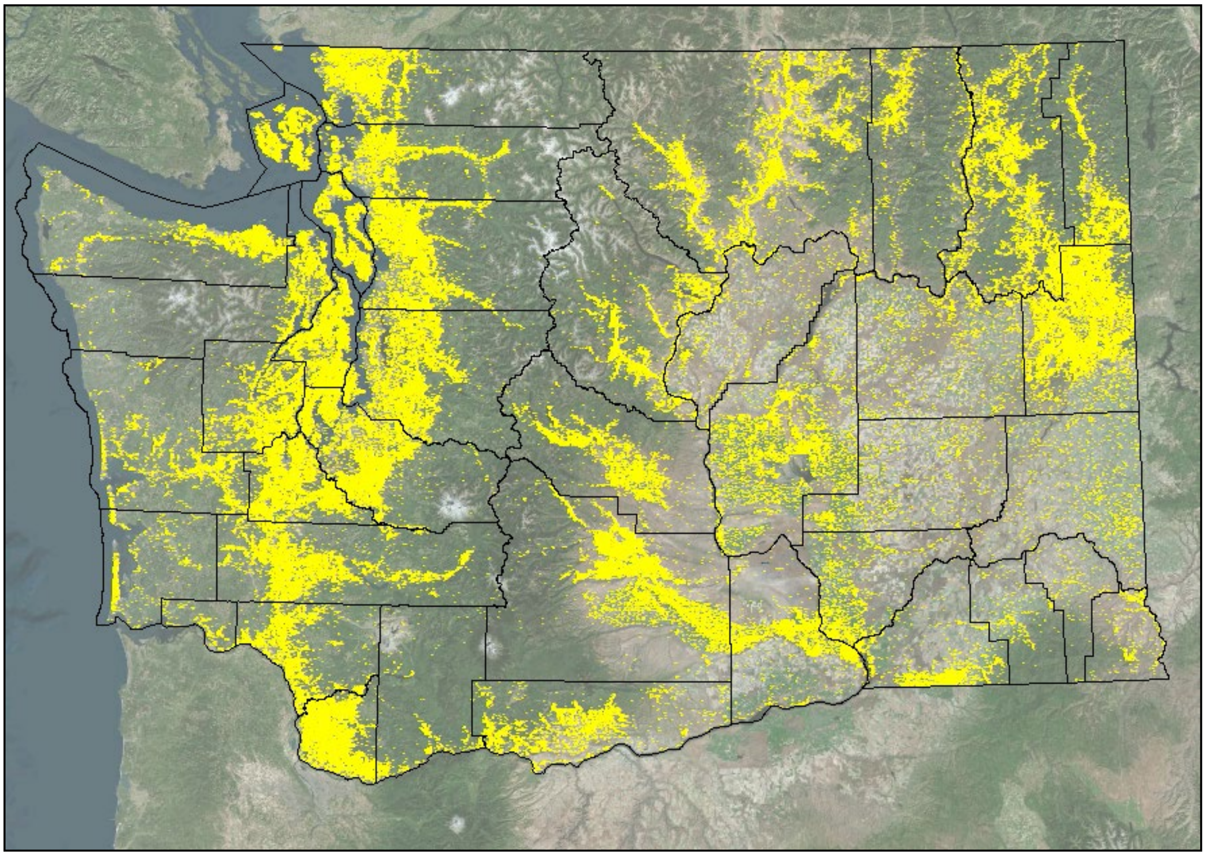

**Figure 4: Water supply well logs in the Ecology Well Log Database**
(residential, agricultural, industrial – does not include environmental monitoring wells or abandoned wells).

Figure 4 shows some 285,463 water well logs in the Ecology Well Log Database. Not all water wells in Washington have a well log in the database. Both public water supply wells and single residential wells are included, along with agricultural and industrial wells.

# Nitrate contamination is bad for public health

The health effects of drinking water with high nitrates include blue baby syndrome, also known as methemoglobinemia. This is a condition where red blood cells are less able to carry oxygen. Less oxygen in the blood stream gives the skin an apparent blue color. The EPA limit for nitrate concentration in drinking water is 10 mg/L to prevent this condition.

Individuals with susceptible health conditions should not drink water with nitrate concentrations above 10 mg/L. This includes those who do not have enough stomach acids, those who lack an enzyme needed to return affected red blood cells back to normal, and women who are pregnant or trying to become pregnant. High nitrate levels may increase the risk of spontaneous abortion or certain birth defects (Washington State Dept. of Health, 2012a; Ward, 2005).

# Nitrate contamination is very expensive for water systems

Any of the options to cope with nitrate contamination are costly. They include drilling a new well, deepening a well, treating the water with reverse osmosis or ion exchange, blending the water, or obtaining water from another water system.

Costs can run into the millions of dollars. For example:

- Royal City had to remove an existing well due to high nitrates and then construct a new well at a cost of nearly $1.5 million dollars (Washington State Dept. of Health, 2012b).
- Several public water supply systems in northern Whatcom County are under WDOH compliance orders for exceeding the nitrate health limit of 10 mg/L. A new source of drinking water is hard to come by due to the limited nature of the aquifer and water rights issues. Strategies to reduce nitrate consumption include installing expensive treatment systems, providing bottled water to laborers, and investigating ways to transport clean water to the area (Cornerstone Management, Inc., 2010).

These kinds of costs are repeated across the state for public water systems where nitrate levels are too high. The table in Appendix A shows several projects funded by the Drinking Water Source Revolving Fund to mitigate groundwater nitrate contamination (Washington State Dept. of Health, 2012b).

For the projects shown in Table A-1, costs range from $107,000 to $6 million per project with total project costs of approximately 12.2 million dollars. Many operating and capital costs incurred are not reflected in loan amounts granted by the state – they are paid for by local rate payers. A statewide estimate of costs incurred due to nitrate contamination of groundwater would be useful.

The WDOH *Guidance Document – Nitrate Treatment Alternatives for Small Water Systems* (Washington State Dept. of Health, 2005) presents an overview of what water systems face when nitrate levels exceed the MCL of 10 mg/L.

# How nitrate gets into groundwater

Precipitation or irrigation water that moves down to groundwater from the land surface is called *recharge*. Recharge carries contaminants from land use activities to groundwater. Nitrate is one such contaminant. Once nitrogen compounds move below the root zone, any nitrate that was not captured by plants, lost through volatilization to the air (as ammonia), or denitrified by microbes, begins to travel downward. Gravity and water carry contaminated recharge to groundwater. When recharge carries contaminants, it is a discharge of pollutants to groundwaters of the state.

Chemical fertilizers, manure, and biosolids all contain nitrogen compounds that convert to nitrate at various rates. Nitrate is very soluble in water, so it travels downward with recharge to groundwater.

Nitrate in recharge water mixes with groundwater in the upper part of the aquifer and is transported in the direction of groundwater flow. Water samples from downgradient wells that withdraw groundwater from the contaminated part of the aquifer (the "plume") will contain elevated nitrate concentrations.

## Why some wells are high in nitrate while others in the same area are not

Wells with low groundwater nitrate levels can be in the same area where groundwater nitrate levels are high. This is because of differences in well depths, well construction, local nitrogen loading, and variations in physical and chemical conditions for the vadose zone and aquifers, as well as complexities of groundwater flow paths.

Some wells are shallow and withdraw groundwater from the upper unconfined aquifer. Some wells withdraw water from a lower aquifer that is confined by a layer of finer geologic materials, like glacial till or clay. These wells can be very near to each other on the land surface, but have very different sample results. Shallow wells tend to have higher nitrate levels because nitrate tends to collect in the top part of the aquifer and it takes a very long time for water to reach a deep confined aquifer.

Some wells may draw water where oxygen levels are low. This can cause nitrate to be used up by microbes, a process called denitrification. There also may be preferential paths so that nitrate contamination is more concentrated in one area and less in another. One well might be in the path of a plume, where there is a concentrated loading source upgradient, while another well in the area could be upgradient of the source, or located outside of the plume. Pumping of area wells causes changes in the groundwater flow regime, which changes the direction and rate of contaminant transport.

For deeper wells, one well could have open hole construction or a poor well seal, so that samples of water include shallow water that has traveled down the outside of the well into the opening where the water is pumped, whereas another properly-constructed well samples only the deep water. If shallow groundwater is high in nitrates the poorly constructed well samples would be high in nitrates, whereas the properly constructed well would likely not.

The areal extent of groundwater that contains a contaminant is called a contaminant plume. Point sources, such as might develop from a leaking underground storage tank, develop distinct contaminant plumes where the source can be easily identified. Nitrate plumes often originate from many sources across a land area. This is called a "nonpoint" source and makes identification of a contaminant source much more difficult.

Well water captured outside of a contaminant plume will not show as high a contaminant concentration as water within the plume. Wells in the same area can have varying nitrate levels depending on where they are located with respect to the contaminant source and their location relative to the contaminant plume.

# Previous Studies

Numerous studies have been conducted in various areas of the state looking at nitrate contamination of groundwater. The following are a few examples.

The establishment of the Columbia Basin Ground Water Management Area (GWMA) was preceded by an Interagency Ground Water Committee report on nitrate contamination of groundwater in the mid-Columbia basin (Washington Interagency Ground Water Committee, 1996). Several consultant and USGS studies have been undertaken since that time in the GWMA, including nitrate sampling, analyses for trends, and groundwater modeling (http://cbgwma.org/).

Ecology has published several studies related to groundwater nitrates in Whatcom County. These are summarized in the publication *Sumas-Blaine Aquifer Nitrate Contamination Summary* (Carey, 2012). Ecology has also completed several other groundwater nitrate studies. Here are a few examples:

- Sinclair, Kirk, 2003. *Groundwater Quality in the Central Ahtanum Valley, Yakima County, March 2001 - December 2002*. Washington State Dept. of Ecology Publication No. 03-03-017, 55 pp. Online at https://fortress.wa.gov/ecy/publications/summarypages/0303017.html.
    - Sinclair, Kirk, 2003. *Groundwater Quality in the Agnew and Carlsborg area, Clallam County, December 2000-September 2002*. Washington State Dept. of Ecology Publication No. 03-03-017, 52 pp. Online at https://fortress.wa.gov/ecy/publications/SummaryPages/0303017.html
- Garrigues, Robert, 1996. *Ground Water Quality Characterization and Nitrate Investigation of the Glade Creek Watershed*. Washington State Dept. of Ecology Publication No. 96-348, 62 pp. Online at https://fortress.wa.gov/ecy/publications/summarypages/96348.html.

Examples of USGS regional nitrate studies include:

- Frans, L.M., and Helsel, D.R., 2005, *Evaluating regional trends in ground-water nitrate concentrations of the Columbia Basin Ground Water Management Area, Washington*: U.S. Geological Survey Scientific Investigations Report 2005-5078, 7 p.
- Cox, S.E., and Kahle, S.C., 1999, *Hydrogeology, ground - water quality, and sources of nitrate in lowland glacial aquifers of Whatcom County, Washington, and British Columbia, Canada*: U.S. Geological Survey Water-Resources Investigations Report 98-4195, 251 p.
- Ebbert, J. C., Cox, S. E., Drost, B. W., and Schurr, K.M., 1995, *Distribution and sources of nitrate, and presence of fluoride and pesticides, in parts of the Pasco Basin, Washington, 1986-88*: U.S. Geological Survey Water-Resources Investigations Report 93-4197, 173 p.

The following USGS studies evaluated the entire state, and are particularly helpful for the Washington Nitrate Prioritization Project:

- *Estimating the probability of elevated nitrate concentrations in ground water in Washington State*, U.S. Geological Survey Scientific Investigations Report, Lonna Frans, 2008.
- *Vulnerability of Shallow Groundwater and Drinking-Water Wells to Nitrate in the United States*, Bernard Nolan and others, 2006.

EPA completed comprehensive groundwater nitrate studies in the Lower Yakima Valley, followed by enforcement action on five dairies.

- U.S. EPA, 2013. *Relation Between Nitrate in Water Wells and Potential Sources in the Lower Yakima Valley, Washington*. Pub. No. EPA-910-R-13-004, 311 pp.
- EPA. 2012a. *Relation Between Nitrate in Water Wells and Potential Sources in the Lower Yakima Valley, Washington*. EPA-910-R-12-003. September 2012.

Local universities and others completed nitrate monitoring projects. Here are two examples:

- Mitchell RJ, Babcock RS, Gelinas S, Nanus L, Stasney DE, 2003. *Nitrate distributions and source identification in the Abbotsford-Sumas Aquifer, northwestern Washington State*. J Environ Qual. 2003 May-Jun;32(3):789-800.
- King County, 2004. *Ambient Groundwater Monitoring – 2001 – 2004 Results*. Prepared by Anchor Environmental and King County Dept. of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington, 29 pp. http://your.kingcounty.gov/dnrp/library/2004/KCR1855/GW_Ambient_Report.pdf

# Methods

The objectives of this project are to identify areas of Washington where groundwater has been contaminated by nitrates, to examine the conditions that lead to contamination, and to prioritize these areas by the affected population and severity of contamination.

In order to accomplish these objectives, the following information was collected and organized for use in this project:

- Groundwater nitrate sampling data for the state (from WDOH, Ecology, and USGS)
- USGS nitrate risk studies and maps to determine where there is a higher risk of groundwater contamination by nitrate.
- NRCS soil drainage properties and calculated travel time through the soil profile.
- Distribution of land-uses such as crops and dairies, as potential indicators of nitrogen loading from fertilizer and manure.

  Nitrogen source loading tracking is under-developed so that a full accounting and mapping of nitrogen sources was not available. Other important nitrogen-loading sources include human waste from septic systems and biosolids, as well as manure from cattle, horses, poultry, swine and other animals.
- Irrigation and precipitation distribution
- Surficial geology/hydrogeology
- Topography
- Population data from the 2010 U.S. Census
- Draft boundaries for Nitrate Priority Area candidates guided by the previously-listed factors

The following sections discuss each of these inputs.

## Groundwater nitrate concentrations

Historical nitrate maximums are signposts that tell us if an area is prone to nitrate contamination of groundwater. Mapping the historical maximums gives us an idea of the distribution of where nitrate has exceeded a level of concern. The statewide dataset also shows where and when monitoring occurred and what was found.

Statewide databases that have nitrate testing results for groundwater are available from the WDOH, Ecology, and the USGS. Nitrate data from these sources were downloaded and organized into a single database so that the maximum nitrate for each sampled well could be determined and mapped (Table 1 and Figure 5).

**Table 1: Categories of nitrate concentrations used for maps and analyses**

| Nitrate as N concentrations | Reason for Division |
|---|---|
| < 3 mg/L | Less than 3 indicates little significant human produced nitrate source*. |
| >= 3 and < 5 mg/L | Man-made discharge potential, Public Water Supply systems do NOT have increased monitoring at this level, concern rises as levels approach 5 mg/L due to increased requirements. |
| >= 5 and < 10 mg/L | Watch for levels that are rising over time and may exceed the MCL of 10 mg/L. Larger (Group A) Public Water Supply systems must monitor more frequently and have other requirements added. |
| >= 10 mg/L | Exceeds the MCL of 10 mg/L. Nitrate is an acute contaminant for vulnerable populations (infants, immune compromised people) for “blue baby syndrome” and is suspected in certain cancers and miscarriages (Washington State Dept. of Health, 2012a; Dubrovsky, 2010). Public Water Supply Systems are subject to compliance orders and may have to install and maintain treatment systems; deepen wells, drill new wells, or blend with water from cleaner/deeper sources. |

* A USGS study lowers this value to 1 mg/L: “Rather, nitrate concentration greater than about 1 mg/L suggests greater influence by anthropogenic factors and the need for additional monitoring to protect water resources” (Nolan, 2003). Three mg/L has been used by many past studies and is suitable for the purposes of this report.

The following map shows the distribution of the maximum historical nitrate concentration for each well location, categorized as listed in Table 1.

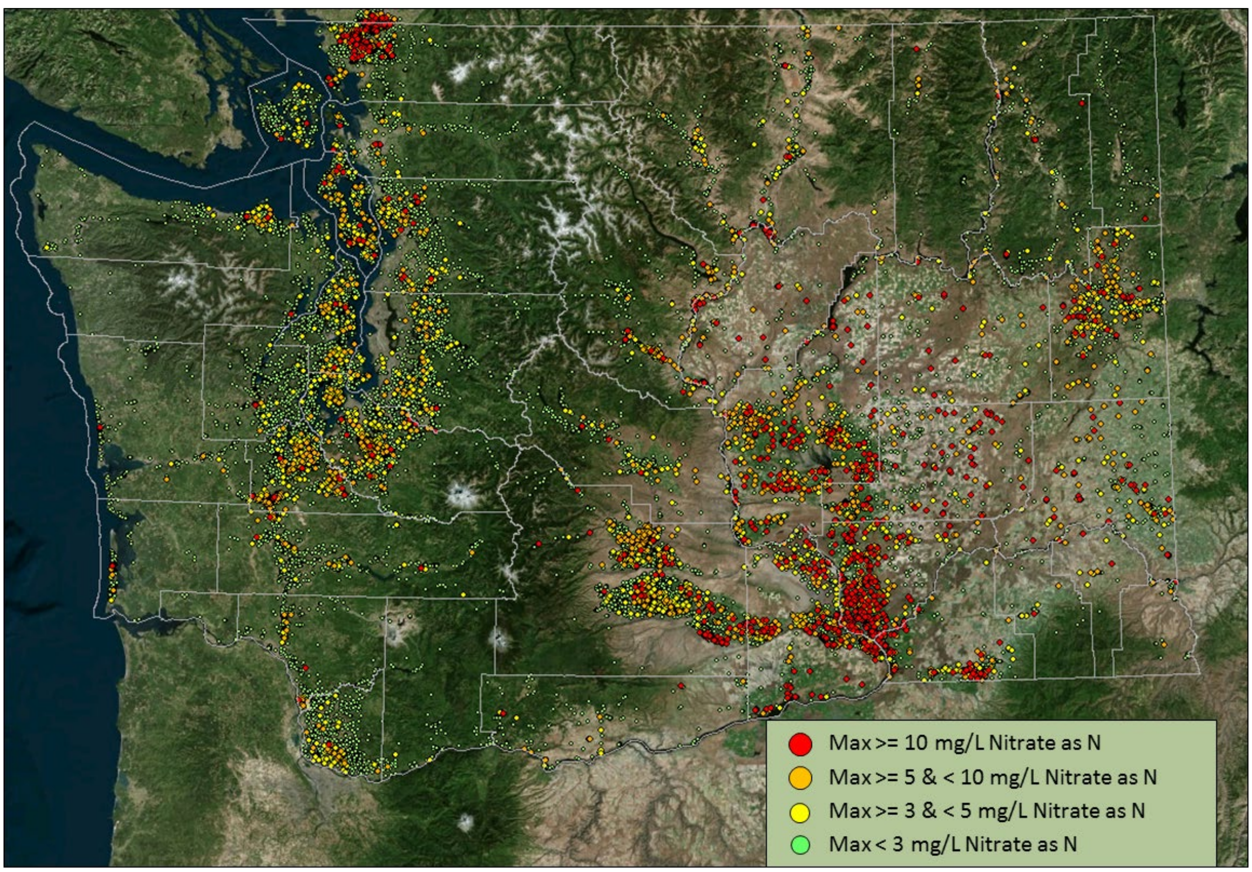


**Figure 5: Distribution of Historical Nitrate Maximums in Groundwater (WDOH 2000 to 2011, Ecology 1982 to 2013, USGS 1970 to 2013)**

Clusters of nitrate concentrations that are at, or higher than the health limit are very noticeable on this map. These results were used as one of the factors for draft delineations of Nitrate Priority Area candidates. A detailed explanation of the data sources and how the data was processed follows.

## Statewide nitrate data

Statewide groundwater monitoring results are available from the WDOH, Ecology, and the USGS. These databases are online and accessible to anyone from the following websites:

- WDOH SENTRY: http://www.doh.wa.gov/DataandStatisticalReports/EnvironmentalHealth/DrinkingWaterSystemData/SentryInternet

  The public interface to SENTRY provides excellent detailed information. Due to the statewide scale of this project, it was necessary to obtain a custom download from WDOH (Washington State Dept. of Health, 2012c).

- Ecology's Environmental Information Management System (EIM): http://www.ecy.wa.gov/eim/groundwater.htm
- USGS National Water Information System (NWIS): http://waterdata.usgs.gov/wa/nwis/nwis

The following tables summarize the data downloaded from these sources:

**Table 2: Total Number of Nitrate Samples for Each Data Source[1]**

| Data Source | Number of Samples | For Date Range |
|---|---|---|
| Washington State Dept. of Ecology | 3,382 | 1982 to 2013 |
| U.S. Geological Survey | 9,157 | 1970 to 2013 |
| Washington State Dept. of Health | 79,141 | 2000 to 2011 |
| Total | 91,680 | |

[1]Duplicates/replicates were removed. USGS data that had multiple nitrate methods on the same day for the same well were reduced to a single sample result per well, per day. EIM data from facilities such as landfills and cleanup sites are not included. WDOH samples from blended sources are not included.

**Table 3: Number of Wells Sampled by Agency in the Final Statewide Data Set[1]**

| Maximum Nitrate Concentration (mg/L as N) | ECY | USGS | WDOH | Total | Percent |
|---|---|---|---|---|---|
| **>= 10** | 338 | 363 | 421 | 1,122 | 5.0 |
| **>= 5 and < 10** | 302 | 465 | 1,021 | 1,788 | 8.0 |
| **>= 3 and < 5** | 223 | 485 | 1,377 | 2,085 | 9.2 |
| **< 3** | 879 | 4,347 | 12,401 | 17,627 | 78.0 |
| **Totals** | 1,742 | 5,660 | 15,220 | 22,622 | 100 |

[1]A well may have been sampled by more than one agency so it may be counted more than once.

This dataset allows us to examine and summarize the nitrate records from thousands of well locations around the state. The following sections describe the data sources in more detail.

## WDOH nitrate data

The largest data set for nitrates in groundwater by far is from the WDOH SENTRY database, which houses data pertaining to public water supply systems. Regulations for monitoring depend on whether the system is a Group A or Group B system. *Group A* Systems have 15 or more connections or serve 25 or more people and include schools, restaurants, campgrounds or similar facilities. *Group B* Systems have 14 or fewer connections and serve less than 25 people.

The purpose of this data system and the monitoring requirements for public drinking water supply is to ensure the delivery of clean, safe drinking water. Wells for public water supply are designed to efficiently extract the maximum amount of water from the aquifer, as opposed to monitoring wells that are designed to test groundwater quality. Public water supply wells and sampling are not therefore targeted at determining the groundwater quality as it exists in aquifers. Sampling is directed more toward making sure delivered water is clean and safe.

Public water supply systems that test too high for nitrate may blend water from multiple sources so that the contamination level is below the regulated limits. Blending is strictly regulated by the WDOH and requirements include daily checks and monthly lab analyzed samples for nitrate.

Public water supply systems may also have to treat water to remove contaminants. An example of a treatment system to remove nitrate is a *reverse osmosis system*. Another type of treatment system is *ion exchange*. These are expensive systems that produce a waste stream requiring a permit to discharge and that have on-going maintenance costs (WDOH, 2005).

In addition to nitrate sample results, the following is useful information supplied to help interpret WDOH Public Water Supply data appropriately:

- Whether the source samples are from a well or a well field. Wells are preferred over well fields and well field data should be clearly labeled.
- Whether treatment or blending is occurring and when it started. If a sampling record shows a sharp decrease and it is due to blending or treating the water, the nitrates at that location in the aquifer may still be very high. Periodic source samples are required for systems that are blending or treating.
- Whether a source has become inactive and when (especially if nitrates were high). Well log records may show whether the well was abandoned and a new well drilled.

For the current project, a download of nitrate data for the state from 2000 to 2011 was used. Blended samples (composites from more than one well) were removed from the final data table.

## USGS nitrate data

Nitrate data from USGS was downloaded from the National Water Information System (NWIS) (USGS, 2013). Since the data is not linked to its project report, the purpose of sampling was not available. Therefore the USGS data could not be screened for ambient monitoring vs. monitoring at suspected nitrate sources. NWIS includes the well depth and often the aquifer from which the sample was taken.

There was often more than one nitrate sample for a well on the same day, with each sample tested by a different method. The methods were prioritized so that a single method with its corresponding sample result was used. The maximum value of duplicates (same day, same method) was used. The end result is one nitrate sample result per day, per well.

## Ecology nitrate data

Nitrate data from Ecology was downloaded from the Ecology Environmental Information Management System (EIM) (Washington State Dept. of Ecology, 2013).

The Ecology data was screened to include area-wide studies as opposed to source specific monitoring (such as at regulated facilities, landfills or cleanup sites). Duplicates and replicates were also removed.

## Data Processing

Common data structure: each of the data sources has variations in field names and associated data, so a common data structure was created to accommodate the data for statewide analysis (Table 4). An example data record is provided in Appendix D. The draft data dictionary that was developed is available for review as a Microsoft Excel™ spreadsheet.

Ecology also received a copy of the Lower Yakima nitrate database for the purpose of comparing database structure and fields.

**Table 4: Nitrate sampling results data fields**

| Field | Explanation |
|---|---|
| Data source | WDOH Public Drinking Water Supply (WDOH); Ecology EIM (ECY); USGS NWIS (USGS) |
| Unique ID | Linking ID - the ID that links to other tables and uniquely identifies a well with respect to the original data source. |
| Site name | ECY: The Study Name; WDOH: The PWS System Name; USGS: The Site Name |
| Parameter | Chemical name as recorded in the original data source |
| Qualifier | Sampling result qualifier from original data source |
| Original Result | Original result from the source data. The method detection limit is listed for non-detects (U, LT) |
| Original Result Units | Original sample result units |
| Result | Calculated if result was qualified as "less than" (as ½ of the method detection limit) or if reported "as NO3" |
| Result Units | mg/L |
| Sample Date | Sample Date |
| Latitude | Decimal degrees |
| Longitude | Decimal degrees |
| County | County |
| Well Depth | Feet |

Well nitrate concentration summary: For this project, a summary table of the nitrate concentrations for the well location also has been produced. Appendix D shows example records. Table 5 lists the fields used:

**Table 5: Nitrate summary data fields**

| Field | Explanation |
|---|---|
| Data source | WDOH Public Drinking Water Supply (WDOH); Ecology EIM (ECY); USGS NWIS (USGS) |
| Unique ID | Linking ID - the ID that links to other tables and uniquely identifies a well with respect to the original data source. |
| Site name | ECY: The Study Name; WDOH: The PWS System Name; USGS: The Site Name |
| SampleCount | Number of samples for this LID (well) |
| Min | Minimum of sample results |
| Avg | Average of sample results |

| Field | Explanation |
|---|---|
| Max | Maximum of sample results |
| DateMax | Date Max Value for sample occurred. If more than one with the same Max value, use most recent date. |
| StDev | Standard Deviation of sample results |
| DateBegin | Earliest Sample Date |
| MostRecent | Most recent sample result |
| DateMostRecent | Most Recent Sample Date |
| LAT_DD | Latitude, decimal degrees |
| LONG_DD | Longitude, decimal degrees |
| County | County |
| WellDepth | Well depth where available |
| Hyperlink | LInk to web page for well |

Associated tables with more information about the well site, study, or water system were downloaded and are also being maintained in the database. For example, the Water System ID for the WDOH data can be used to look up information in the WDOH Sentry database online. For Ecology data, the study report for which the well samples were collected is linked to the results. The USGS data includes many attributes, such as the aquifer that the well is completed in. The data dictionary lists all of these tables and fields with their descriptions.

The utility of maintaining this in the statewide nitrate database is that the ancillary fields can be used for queries. One example would be to show all the public water supply wells that are part of public water supply systems that serve 1,000 or more people and have had a nitrate result >= 10 mg/L.

Duplication eliminated and one sample per well per day used: Post-processing of the nitrate data downloads involved selecting appropriate nitrate analytical methods and eliminating double accounting due to replicates or duplicates. For example, a well sampled by the USGS could have more than one nitrate lab method. The data is reduced to one sample per well, per day, selecting the lab method by the priority order used in a USGS nitrate study (Mueller, 1995; See Figure 6). Data reported "As Nitrate" was converted to "As Nitrogen." "As Nitrate" samples at 45 mg/L are equivalent to "As Nitrogen" samples at 10 mg/L.

Well location data availability: Well locations are publically available for Ecology and USGS data. WDOH location data is restricted to agencies or entities with permission to use these locations for in-house use. The WDOH lat/longs are included in the database, but will need to be generalized for public use in accordance with WDOH policy.

Query Ideas: From this data, many queries can be run with the results mapped. Here are a few examples:

- Which wells had *all* results greater than the MCL of 10 mg/L?
- When was a well last sampled and what was the most recent nitrate level?

- When did monitoring for nitrate last take place in this area (by WDOH, Ecology, or USGS)?
- Are there any wells deeper than 200 feet that have high nitrates?
- Where have nitrates over time exceeded the 10 mg/L MCL?
- Where is there little or no monitoring in an area at high risk for nitrates in groundwater?
- Are there clusters of high nitrate results (an indicator of a nitrate impacted area)?

**Table 2.** Summary of procedures used to aggregate nutrient data into constituent groups

[mg/L, milligram per liter; N, nitrogen; $NH_4$, ammonium; $NO_2$, nitrite; $NO_3$, nitrate; P, phosphorus; $PO_4$, orthophosphate; *, parameter determined by using the procedure listed for nitrite, as N; **, parameter determined by using the procedure listed for nitrate, as N]

| Constituent group | Nutrient data parameter name | Nutrient data parameter code[1] |
|---|---|---|
| Ammonia, as N | Nitrogen, ammonia, dissolved (mg/L as N) | 00608 |
| | Nitrogen, ammonia, dissolved (mg/L as $NH_4$) | 71846 (multiplied by 0.7765) |
| | Nitrogen, ammonia, total (mg/L as N) | 00610 |
| | Nitrogen, ammonia, total (mg/L as $NH_4$) | 71845 (multiplied by 0.7765) |
| Nitrite, as N | Nitrogen, nitrite, dissolved (mg/L as N) | 00613 |
| | Nitrogen, nitrite, dissolved (mg/L as $NO_2$) | 71856 (multiplied by 0.30446) |
| | Nitrogen, nitrite, total (mg/L as N) | 00615 |
| | Nitrogen, nitrite, total (mg/L as $NO_2$) | 71855 (multiplied by 0.30446) |
| Nitrate, as N | Nitrogen, nitrite plus nitrate, dissolved (mg/L as N) | 00631 |
| | minus [2]nitrite, as N | * |
| | Nitrogen, nitrite plus nitrate, total (mg/L as N) | 00630 |
| | minus [2]nitrite, as N | * |
| | Nitrogen, nitrate, dissolved (mg/L as N) | 00618 |
| | Nitrogen, nitrate, dissolved (mg/L as $NO_3$) | 71851 (multiplied by 0.2259) |
| | Nitrogen, nitrate, total (mg/L as N) | 00620 |
| | Nitrogen, nitrate, total (mg/L as $NO_3$) | 71850 (multiplied by 0.2259) |
| Total nitrogen | Nitrogen, total (mg/L as N) | 00600 |
| | Nitrogen, total (mg/L as $NO_3$) | 71887 (multiplied by 0.2259) |
| | [3]Nitrogen, ammonia plus organic, total (mg/L as N) | 00625 |
| | plus [2]nitrate, as N, plus [2]nitrite, as N | ** |
| | | * |
| Orthophosphate, as P | Phosphorus, orthophosphate, dissolved (mg/L as P) | 00671 |
| | Phosphate, ortho, dissolved (mg/L as $PO_4$) | 00660 (multiplied by 0.3261) |
| | Phosphorus, orthophosphate, total (mg/L as P) | 70507 |
| | Phosphate, total (mg/L as $PO_4$) | 00650 (multiplied by 0.3261) |
| Total phosphorus | Phosphorus, total (mg/L as P) | 00665 |
| | Phosphorus, total (mg/L as $PO_4$) | 71886 (multiplied by 0.3261) |

[1]From the USGS National Water Information System (NWIS) and the USEPA Data Storage and Retrieval System (STORET).
[2]Missing values or values less than detection are not included in this calculation.
[3]Also called total Kjeldahl nitrogen. If this value is missing or less than detection, total nitrogen is not computed.

**Figure 6: USGS Summary of procedures used to aggregate nutrient data into constituent groups** (Mueller, 1995)

## Nitrate sampling data limitations

This data is very useful when used with knowledge and thoughtfulness. However, there are a few caveats to keep in mind:

- Due to resource limitations nitrate testing data collected by Conservation Districts, Universities, Counties and Cities is not included in this data set, unless it was entered into Ecology's EIM System as part of a grant requirement. Once Ecology has a template for sharing nitrate data, a data exchange could be used to make the data more accessible.
- Uncertainty occurs in measurements – the number that is reported from a sample analysis is always somewhat higher or lower than the "true" value. For example, if you sample a well for nitrate multiple times over a single day, there would be slight differences from one sample to the next. These differences are usually very small, and there is commonly a procedure in the QA/QC plans to evaluate and make a decision whether to retain any given result. Often duplicate and replicate samples are taken to both check the sample variability and for field and lab QA/QC.
- Uncertainty is also introduced from the actual taking of the sample, to the conditions and time of transport to the lab, to the lab analytical method, and actual carrying out of the analysis. Uncertainty also results from the fact that one is sampling a very small quantity of water and using it to represent a much larger volume of groundwater at that location. Well construction issues, like whether the well draws water from near the water table, or deep within the aquifer, are also important.
- Monitoring of nitrate in groundwater is done by various agencies for various purposes over time.
- A few records seem to have anomalous values. As an example, one well has a sample that is 11 mg/L, while all the other samples are < 2 mg/L. This is possibly a data entry error (the result is actually 1.1 mg/L). If this sample occurs in an area where there were few maximum nitrate values over 10 mg/L, the author examines the surrounding graphs to help guide decisions on the category the area should be put into (high to low). This type of error is expected to be uncommon, but should be looked at more closely for high priority areas as they are addressed.
- Wells vary in construction. Many wells in Eastern Washington, for example, are only partially cased through the upper unconsolidated deposits, and are uncased deep (open hole) into the basalt aquifers. Some wells have long screens and others are just open at the bottom of the casing.
- Poorly constructed wells may be conduits for shallow groundwater contaminated with nitrates to be transported to deeper aquifers or to get into well water being sampled.
- Wells used for large public water supplies may be very large in diameter, very deep, with long screens. A monitoring well of small diameter that measured near the top of the uppermost water table would have a very different result at the same location.
- The determination of well locations have improved over the years. Formerly wells were located on a gridded section basis, to the Township and Range Section Quarter-Quarter (40 acres), or by GPS that had error built in because of military concerns (typically about 50 meters or 164 feet). Therefore some locations will look off if compared to an orthophoto

background, but they are typically within range of the correct location, especially at the regional scale.

- A few locations may be erroneous. An example error would be transposing a digit when entering a latitude or longitude. Some erroneous locations may be identified by ancillary data (the locations plot in a different county than where the data says they should be). Evaluating location accuracy should be done for high priority areas as they are addressed, since assessing locations on a statewide scale requires more resources than are available at this time.

## Graphs of nitrate data

Ecology produced graphs for well records with at least four sample results and with at least one result equal to or greater than 5 mg/L. Figure 7 shows the distribution of the graphs for Dept. of Ecology and USGS well locations.

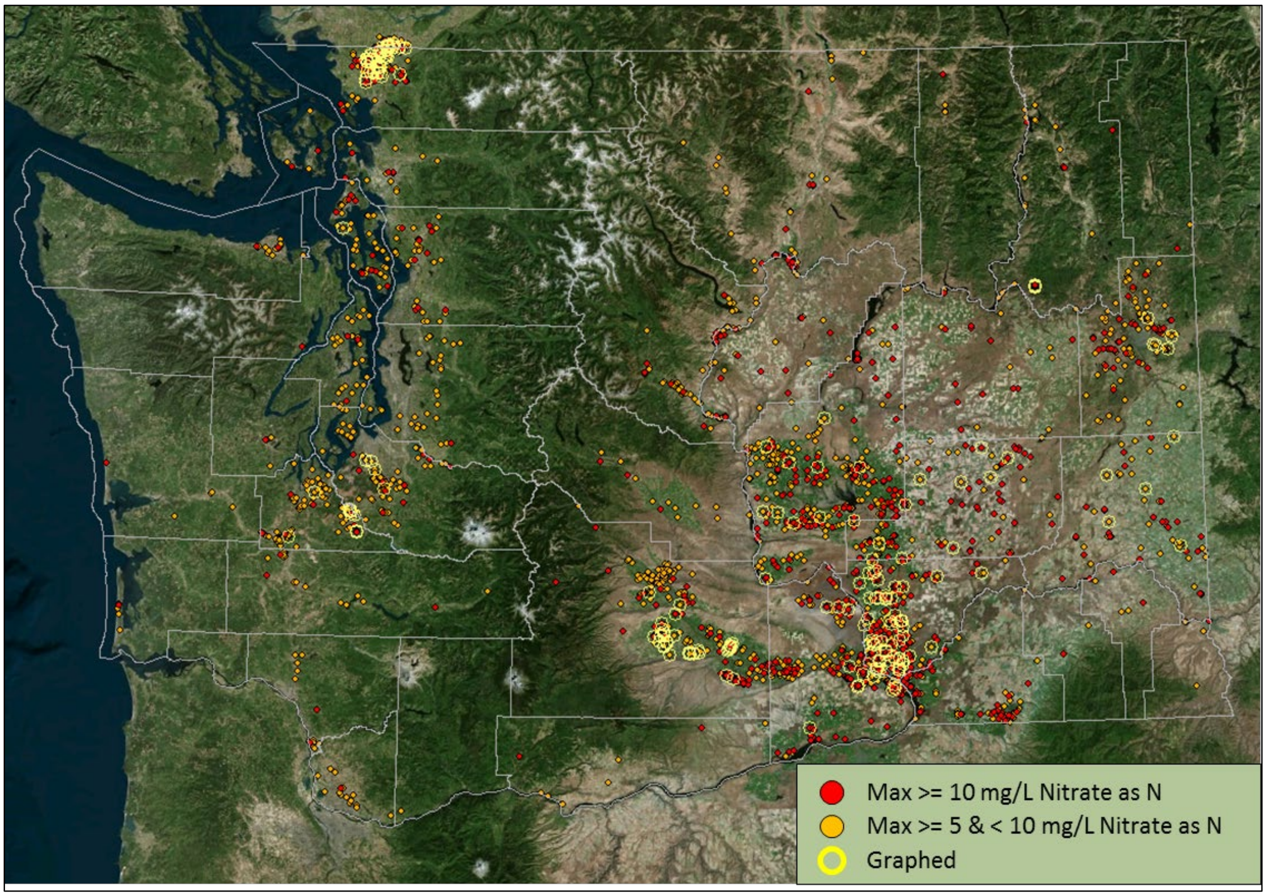


**Figure 7: Statewide distribution of nitrate graphs for USGS and Ecology wells with at least 4 samples and where the maximum nitrate level is at least 5 mg/L as N.**

The graphs were produced using the open source R statistical software package. The output is a pdf file, which is then linked to the well location on the map in GIS as a pop-up. Figure 8 is an example.

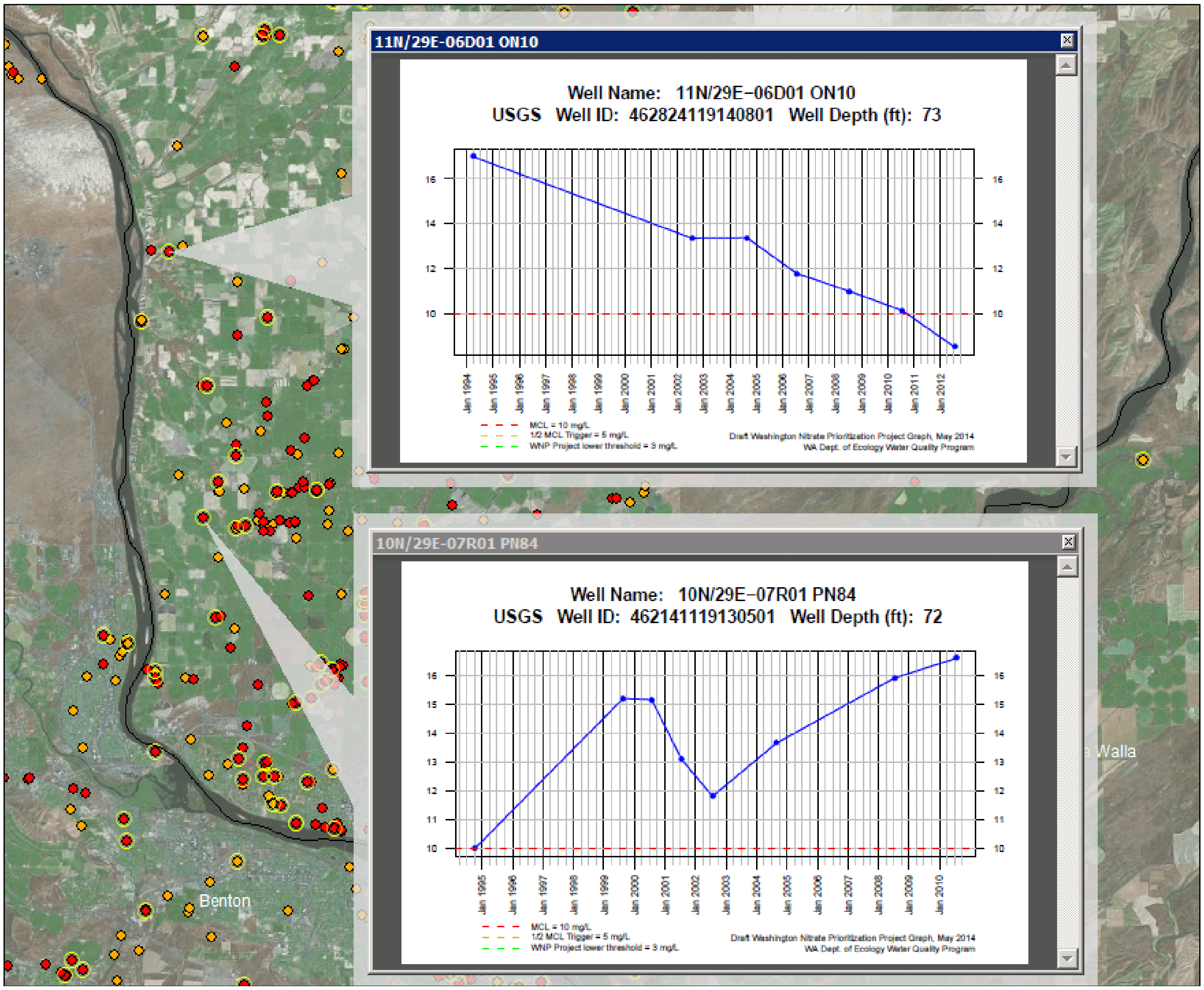


**Figure 8: Example of nitrate graphs on a map**

The R script can be changed and produces the graphs in minutes, making it easy to update graphs when there is a data update. The graphs attached to the map helps in understanding the sampling records while considering areas for classification. The graphs also show the well depth.

# USGS groundwater nitrate risk grids

The two previously mentioned USGS studies that have evaluated nitrate risk for the entire state (Frans, 2008; Nolan, 2006) have been used to guide the selection of priority areas, along with the other factors detailed in this report.

These reports include analyses of the factors that contribute to nitrate leaching risk, and compares the occurrence of these factors to USGS monitoring data. Each of these factors is represented by a GIS layer in some fashion.

## Frans Nitrate Probability Grid

Factors that relate to risk of nitrate occurrence in groundwater are summarized in Frans (2008).

The following is excerpted from the study abstract (partly paraphrased). The entire abstract and report are available online at http://pubs.usgs.gov/sir/2008/5025/.

> This study used the statistical method called logistic regression to relate factors that contribute to elevated nitrate occurrence, to the occurrence of elevated nitrate concentrations in groundwater. The factors that were analyzed included well depth, groundwater recharge rate, precipitation, population density, fertilizer application amounts, soil characteristics, hydrogeomorphic regions, and land-use types. The factors that best explained the occurrence of elevated nitrate concentrations (defined as concentrations of nitrite plus nitrate as nitrogen greater than 2 milligrams per liter) were the percentage of agricultural land use in a 4-kilometer radius of a well, population density, precipitation, soil drainage class, and well depth. Based on the relations between these variables and measured nitrate concentrations, logistic regression models were developed to estimate the probability of nitrate concentrations in ground water exceeding 2 milligrams per liter. Maps of Washington State were produced that illustrate these estimated probabilities for wells drilled to 145 feet below land surface (median well depth) (Frans, 2008).

The resultant nitrate probability grid was provided by the USGS and used for this project. The following illustration shows the Frans probability grid for the entire state. This is followed by a map that shows only the higher probability areas. This makes it easier to see distinct areas of higher probabilities.

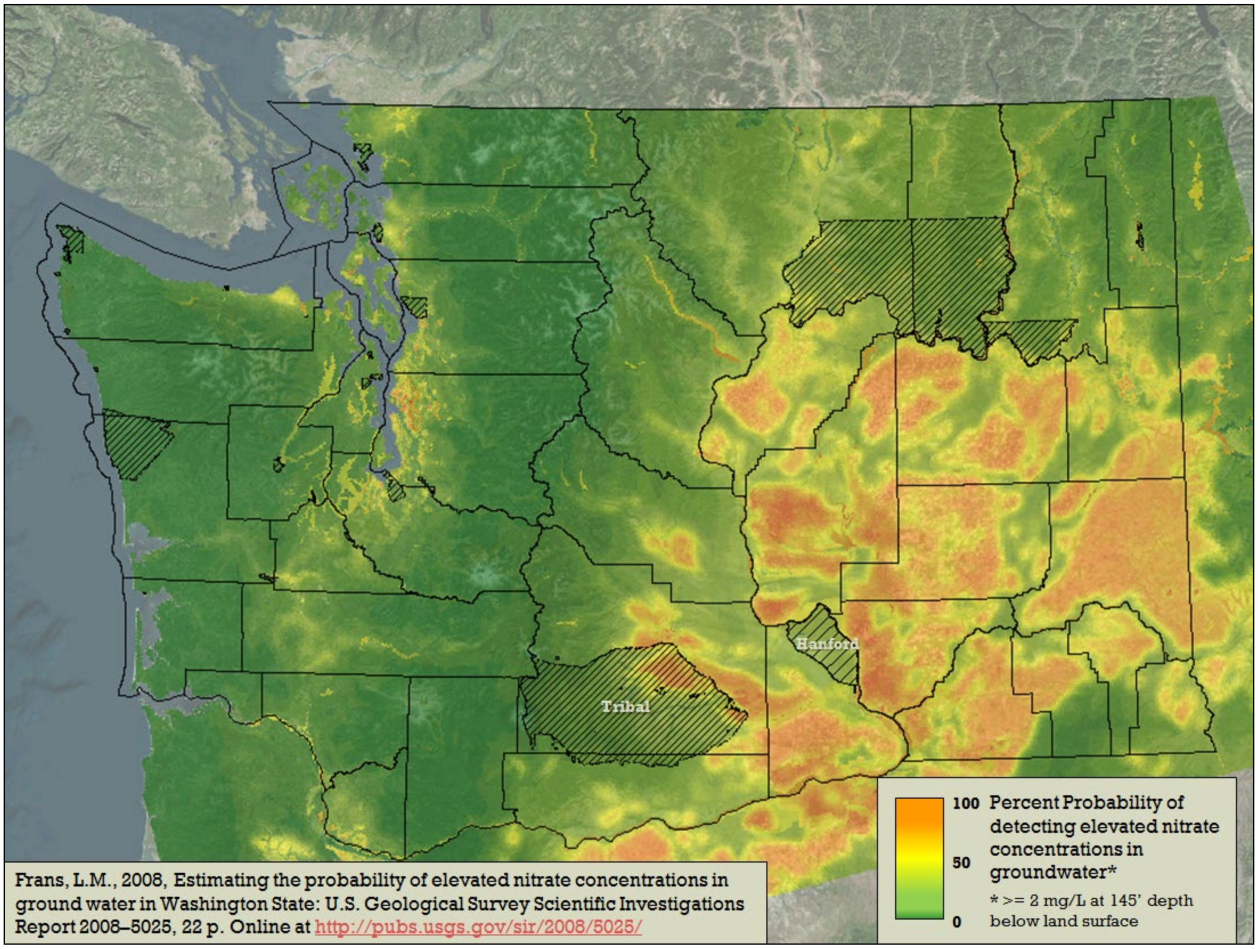


**Figure 9: USGS percent probability of detecting elevated nitrate concentrations in groundwater greater than or equal to 2 mg/L at 145 feet depth below land surface (Frans, 2008).**

It is easier to see distinct areas of high probability by removing the large areas of low probability. Figure 10 displays probabilities at 70% or greater for Eastern Washington and 50% or greater for Western Washington, where the probabilities are generally lower.

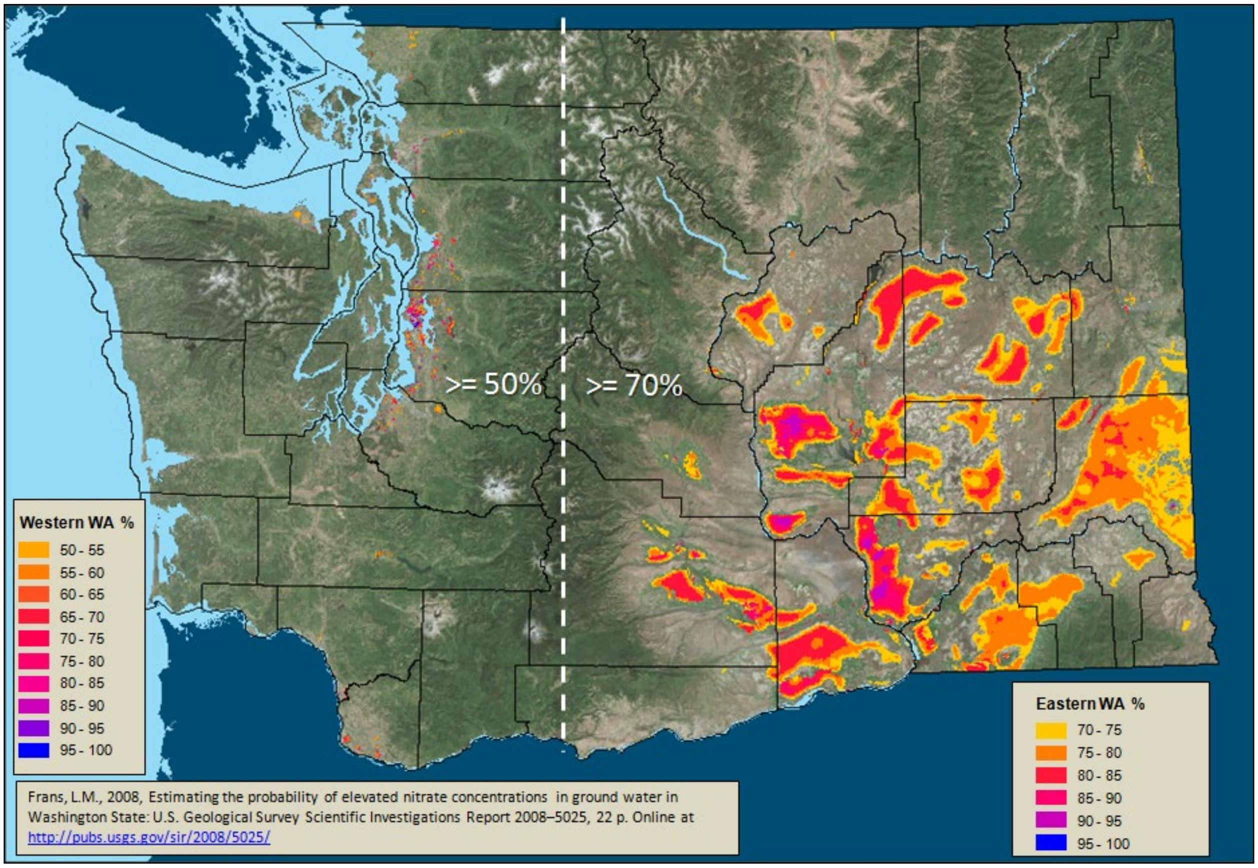


**Figure 10: USGS probability of detecting elevated nitrate concentrations in groundwater greater than or equal to:**

**2 mg/L at 145 feet depth below land surface, at 70 percent or greater for Eastern Washington, and 50 percent or greater for Western Washington.**

## Nolan Nitrate Prediction Grid

This USGS nitrate prediction grid was developed for the entire nation. The grid was extracted for Washington and reprojected from the original USGS grid. The following is excerpted from the study abstract (Nolan, 2006). The entire abstract and report are available online at http://water.usgs.gov/nawqa/nutrients/pubs/est_v40_no24/est_v40_no24.pdf.

> Two nonlinear models were developed at the national scale to (1) predict contamination of shallow ground water (typically < 5 m deep) by nitrate from nonpoint sources and (2) to predict ambient nitrate concentration in deeper supplies used for drinking. The new models have several advantages over previous national-scale approaches. First, they predict nitrate concentration (rather than probability of occurrence), which can be directly compared with water quality criteria. Second, the models share a mechanistic structure that segregates nitrogen (N) sources and physical factors that enhance or restrict nitrate transport and accumulation in ground water. Finally, data were spatially averaged to minimize small-scale variability so that the large-scale influences of N loading, climate, and aquifer characteristics could more readily be identified. *Results indicate that areas with high N application, high water input, well-drained soils, fractured rocks or those with high effective porosity, and lack of attenuation processes have the highest predicted nitrate concentration [emphasis added].*

The Nolan model, used to create the nitrate prediction grid, uses a mathematical analysis that factors in nitrogen sources, transport and attenuation and results in the "observed mean ambient nitrate concentration" associated with well monitoring networks across the U.S.:

Groundwater Concentration of Nitrate = N Loading + Transport Factors + Attenuation Factors.

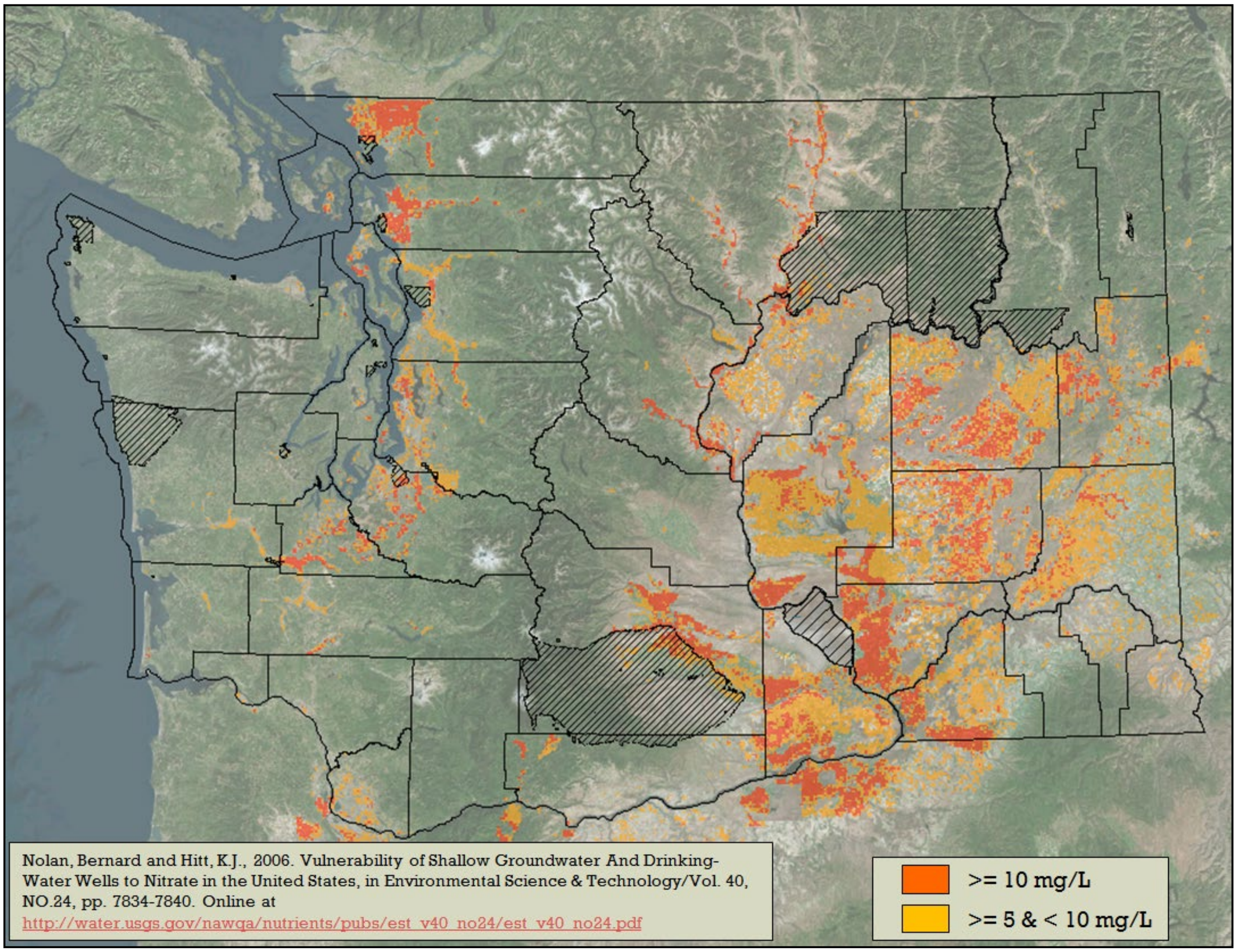


**Figure 11: USGS nitrate prediction grid categories greater than or equal to: 5 mg/L Nitrate as N in shallow groundwater (extracted from Nolan, 2006).**

The following is a list of factors summarized by Nolan (2006) and how the GIS and data assets used for this project are related.

- **High N Application**

  *"As N loading at the land surface increases, nitrate concentration in shallow groundwater increases"*

  For this phase of the project, crop land is used as a simple indicator of N loading.

  In the future, N loading could be broadly represented by crop maps and by assuming typical fertilizer application rates. Manure could be broadly estimated by number of animals in an area. These methods are basic but informative. Clusters of any animal operations with high numbers of animals implies large amounts of manure concentrated in an area. A more sophisticated loading estimation method should be applied within nitrate priority areas.

- **High Water Input**

  Washington State Dept. of Agriculture (WSDA) provided Ecology with a map of irrigated lands. Mean annual precipitation is also a contributor of water input and is available as a statewide GIS layer.

  The USGS produced a recharge map of Puget Sound (Vaccaro, 1998). The USGS also mapped recharge estimates for other areas of the state. Proposed future work should include obtaining these GIS layers and organizing them as part of the hydrogeology information development.

- **Well-Drained Soils**

  Natural Resources Conservation Service (NRCS) soil data, called SSURGO, includes soil drainage classes that are mappable at the statewide scale. Areas where soil drainage is excessive indicates that both water and contaminants tend to drain below the root zone more quickly.

- **High effective porosity soil/ fractured rock**

  Other measures of water transmissivity through soils are available from SSURGO. A very good measure that relates directly to the transmission of recharge and dissolved nitrates is the time of water travel through all of the soil layers.

- **Lack of attenuation processes**

  Elevated nitrate in groundwater is an excellent indicator of where attenuation processes are lacking. Where nitrate is not elevated, vigorous denitrification or lack of nitrogen loading may be the reason. Dilution from leaking irrigation canals can also decrease nitrate concentrations in groundwater.

## Limitations

The risk grids are analyses of several input layers, including soils and nitrogen loading. Each layer has limitations. The grids themselves are spatially limited by the cell size. For Frans, the cell size is ½ kilometer$^2$ (km$^2$). For Nolan, the cell size is one km$^2$. The power of statistical analysis in these studies is that it relates the inputs to actual sampling data so that the correctness of the results may be determined. For a full discussion of methods and limitations, please see the reports Frans (2008) and Nolan (2006), which are available online.

# NRCS soil maps

The NRCS maps soil characteristics for soil surveys nationwide. SSURGO data and the associated GIS layer is available for the state.

For Washington, the NRCS has evaluated the nitrate leaching potential of irrigated and non-irrigated soils using expert knowledge and soil properties available from the NRCS Soil Survey Geographic database (SSURGO) dataset (Campbell, 2011). Two of the soil properties are presented here: soils drainage class and water travel time through the entire soil profile. These soil properties relate to how easily and how fast water can move through the soil profile. It is very useful to see the landscape patterns of these characteristics. These landscape patterns are a reflection of the broad scale geologic processes that have formed the ground surfaces of the state over geologic time.

Since SSURGO allows up to three component soil types in a GIS map unit, an NRCS method that uses the dominant factor is employed to represent the map unit. NRCS cautions that these maps and their interpretations are for planning purposes only, and that more detailed study would be needed for intensive uses at sites.

## Soil Drainage Class

Excessive soil drainage indicates that water moves through the soil profile easily and rapidly. This is a risk factor for nitrate leaching, since any water and dissolved nitrate would move quickly below the root zone with little or no attenuation.

Figure 12 shows both excessive and somewhat excessive soil drainage classes for the entire state. The excessive (red) and somewhat excessive (yellow) drainage classes cover distinct areas.

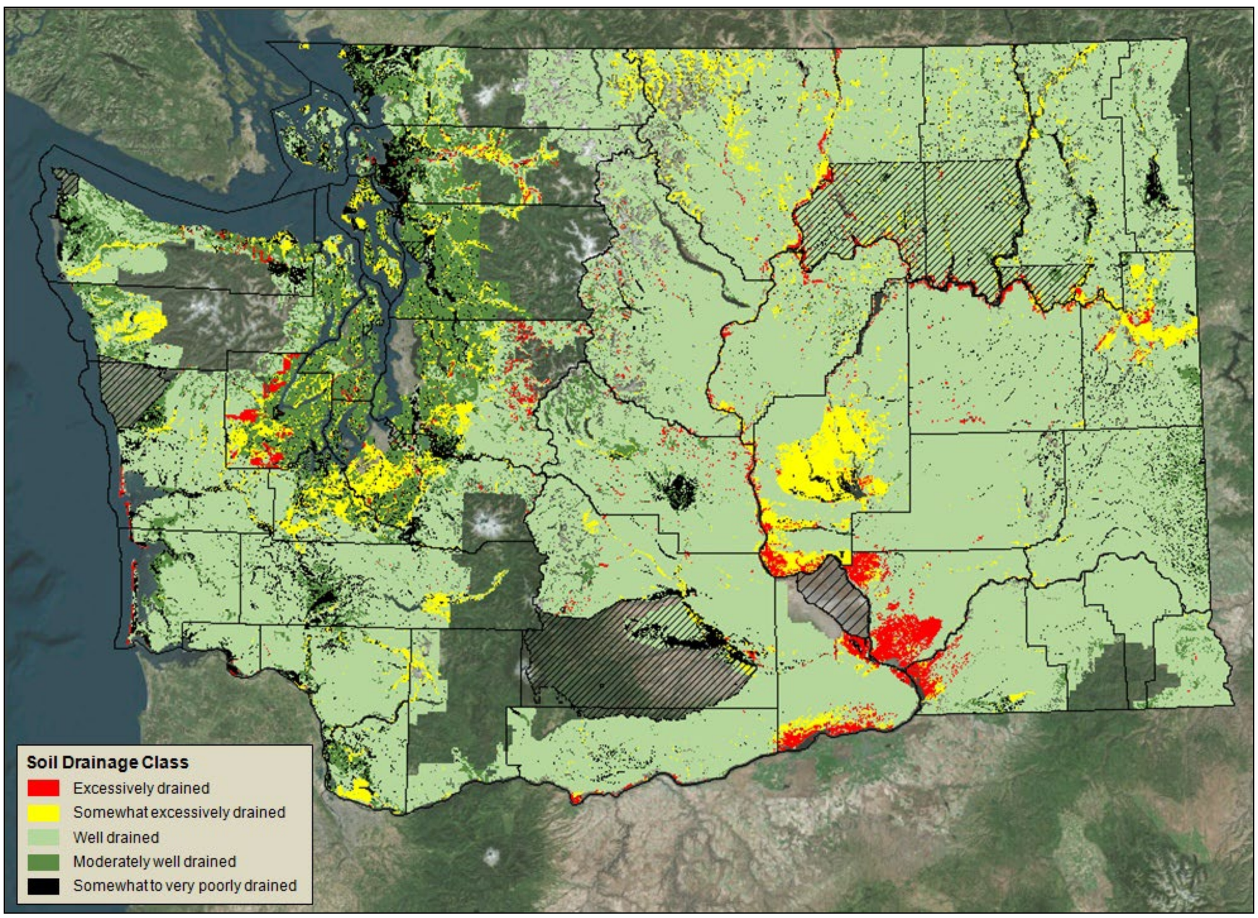


**Figure 12: NRCS SSURGO Soils Drainage Classes of Washington. Most of the state is well-drained. (NRCS, 2013)**

Soil drainage is one of the main contributing factors identified in nitrate risk studies (Frans, 2008; Nolan, 2006). Excessive drainage equates to a higher risk of nitrates in groundwater. Several candidates for Nitrate Priority Areas have excessive drainage.

The following is information about drainage class from the NRCS National Soil Survey Handbook (U.S. Department of Agriculture, 2014):

A. Definition.—"Drainage class" identifies the natural drainage condition of the soil. It refers to the frequency and duration of wet periods.

B. Classes.—The eight natural drainage classes are listed below. Chapter 3 of the Soil Survey Manual provides a description of each natural drainage class.

I. Excessively drained

Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have very high hydraulic conductivity or are very shallow.

II. Somewhat excessively drained

Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have high saturated hydraulic conductivity or are very shallow.

III. Well drained

Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.

IV. Moderately well drained

Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m, periodically receive high rainfall, or both.

V. Somewhat poorly drained

Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep, and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.

VI. Poorly drained

Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season, or remains wet for long periods. The occurrence of internal free water is shallow or very shallow, and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity of nearly continuous rainfall, or of a combination of these.

VII. Very poorly drained

Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.

VIII. Subaqueous

C. Significance.—Drainage classes provide a guide to the limitations and potentials of the soil for field crops, forestry, range, wildlife, and recreational uses. The class roughly indicates the degree, frequency, and duration of wetness, which are factors in rating soils for various uses.

## Water travel time through the entire soil profile

NRCS uses a method to calculate this for their Nitrate Leaching Index (Campbell, 2011). They use the saturated soil conductivity (Ksat) in terms of the hours it takes to travel through the subject soil layer, and sum the time of travel for each layer, to get the total time of travel.

The following is excerpted from *Development of a Nitrate Leaching Potential Interpretation in the National Soil Information System (NASIS)*, December 2011 by Steve Campbell, Soil Scientist for the NRCS (Campbell, 2011).

> **Water travel time through entire soil profile** - this factor uses the saturated hydraulic conductivity (Ksat) and thickness of each soil horizon, to estimate the number of hours that would be required for a given volume of water to move through the entire soil profile. One advantage of this method for accounting for the rate of water movement is that the properties and thickness of each soil horizon are accounted for, rather than using an overall hydraulic conductivity or permeability class for the entire profile. This method will account for subtle differences between soils in texture, structure, horizon thickness, and depth to water-restricting layers. More discussion of this method is available at the Oregon State University Extension Publication available at: http://osuext.intermountaintech.org/download/determination%20of%20soil%20sensitivity%20ratings.pdf (4).

Here is information about Saturated Hydraulic Conductivity from the NRCS National Soil Survey Handbook (U.S. Department of Agriculture, 2014):

A. Definition.—"Saturated hydraulic conductivity" is the ease with which pores of a saturated soil transmit water. Formally, it is the proportionality coefficient that expresses the relationship of the rate of water movement to hydraulic gradient in Darcy's Law (a law that describes the rate of water movement through porous media). It is expressed in micrometers per second. To convert micrometers per second to inches per hour, multiply micrometers per second by 0.1417. The historical definition of "saturated hydraulic conductivity" is the amount of water that would move vertically through a unit area of saturated soil in unit time under unit hydraulic gradient.

B. Significance.—Saturated hydraulic conductivity is used in soil interpretations. It is also known as Ksat.

The following map shows the NRCS calculated time of travel through the soil layers as represented in the SSURGO database. Because a map unit can represent up to three soils, the dominant condition is used by NRCS to represent the soil map unit as a whole. Each soil layer represented in SSURGO has its own Ksat value. The total time of travel through all layers is the sum of these.

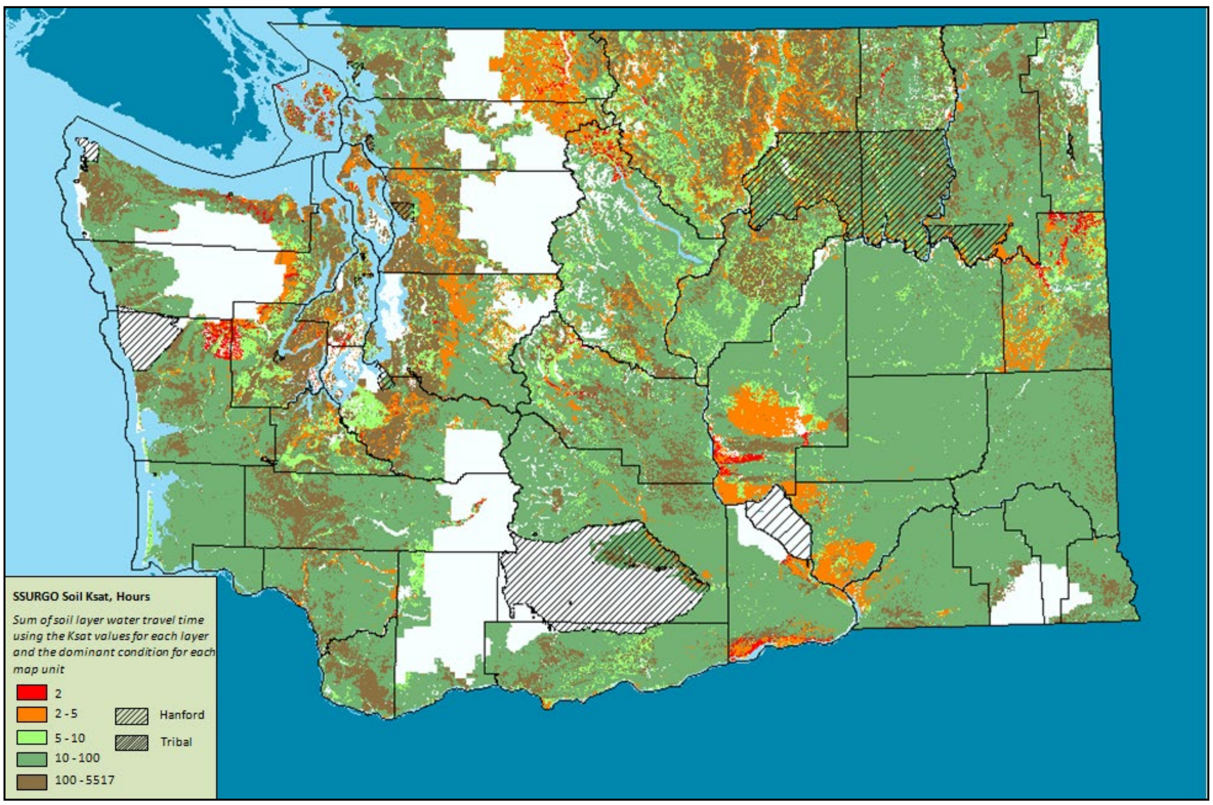


**Figure 13: Travel time of water through the soil profile as represented in the NRCS SSURGO database,** and calculated for the Nitrate Leaching Index by Steve Campbell, NRCS Soil Scientist (Campbell, 2011). Areas of red and orange represent rapid (<5 hr) movement through the soil horizon.

# Landuse as an indicator of nitrate loading

Nitrogen sources that can end up contributing to nitrate concentrations in groundwater include manure, chemical fertilizers, on-site sewage systems, land application of biosolids, and land application of food processing waste. Nitrogen sources, especially agricultural use of fertilizers, increased livestock densities and growth in human population, have increased for decades, leaving a legacy of nitrate in groundwater.

Nitrate loading from irrigated agriculture using chemical fertilizer and manure from confined animal operations contributes significantly to groundwater nitrate contamination. One recent USGS report on nitrates in private wells in glacial settings across the U.S. states: "A source variable such as the rate of nitrogen applied to farms was useful in predicting regional nitrate concentration" (Warner, 2010).

Figure 14 shows the distribution of crops across the state (WSDA, 2010) and is a general indication of where fertilizers would be applied. A more detailed estimate of nitrogen loading should be accounted for in future more detailed loading studies of individual areas.

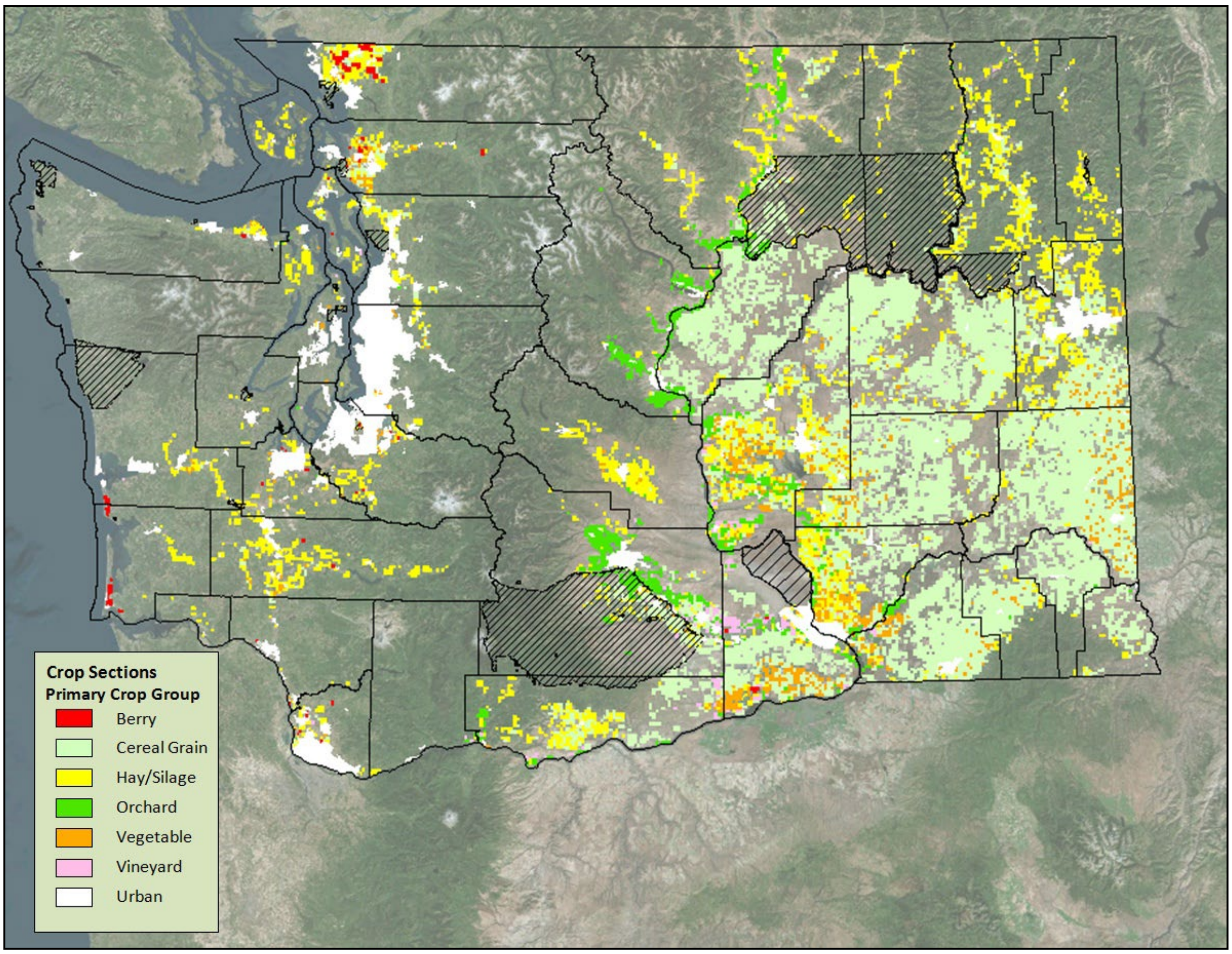


**Figure 14: Sections with Primary Crop Group (Washington State Dept. of Agriculture [WSDA], 2010) and Urban Areas**

# Irrigation and precipitation

Irrigation and precipitation are the sources of recharge to groundwater, after water is removed by evaporation, plants, and runoff. Recharge is the carrier of dissolved nitrate to groundwater. Irrigation in drier Eastern Washington is a major factor for nitrate leaching risk. Precipitation is more of a factor in Western Washington, although irrigation does occur, most notably over the shallow Sumas-Blaine aquifer.

Along with crop mapping, WSDA has also mapped irrigation practices (Figure 15) across the state (WSDA, 2010).

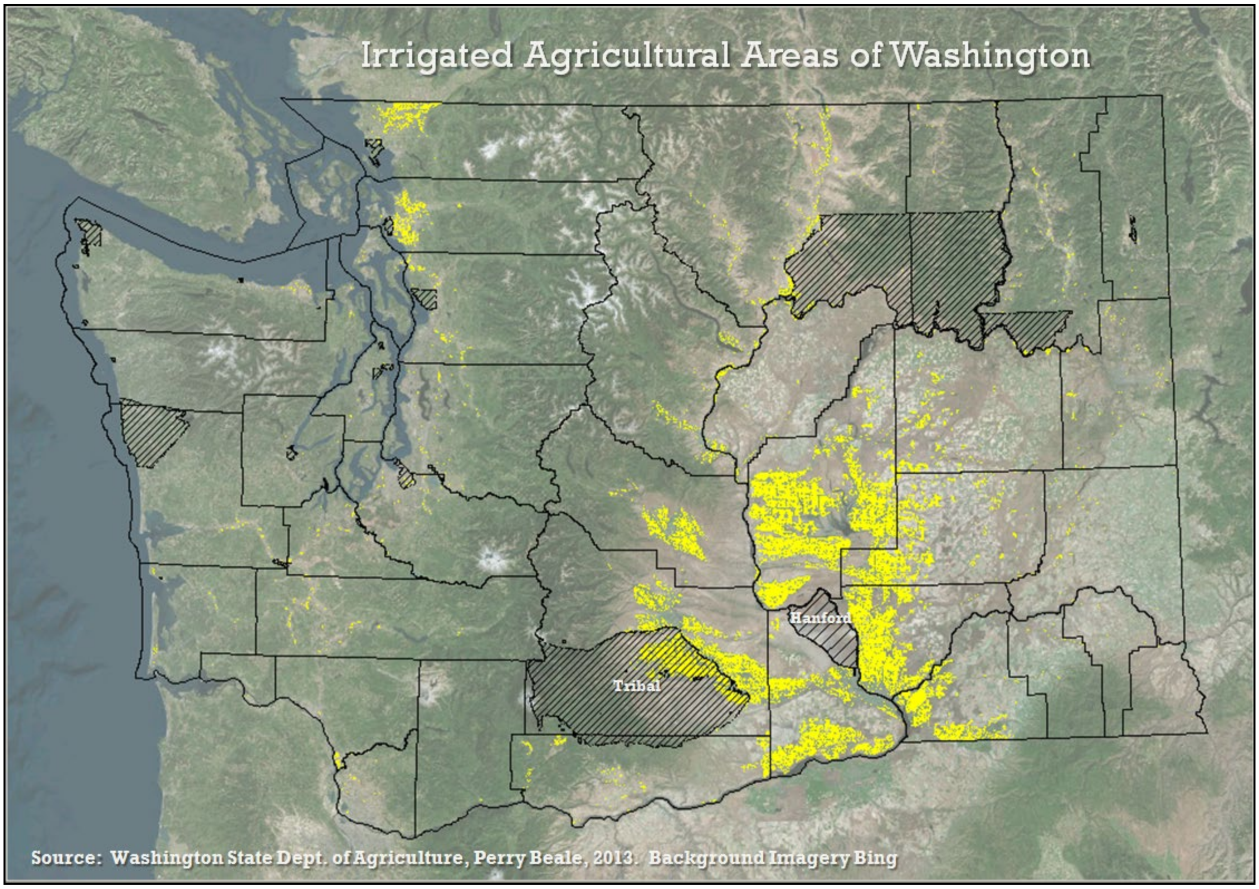


**Figure 15: Irrigated crop lands of Washington (Washington State Dept. of Agriculture, 2010)**

Figure 16 is a mean annual precipitation map and shows the range of precipitation and the differences between Western Washington and the drier Eastern Washington.

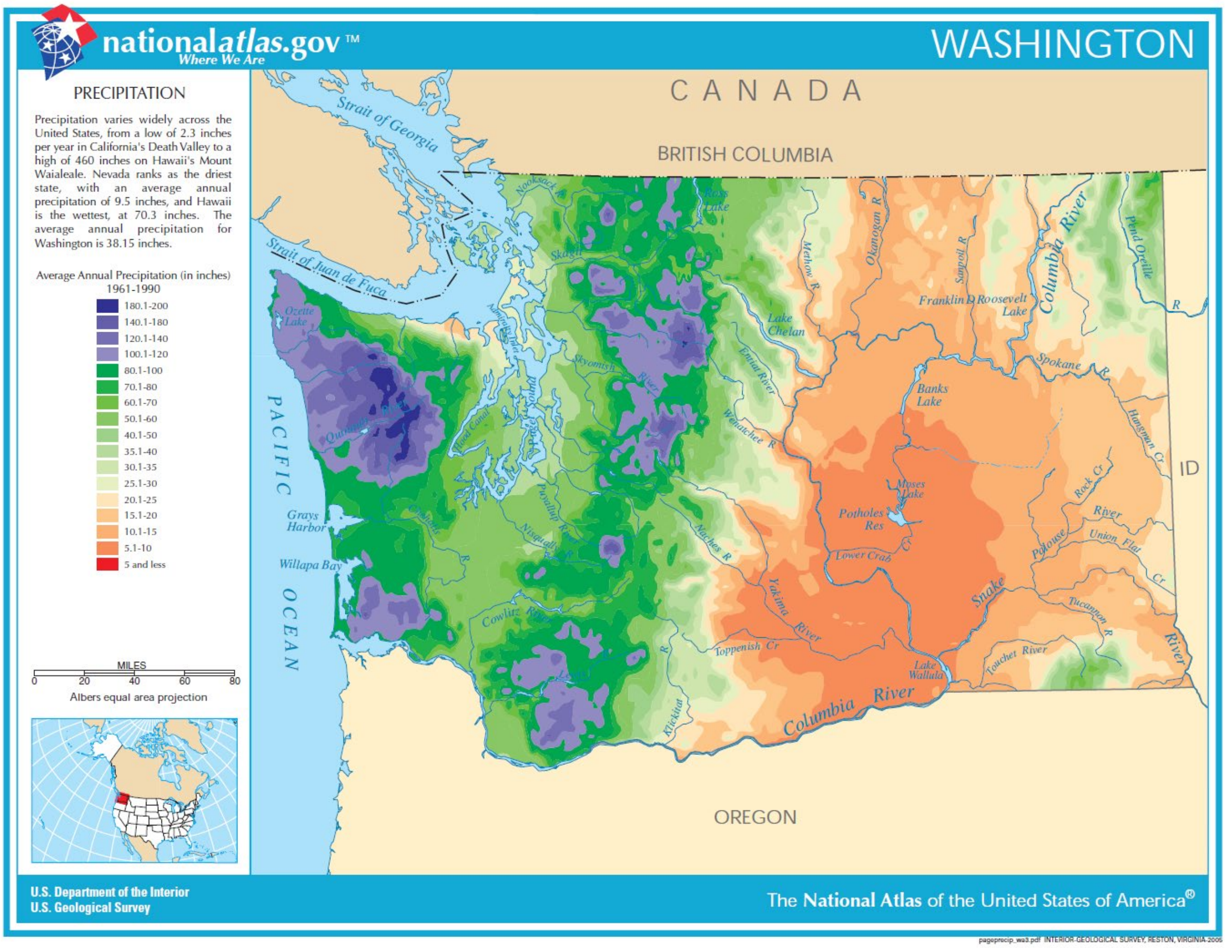


**Figure 16: National Atlas Average Annual Precipitation (inches) based on data from 1961-1990 (USGS, 2005)**

# Surficial geology/hydrogeology

Groundwater in Washington State is extracted from both unconsolidated deposits where most shallow groundwater is found, from fractures in hard rock, and from interbeds between basalt flow layers in Eastern Washington.

Unconsolidated deposits that make up most of Washington's shallow aquifers are the sands, gravels, silts, clays, and mixtures of these that were deposited by rivers, lakes, past glacial episodes, the wind, and the enormous glacial floods. These deposits cover deeper layers of hard rock. In the Columbia Basin, unconsolidated materials overlie flood basalts, vast and deep layers of volcanic flows that have space in between the flows called *interbeds* that can produce enormous amounts of groundwater.

For nitrate contamination of groundwater, Ecology is mainly concerned with shallow groundwater. The unconsolidated deposits that contain groundwater nearer the land surface are called *surficial aquifers*.

Washington's major surficial aquifers are within the unconsolidated deposits that overlie igneous and basaltic rocks. Several maps have been made of surficial aquifers, some of which are shown in the following sections.

## USGS Principal Aquifers of the Pacific Northwest

Figure 17 is a very generalized categorization and mapping of principal aquifers of the Pacific Northwest (USGS, 1995). It does not attempt to define topographically distinct aquifers that may not be connected. Rather, it bases categorization on general geography and similarity of material. Thus it cannot be used to outline topographically distinct aquifers; it is a general guide.

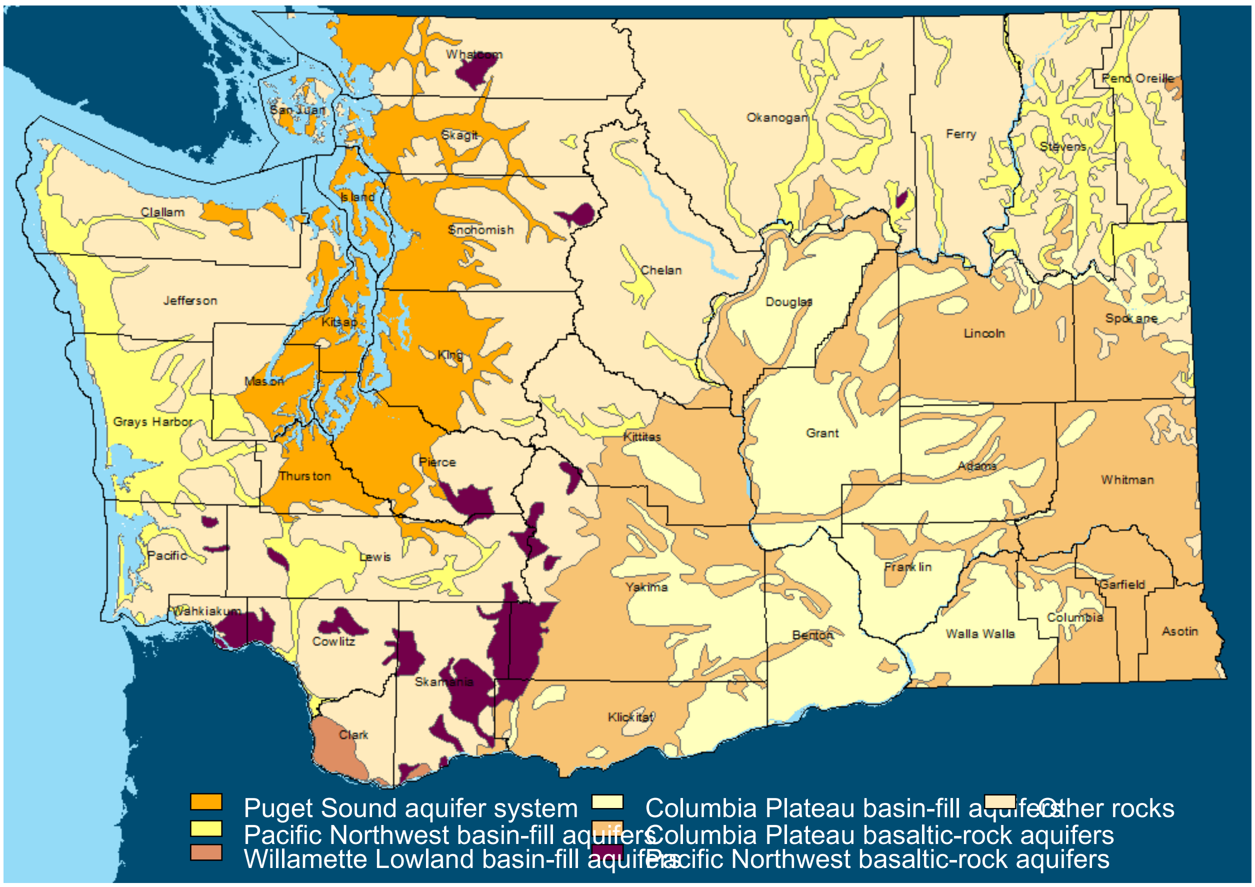


**Figure 17: Principal Aquifers of the Pacific Northwest (USGS, 1995)**

## Unconsolidated Deposits of Washington State

The map shown in Figure 18 (Morgan, 2015) was created from the geological unit GIS cover from the Washington State Department of Natural Resources, Division of Geology & Earth Resources. The GIS cover of geologic units was queried for the presence of a categorical term (e.g., "glacial"). Any sort of glacially derived material is called "Glacial" on this map, divided into categories of glacial outwash and other glacial materials. A similar process was used for the other categories of unconsolidated deposits. There are other types of unconsolidated deposits, such as landslides, that are limited in areal coverage on a statewide scale and so were not included on this map.

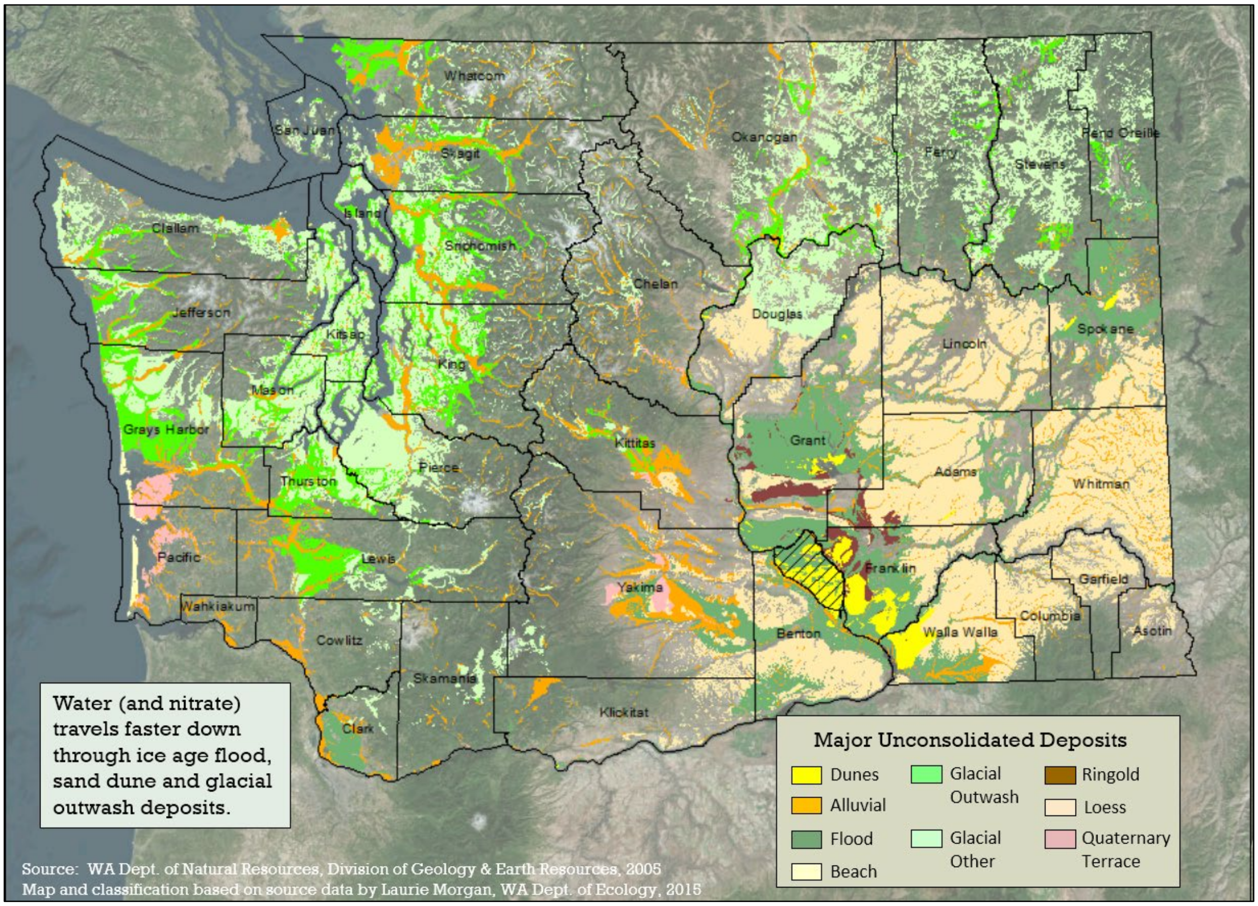


**Figure 18: Unconsolidated Deposits of Washington State**
**(Morgan, 2015, based on Washington State Dept. of Natural Resources Geologic Map, 2005)**

Other than the very generalized Principal Aquifers of the Pacific Northwest, Washington does not have a statewide centralized collection of hydrogeological information in GIS format. There are several GIS layers for various parts of Washington.

## USGS Hydrogeology of the Puget Sound Lowlands

The USGS produced a report entitled: *Hydrogeologic Framework of the Puget Sound Aquifer System* (Vaccaro et al, 1998). The following two figures use the GIS layers from that report. The author consolidated the hydrogeologic units into several categories so the patterns of fine material and coarse material can be better seen on a landscape scale. Coarse material allows infiltration of recharge and contaminants much more readily. For the original USGS report, please see http://pubs.usgs.gov/pp/1424d/report.pdf.

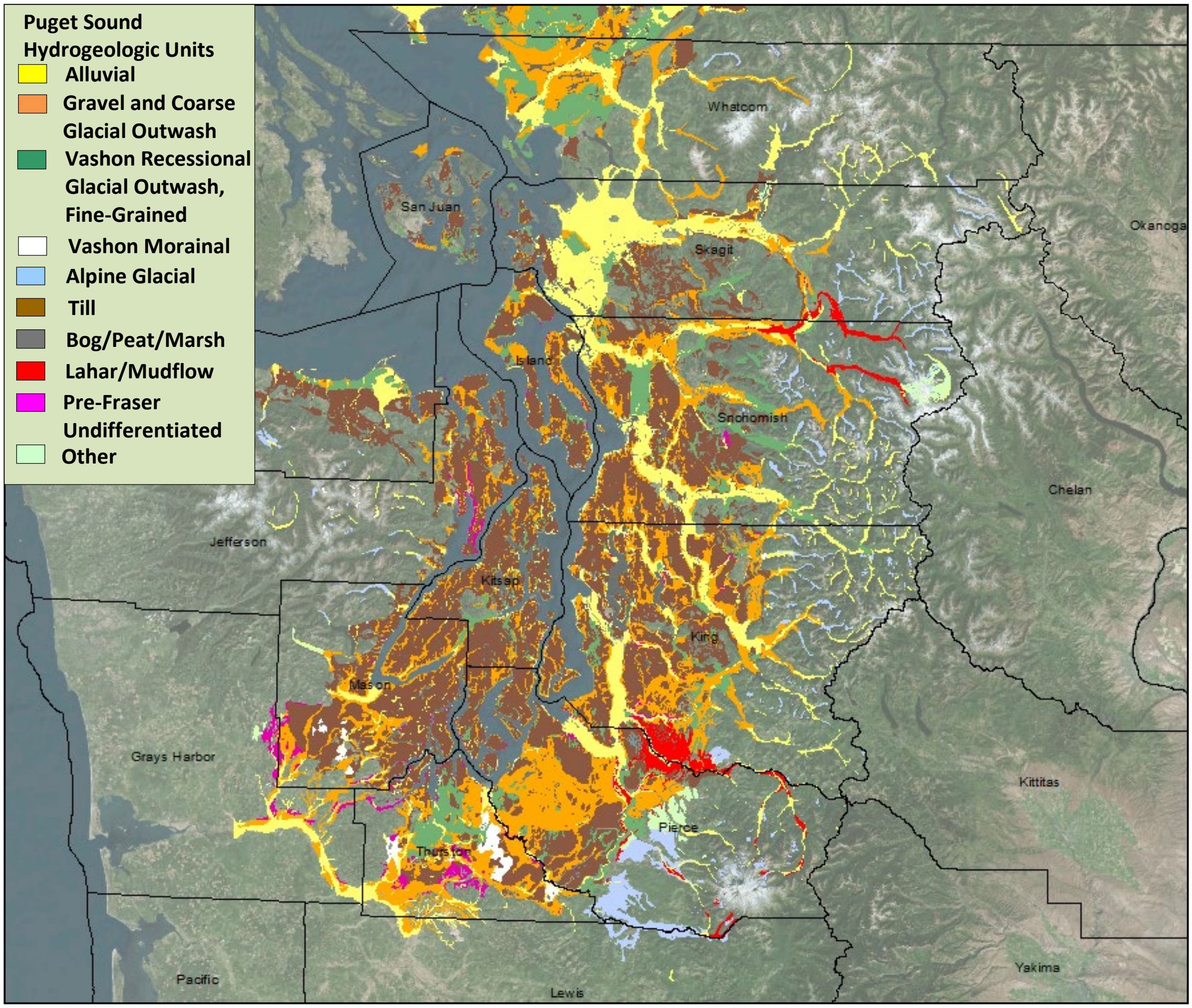


**Figure 19: Puget Sound Hydrogeological Units (after Vaccaro, 1998)**

## USGS Puget Sound Aquifer Recharge

Figure 20 also uses the USGS GIS layer from the Vacccaro report. It shows the distribution of recharge in the Puget Sound region. Recharge is the water that infiltrates from the land surface into groundwater. The land cover, soil types, and evapotranspiration determine how much of precipitation and irrigation applied to the land surface becomes recharge.

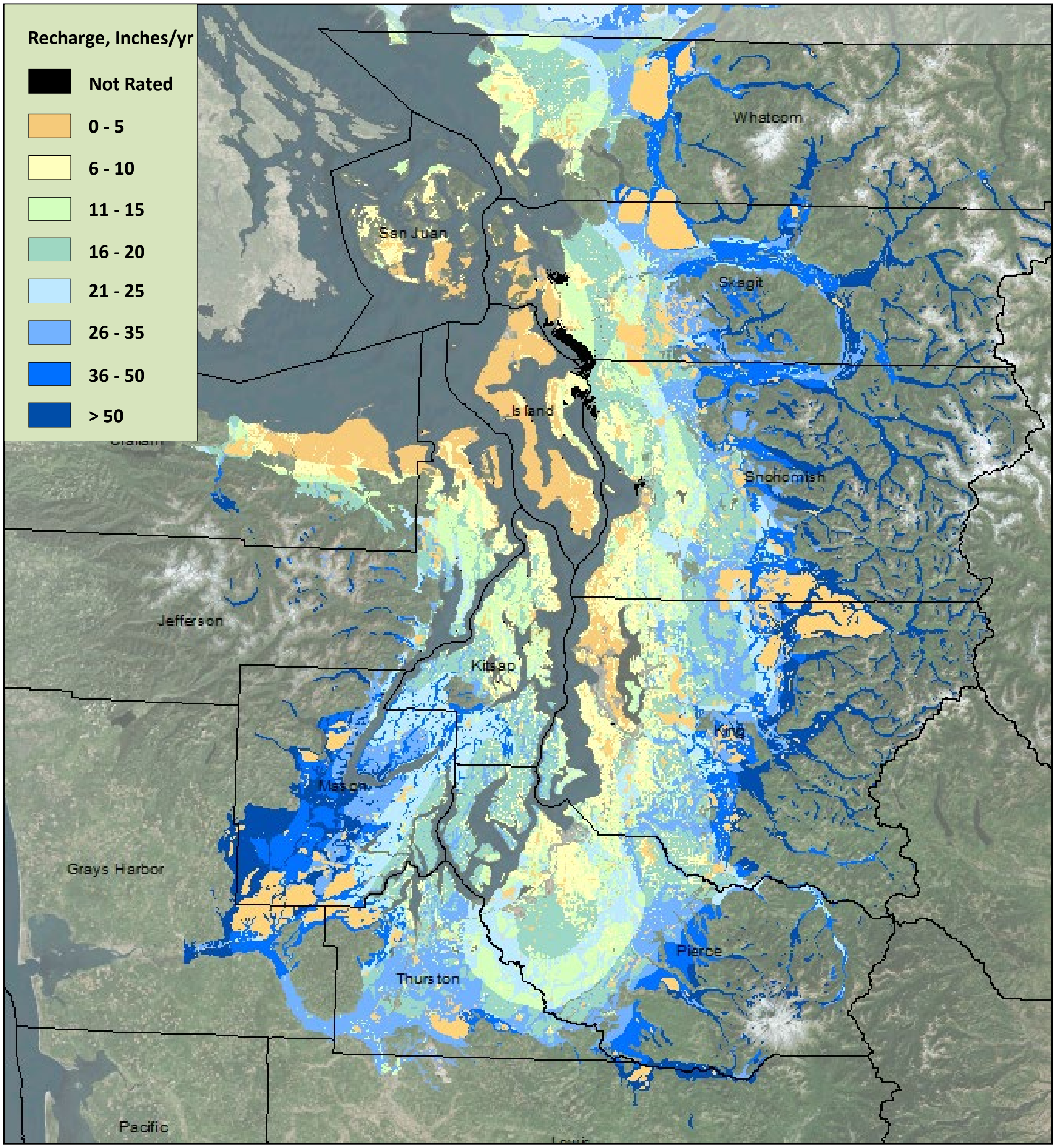


**Figure 20: Annual Average Recharge Rates, Inches per Year (after Vaccaro, 1998)**

## Sole Source Aquifers

EPA designates Sole Source Aquifers under the Safe Drinking Water Act when they receive a petition. A Sole Source Aquifer is the sole or principal source of drinking water for an area. To receive designation as a Sole Source Aquifer more than half the population must rely on the aquifer for drinking water; there can be no feasible alternate source of drinking water; and contamination of the aquifer would create a significant hazard to public health (EPA, 2014). More information about the Sole Source Aquifer program is online at http://yosemite.epa.gov/r10/water.nsf/Sole+Source+Aquifers/SSA. The following map

(Figure 21) shows Sole Source Aquifers in Washington. There are aquifers in Washington that are effectively the only source of drinking water and there is not a feasible alternative, besides the ones that are federally designated.

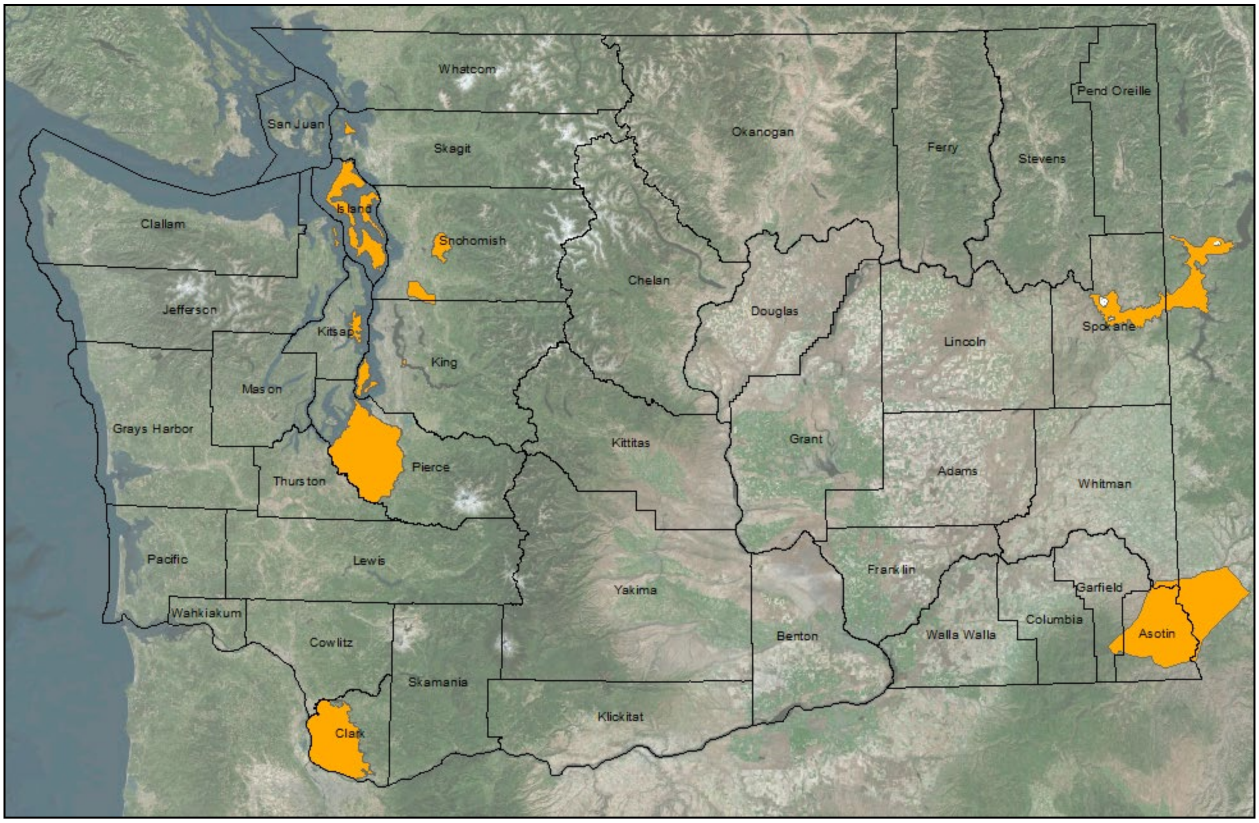


**Figure 21: Federally Designated Sole Source Aquifers (USEPA, 2013)**

## Local hydrogeologic studies

Groundwater occurrence and movement characteristics are very important for understanding and managing nitrate contamination of groundwater. The depth to the water table, general groundwater flow directions, how fast groundwater flows, where recharge and discharge occurs, and how thick the aquifer is tell us where contamination could be coming from, where it could go, how fast it might get to a water supply well or surface water, and the vertical and horizontal extent of the aquifer.

This information is typically developed during hydrogeologic studies. The Nooksack Surficial Aquifer study (Tooley, 1996), which included the Sumas-Blaine aquifer, specifically developed this information in GIS-useable form for Whatcom County (Figure 22).

The Columbia Basin Ground Water Management Area (GWMA) mapped and modeled the hydrogeology of the GWMA, which initially consisted of Adams, Grant, and Franklin Counties, and then added Lincoln County. This information will be incorporated into future analysis and review of Nitrate Priority Areas as resources allow. Extensive hydrogeologic work and reporting has been completed by consultants to the GWMA – see http://cbgwma.org for information.

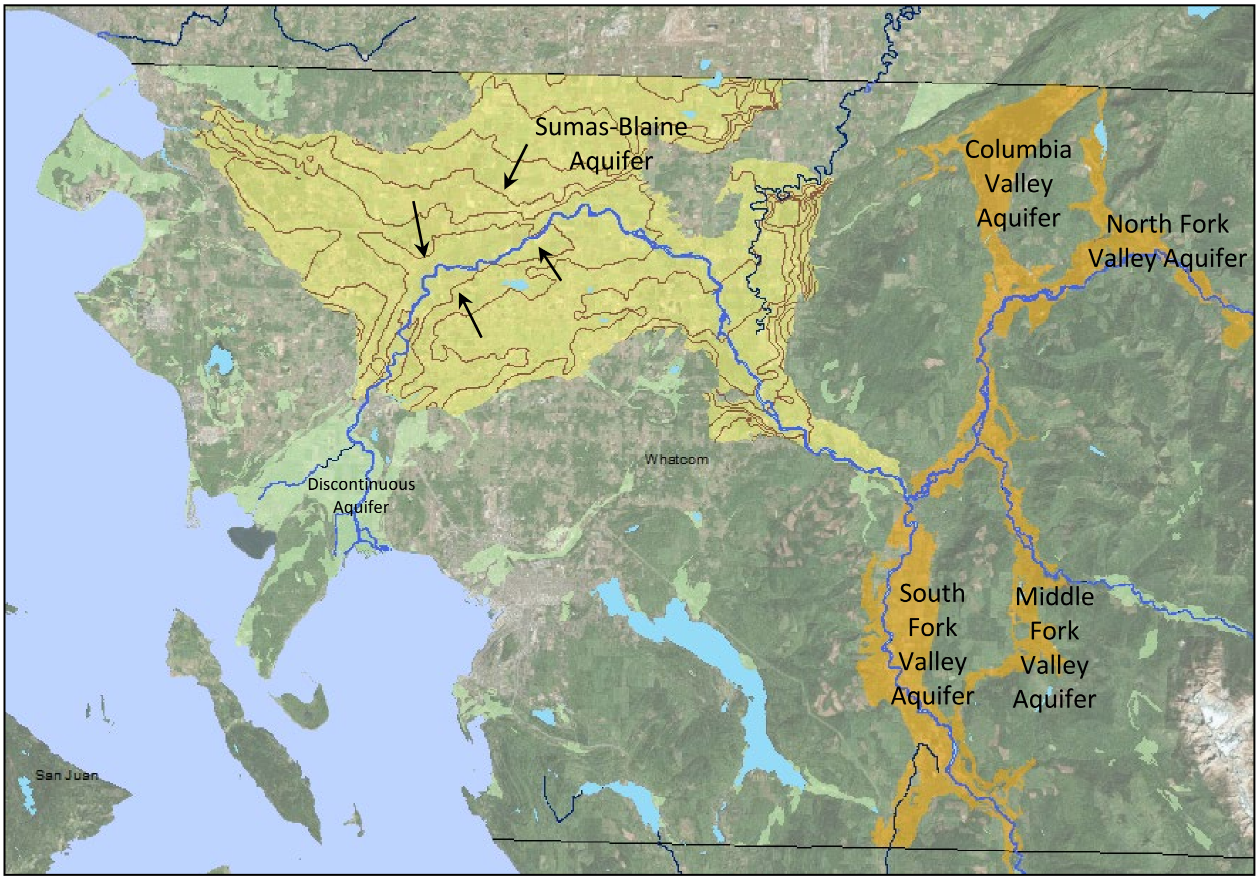


**Figure 22: Major Whatcom County Aquifers and Groundwater Flow Direction within the Sumas-Blaine Aquifer (after Tooley, 1996)**

Many other aquifer studies have been completed across the state by the USGS, Ecology, local government, universities, consultants and others. Some of this information is available on an ad hoc basis by request. The task of collecting and organizing hydrogeologic information and aquifer boundaries for the entire state is beyond the scope of this phase of the project. However, it is highly recommended for future work. Where Ecology has access, hydrogeological information in GIS form allows for the determination of the surface expression of aquifer boundaries, general depth to water, and general groundwater flow direction and rates. Such information tells us where groundwater is stored, as well as where it flows and generally how fast. This information helps with understanding the effects on well water that may occur from upgradient sources.

# How Nitrate Priority Areas were determined

Boundaries were based on a number of factors, including topography; the USGS risk grids; recharge; land use; landscape patterns of coarse unconsolidated deposits; soil excessive drainage; and travel time through the soil profile; and excessive nitrate concentrations.

The first requirement for a draft Nitrate Priority Area is that it be *topographically distinct*. This is because typically groundwater that is topographically isolated in one area is not connected to groundwater in adjacent areas. Topography is typically reflective of these groundwater divides. The Mattawa area of Grant County is a good example. It is bounded by the Saddle Mountains to the North and East, and the Columbia River to the West and South. Nitrate contamination, management, and improvement in this area would not be impacted by activities in other areas, such as the Quincy Basin or the Royal Slope to the North.

Based on topography, several areas in the Columbia Basin emerge as likely candidates. These include the Quincy and Pasco Basins.

Nitrate Priority Area boundaries must be drawn in GIS. Natural boundaries, such as rivers and the edge of valley floors, are preferred. However, since these take time and resources to draw, section outlines were used at this stage of the project to approximate topographically appropriate boundaries.

The physical characteristics of the landscape, as previously described in this section, and the USGS nitrate risk grids were used as additional guides for the initial boundaries (Figure 23).

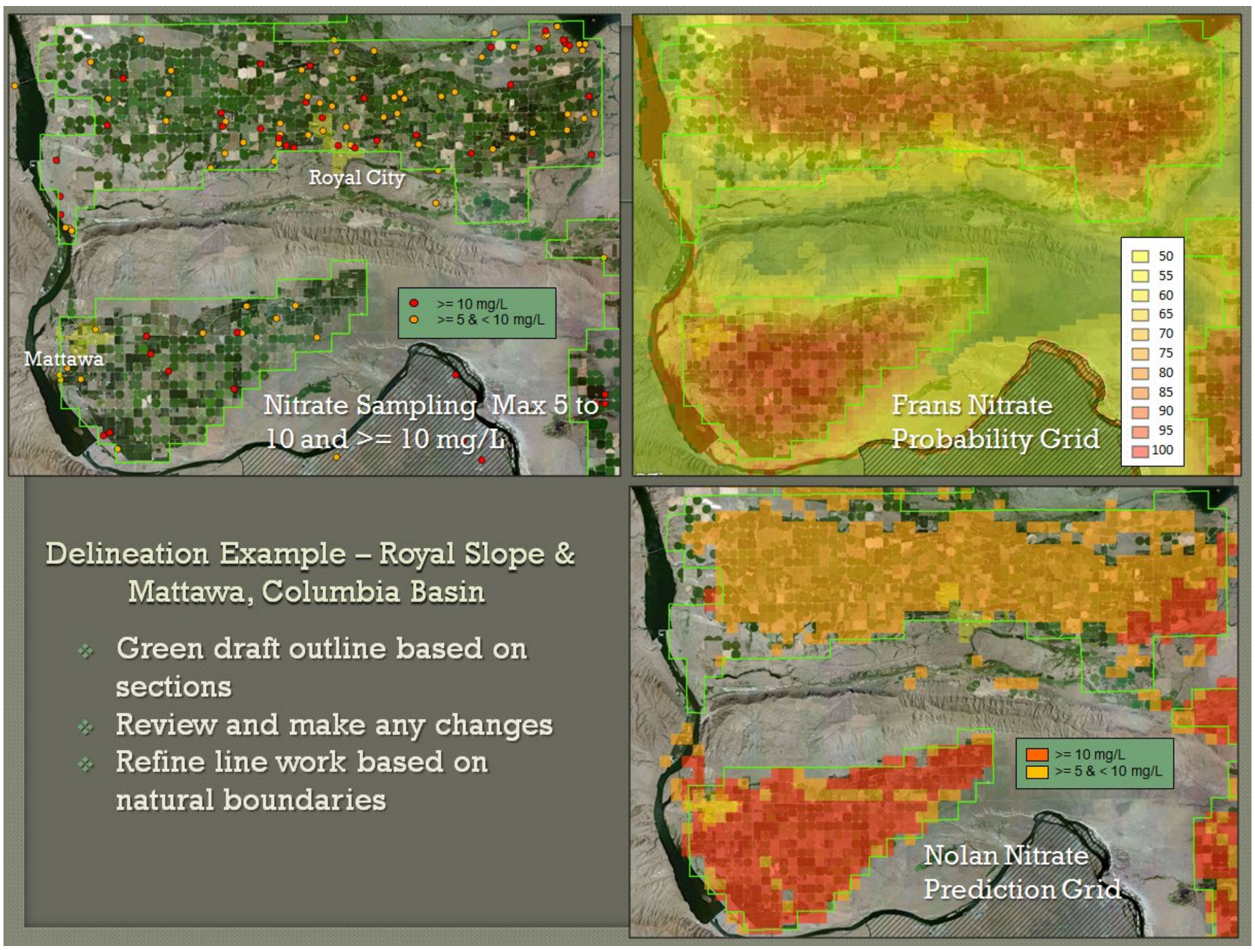


**Figure 23: Example draft delineation of the Mattawa and Royal Slope areas of the Columbia Basin, Grant County.**

# How Nitrate Priority Areas were categorized

Prioritization depends on the likelihood and severity of nitrate contamination and potential public health exposure. The *likelihood* of nitrate contamination is related to the conditions that contribute to nitrate contamination of groundwater, such as excessive soil drainage, coarse geologic materials, irrigation/precipitation, and nitrogen loading. The likelihood, or risk, of nitrate contamination of groundwater has been studied by the USGS as previously noted in this report (Frans, 2008; Nolan, 2006).

Assessing the *severity* of nitrate contamination is dependent on the availability of nitrate analytical results from sampling wells. Where there are little or no nitrate sampling results, the vulnerability of an area to nitrate contamination, based on factors discussed in this report, can be used for assessment.

Public health exposure is related to population and the use of groundwater as a drinking water source.

A table of the initial inventory of the draft Nitrate Priority Areas is included in Appendix B. It includes the number of wells sampled for nitrate, the total number of maximum nitrate results for each range, the census population (2010), crop acres, irrigated acres, number of dairies, and pounds of total N produced by dairies. It should be noted that other nitrate sources, such as other types of livestock operations, are not included. This is because we do not have a sufficient nitrate loading source inventory that includes all sources. Therefore, this inventory should be viewed in a general sense.

These numbers, along with the physical characteristics of the landscape, give us a sense of the severity and impact for each candidate area. This allows us to group these areas very generally into bins for further consideration.

The author used the inventory of each area, vulnerability factors previously discussed in this report, and the USGS risk grids to guide recommendations for categorization. The spreadsheet is attached as Appendix B. Graphs of nitrate concentrations were very useful in providing additional context.

After much consideration, the author recommends the following categories (Table 6).

**Table 6: Classification for initial draft Nitrate Priority Areas**

| Category* | Explanation |
|---|---|
| **Very High** | The top tier of areas with nitrate results over 10 mg/L |
| **High** | The next tier of areas with nitrate results over 10 mg/L |
| **Moderately High** | These areas have significant numbers of well locations where nitrate results have exceeded 10 mg/L, however there is not a clear pattern to designate subareas. These areas are not irrigated and the physical landscape typically consists of loess deposits over basalt. Characterization specific to Eastern Washington dryland areas is needed because the conditions and appropriate potential management measures are unique to this area. |
| **Moderate** | Areas that have vulnerable conditions with many well locations where nitrate results have exceeded 5 mg/L, but not many that have exceeded 10 mg/L. |
| **Moderate (urban)** | Contamination issues and pollution prevention methods over aquifers in highly urbanized areas, such as the area over the Spokane aquifer, are very different from agricultural or rural areas. |
| **Low** | Few nitrate results over 5 mg/L. |
| **Insufficient Monitoring** | Areas that have vulnerable conditions with insufficient monitoring data. |

*Colors correspond to map in figure 24.

These categorizations are an initial cut based on the data available for use in this phase of this project and are subject to change with additional project work. Table B-2 in Appendix B shows the areas in order of the number of historical nitrate sample maximums that exceed 10 mg/L as N.

# Results

Figure 24 shows a statewide view of the current draft candidate Nitrate Priority Areas. These areas and their categorization are the result of analysis by the author, using the information available statewide. These are subject to change with additional knowledge, information, and change in conditions.

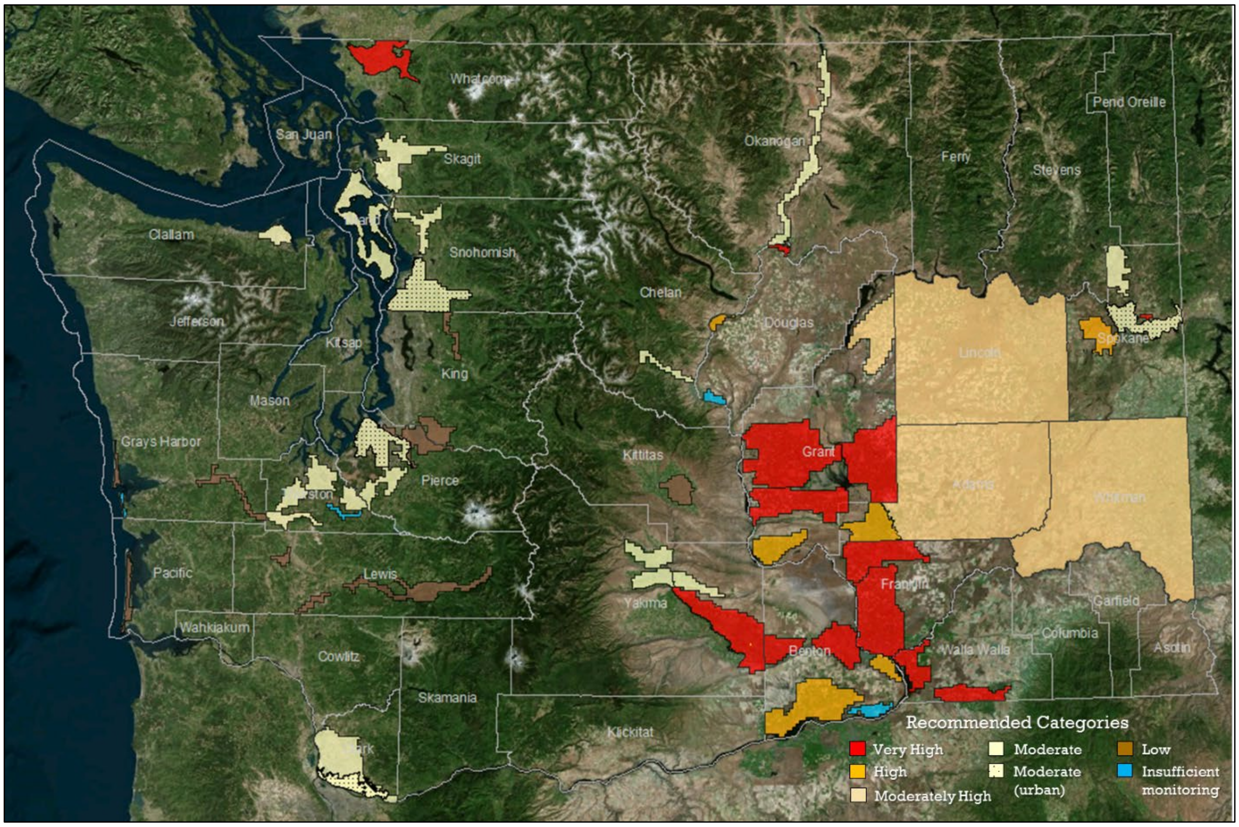


**Figure 24: Recommended Draft Nitrate Priority Areas**

## Draft Nitrate Priority Area candidates

Recommended draft nitrate priority areas are described in the following sections. The statewide inventory maps are presented in Appendix E. See previous sections of this report for maps of landscape patterns of land use, geology, soils, USGS risk maps, and nitrate sampling results that have been used in this project.

### Columbia Basin – Grant and Franklin Counties

The Columbia Basin Ground Water Management Area (GWMA) is comprised of four counties: Adams, Franklin, Grant, and Lincoln. The initial purpose of the GWMA was to address nitrate contamination of groundwater. Subsequently, hydrogeologic mapping and modeling was undertaken to address declining water levels in aquifers and groundwater supply. The website for the GWMA is at http://www.cbgwma.org/.

The geologic setting in the Columbia Basin is a vertical layering of flood basalts with interlayered sediments (interbeds). The near-surface sediment deposits overlaying the basalt sequences are composed of three major geologic types (Ringold formation, glacial flood deposits and loess).

Because of warping of the landscape by geologic forces and erosion by rivers, the Columbia Basin GWMA area has several topographically distinct areas. These include the Pasco Basin, Quincy Basin, the Royal Slope, and the Mattawa area. These are all in Grant and Franklin counties. The other counties are treated separately in a following section.

The Pasco and Quincy Basins have been the topic of a report completed for the GWMA: *Analysis of Nitrate Concentrations and Trends in the Suprabasalt Sediment Aquifers, Pasco and Quincy Basins, Washington, 2006 – 2007* (S.S. Papadopulos & Associates, 2008).

## Eastern Washington Dryland Areas

Adams County has a small portion within the Columbia Basin Irrigation Project area. This small area is a candidate for a draft Nitrate Priority Area. The rest of Adams County and Lincoln County are mainly dryland, as is Whitman County and part of Spokane County. Although the USGS risk grids indicate an elevated probability of nitrate contamination of groundwater within these areas, and there are nitrate sampling results that are above the maximum contaminant level (MCL), the evidence is distributed throughout the area and there is not a clear landscape pattern to base candidate areas on. More input is needed about the reasons for the occurrence of high nitrates in the dryland agricultural area of Washington before considering more specific boundaries within these counties for candidate draft nitrate priority areas.

## Benton County and Walla Walla County

Benton County and Walla Walla County flank the southern boundary of the Columbia Basin GWMA and are themselves within the Columbia Basin. The area of Benton County immediately east of the Lower Yakima GWMA was initially part of that GWMA. This area is a candidate draft Nitrate Priority Area. Other areas of Benton County are proposed candidate areas. The Walla Walla aquifer and the area next to the Columbia River on the west side of Walla Walla County are also proposed candidates.

## Yakima County and Kittitas County

The Lower Yakima GWMA was formed to address nitrate contamination of groundwater and is active in Yakima County. The outline of the GWMA was used as a candidate Nitrate Priority Area.

The valleys to the northwest of the Lower Yakima have indications of nitrate risk to a lesser extent.

The Kittitas agricultural area has some indications for risk of nitrates in groundwater; however, the evidence is less compelling than for other areas of the state.

## North Central Washington – Okanogan County and Chelan County

Much of North Central Washington is mountainous. Alluvial sediments in river valleys provide groundwater resources. Groundwater can also be found in fractured bedrock, sometimes in voluminous quantities, but more often in very small amounts. Candidate draft Nitrate Priority Areas in this region focuses on groundwater in alluvial deposits, since this is also where potential nitrogen loading source land use occurs.

Counties in North Central Washington include Chelan and Okanogan counties. Groundwater that is used for drinking water occurs in the alluvial valleys, as does most of the agricultural land use. Some areas that are directly adjacent to the Columbia River have highly susceptible conditions with agricultural activities. Although these are comparatively very small areas, a strategy for best management practices that applies to these conditions may be warranted in the face of the need for clean water.

## Northwestern Washington Puget Sound Lowlands

The lowland parts of Whatcom, San Juan, Skagit, Snohomish, Island, East Clallam, and Northeast Jefferson counties are part of the Puget Sound Lowlands.

The greatest known groundwater contamination by nitrates for this area is within the Sumas aquifer in Whatcom County. Much of the Sumas aquifer is overlain by coarse glacial outwash and the water table is very shallow.

The western part of the Skagit Valley is shown to be highly vulnerable by the risk maps. High water tables in the lower Skagit valley restrict natural drainage, and so engineered drainage utilities (such as tile drains) now re-route water, which affects the fate and transport of nitrate.

The Dungeness area in Clallam County and Island County, a designated Sole Source Aquifer, are also recommended as draft areas.

## Southwestern Washington Puget Sound Lowlands

The remaining counties in the southwestern Puget Sound Lowlands include: King, Pierce, Thurston, Kitsap, and Mason Counties. Areas of elevated interest include parts of the Central Pierce County Sole Source Aquifer, and the Scatter Creek aquifer area in Thurston County. These areas have vulnerable conditions, however nitrate sample results are much more often in the 5 mg/L to 10 mg/L range for the areas on the map designated as “Moderate” and there are fewer exceedences of 10 mg/L.

## Southwestern Washington

Although there are some localized areas where groundwater concentrations have exceeded the 10 mg/L nitrate as N limit in Lewis, Cowlitz, and Clark Counties, these areas are small, sparsely populated, and limited in extent or time. Other areas of the state with more egregious nitrate contamination should be addressed prior to focusing here.

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# Discussion

The draft Nitrate Priority Areas were based on a compilation from many information sources and relies on what can be inferred from these sources on a statewide basis.

The primary risk factors for nitrate contamination of groundwater are:

- How much water there is available to carry contaminants below the root zone.
- How fast water and dissolved contaminants travel to groundwater.
- Rates and quantities of nitrogen loading.
- Whether or not denitrifying conditions are present.
- Whether previous groundwater monitoring has indicated contamination.

Maps of existing groundwater quality information, geology, soils, irrigation/precipitation and land use reveal landscape patterns that show where there are higher risk conditions for groundwater contamination.

Groundwater monitoring data is the best indicator of risk but is limited in availability and costly to obtain. The other presented factors help fill in where there is little or no monitoring.

Land use and nitrogen-loading information at a statewide scale available for this project at this time is limited to agricultural land use and dairies. It is very important to consider the full spectrum of loading sources including biosolid, septic systems, and other land applications of nitrogen, as well as inorganic fertilizer use and animal manure produced by concentrated animal operations and dairies. Estimates of the percentage of nitrogen loading completed for the Sumas aquifer (Carey, 2012) indicate that the vast majority of loading (~92%) is from manure applied to crops (65%) and fertilizers (27%). On-site sewage only accounted for 1.2%.

The highest priority areas can be investigated in more detail to learn more about nitrogen loading sources, and to identify measures to prevent groundwater contamination that are appropriate for the local conditions.

It is important to understand that the counts of wells presented in the tables represent the combination of agency and well ID. The effect of this is that some individual wells are counted more than once. One major challenge is the lack of a systematic way of identifying which wells sampled by one agency have been sampled by another.

Our approach to this is to recognize the problem and work with the appropriate agencies to identify well overlap (*see Recommendations*). Areas that tend to have nitrate contamination also tend to have more sampling studies. These areas that are at higher risk may have more overlapping well counts.

Boundaries were drafted around areas that the previously mentioned factors indicate are at a higher risk of contamination, using the USGS nitrate risk grids and reports as guides. These were based on topography and the author's judgment using evidence from the aforementioned risk factors and risk grids.

The areas were then inventoried using available information in GIS for severity of nitrate contamination, population, and agricultural land use. The author used this information and professional judgment to recommend draft Nitrate Priority Area classifications. The classification of Nitrate Priority Areas is an attempt to group areas by severity of nitrate contamination, population, and landscape similarities.

The draft Nitrate Priority Area boundaries and their classification require thoughtful discussion and examination and may change as a result.

- Are there areas that should be included that are not currently designated?
- Are there areas that were included that should not be?
- Is the proposed category appropriate for each area?

# Conclusions

Results of this study support the following conclusions:

- Nitrate contamination tends to occur in Washington State under the following conditions:
  - High nitrogen loading to the land surface (such as inorganic fertilizer, animal manure or biosolids).
  - Fast travel time of water from the land surface to groundwater due to highly conductive soils and geologic materials.
  - High amounts of recharge from irrigation and/or precipitation.
  - Lack of conditions that promote denitrification.

  The distribution of these conditions can be mapped and described and/or quantified.
- Management of nitrate sources to prevent groundwater contamination should be adjusted for sensitive conditions like excessively draining soils or very hydraulically conductive geologic materials.
- In excessively drained soils with irrigation or high precipitation, soil nitrate testing is not likely to be informative, either as an indicator of overloading, or as an indicator of risk of groundwater contamination, due to the rapid removal of potential nitrate contamination from the root zone.
- There are distinct geologic settings in Washington State that have significant differences relevant to nitrate environmental fate and transport. The two following settings are common to areas with the most risk of nitrate contamination:

**Eastern Washington**

- Irrigated farming areas on excessively draining soils with highly hydraulically conductive geologic materials (like dunes and ice-age flood deposits). These include several areas within the Columbia Basin Irrigation Project Area (such as the Pasco and Quincy Basins) as well as the Lower Yakima Valley and parts of Benton County.

**Western Washington**

- Irrigated farming on glacial outwash with very high nitrogen loading and high precipitation (Whatcom County Sumas-Blaine Aquifer).

Different geomorphic settings may require different practices or levels of practices to prevent nitrate contamination of groundwater.

Discharge of pollutants to groundwaters of the state occurs when net recharge is sufficient for the downward flow of water containing dissolved contaminants. Net recharge below the root zone is not under the discharger’s control and will travel downward to groundwater under the force of gravity.

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# Recommendations

## Data management

- Scripts should be written to automate the download and processing steps.

  The process of downloading the nitrate data and processing it to use as a single data set is difficult and time-consuming. Database skills and a thorough understanding of the correct use of this data is required. A statewide database such as has been produced for this project would make a statewide dataset available to anyone without having to go through this process.

- Update the WDOH Public Water Supply data set. Use this data to indicate on the graphs when treatment or blending began. Append a longer period of record to the database so that the data could be used to assess conditions over a longer period of time.

- Use the Washington Nitrate Prioritization Database as a starting point to establish a template for sharing nitrate data, and examine options for data exchange.

  Nitrate testing data collected by Conservation Districts, universities, local jurisdictions, and others is not included in this data set, unless it was entered into Ecology's Environmental Information Management System as part of a grant requirement. Once Ecology establishes a statewide framework for nitrate data, a mechanism for adding local data should be developed.

- Determine an appropriate server location for the data. It should be moved from the current Access™ database to a data exchange location or to an agency data server. Data downloads from the future location should be enabled.

- Develop a web-based map application so that the information related to nitrate contamination of groundwater is accessible by the public.

- Link the data in the groundwater monitoring results table to the associated groundwater study reports where possible.

- Link well identifications between agency databases.

  A linking identification would make it possible to identify when a well has records in multiple databases. This would avoid the single well appearing as more than one when combining records.

  Although the well ID tag was instituted to provide a single identification that is unique for a well, not all wells are tagged. The databases have a field that can accommodate the well ID tag number, however not all well ID tag numbers are recorded in databases.

  Efforts have been made for various studies to identify wells that are the same in more than one database. When there is a well tag ID number, this is simple. When there is not, the location and well depth may be used as matching criteria.

In the absence of a well tag ID number, a working ID needs to be implemented in a lookup table that relates the agency well IDs. That way, the work of figuring out which wells are in more than one database doesn't have to be constantly redone.

# Prioritization

- Work with agency personnel and local jurisdictions on refinement of the draft Nitrate Priority Area boundaries where necessary.
- Work with the WDOH Drinking Water Section on review and refinement of the public health prioritization for Nitrate Priority Areas.
- Use this report, associated data, and GIS layers to support a risk-based approach to addressing overloading of nitrate to aquifers.

  The Ecology Dam Safety Office uses a probablistic risk-based approach to dam safety because limited resources means they cannot inspect all the dams of the state all at once. They analyze the people in harm's way and resources at risk if a dam fails and prioritize based on the results of this analysis. Implementation of nitrate source control measures could use similar principles (http://www.ecy.wa.gov/programs/wr/dams/Reports/asdso-rp.pdf).
- Request from the WDOH estimates of statewide costs incurred due to nitrate contamination of groundwater to inform state managers, policy makers, and the public of the cost of this issue. Add the cost information to the Nitrate Priority Area inventory.

# Nitrate source loading

- For this phase of the project, crop land is used as a simple indicator of nitrogen application. A more sophisticated loading estimation method should be applied within Nitrate Priority Areas.
- Loading studies could be done for three public water supply capture zones where there are excessive nitrates in groundwater. Information should include land use, time of travel, groundwater flow rate and direction, and vadose zone estimates. The USGS P-GWAVA model would be extremely useful for this type of study since it models the distribution of nitrate fate and transport in the soil profile. Particle tracking used in conjunction with P-GWAVA would explain where nitrate loading is coming from and how long it takes to get from the source to a well. The USGS proposed a project like this (Bachmann, 2013) – it would be extremely valuable for the state, if approved.
- Management of nitrate sources to prevent groundwater contamination should be adjusted for sensitive conditions like excessively draining soils and hydrologically conductive geologic materials.
- Soil nitrate tests in excessively draining areas with hydrologically conductive geologic materials will not reveal much information about nitrate loss below the root zone, as nitrate washes through quickly with water transport. Therefore other means of determining nitrogen loading should be used in these types of areas to audit nitrate losses from land application of fertilizer or manure.

# Hydrogeology information development

- The USGS and others studied large parts of the state, including the Columbia Basin, the Yakima Basin and the Puget Sound Basin. These studies have associated reports with maps and information about important hydrogeologic characteristics, such as recharge estimates, depth to groundwater, general flow direction and rates, typical yields, lithology, thickness of units, areal extent and cross-sections.

  The USGS constructed groundwater models for many areas of the state. Each of these models is constructed on information that is useful to the state when managing both water resources and water quality issues.

  A focused resourced effort needs to be made to obtain and organize important hydrogeologic information for the state that currently exists as GIS layers and associated data and information with other agencies.

- The previously mentioned organization should include an annotated bibliography of reports on geology, hydrogeology and water quality. The findings of these reports should be summarized and a link to the report online included so one can see the findings in their original context.

# Groundwater nutrient impact on surface water

- The USGS published a report *Vulnerability of Streams to Legacy Nitrate Sources* (Tesoriero, 2013). Ecology also published a report *Estimated Baseflow Characteristics of Selected Washington Rivers and Streams: Water Supply Bulletin No. 60* (Pitz, 1999) that provides the necessary input for using USGS techniques described in their report to provide a first approximation of stream vulnerability to legacy nutrients. By this means, future prioritization enhancements could include impacts to surface water from nitrate loading to groundwater (Pitz, 2014, personal communication).
- Use the Ecology Base Flow Index (Pitz, 1999) and the information in the Tesoriero Report (2013) to identify streams that gain water from groundwater where indications are that groundwater is or has been contaminated by nitrates (Pitz, 2014, personal communication) http://pubs.acs.org/doi/pdfplus/10.1021/es305026x.

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# Appendices

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# Appendix A. Selected costs for public water supply systems due to nitrate contamination of groundwater

**Table A-1: Selected costs incurred by public water supply systems due to nitrate contamination of groundwater issues.**

Excerpted from WDOH Drinking Water State Revolving Fund Data (WDOH, 2012)

| Application/Entity Name/Project | Project Description | Loan Amount/Project Amount | County/Water System Resident Population |
|---|---|---|---|
| 2002-067<br>Pasadena Park Irrigation District No. 17<br>Water System Consolidation | Extend 3,200 ft of 12" water main to connect Pleasant Prairie to Pasadena Park (Pleasant Prairie has nitrate problems). | DWSRF Loan: $228,874<br>Project Cost: $228,874 | County: Spokane<br>Resident Population: 4312 |
| 2003-064<br>Uniontown, Town of<br>New Source Well (Well No. 6) | Drill new municipal drinking water well. Current well's nitrate levels exceeds state standards. Drill new well abandon existing well. | DWSRF Loan: $247,794<br>Project Cost: $247,794 | County: Whitman<br>Resident Population: 345 |
| 2005-005<br>Beneficial Water<br>New Source for Nitrate Mitigation | Construct new well into aquifer with nitrates below MCL, including pump, controls, meters. | DWSRF Loan: $167,214<br>Project Cost: $167,214 | County: Franklin<br>Resident Population: 84 |
| 2006-014<br>Chelan County PUD #1<br>Extend water service to the community of Monitor | Extend PUD water service to the community of Monitor, whose existing water services contain coliform bacteria and nitrate that exceed the maximum contaminant level. | DWSRF Loan: $2,569,642<br>Project Cost: $6,044,200 | County: Chelan<br>Resident Population: 10,757 |
| 2006-060<br>Uniontown, Town of<br>Well #6 Completion | Complete municipal well to include pump, well house, and connection to address nitrate exceedance. | DWSRF Loan: $161,065<br>Project Cost: $237,811 | County: Whitman<br>Resident Population: 324 |
| 2007-015<br>Columbia View Water Services<br>Distribution line increase in support of new source construction for nitrate removal | Need additional engineering, design, construction permits & activities to address need to increase size of distribution system due to constructing new 1600' nitrate well (DWSRF 2006-018) | DWSRF Loan: $107,541<br>Project Cost: $107,541 | County: Walla Walla<br>Resident Population: 350 |

| Application/Entity Name/Project | Project Description | Loan Amount/Project Amount | County/Water System Resident Population |
|---|---|---|---|
| 2007-023<br>Desert Canyon Utility Company<br>Nitrate Reduction | Phase I - Construction of new nitrate facility; drill new well(s); Phase II - installation 6000 irrigation line; 5000 LF transmission line from nitrate facility; service meters. | DWSRF Loan: $423,695<br>Project Cost: $423,695 | County: Douglas<br>Resident Population: 43 |
| 2007-051<br>Rathbone Park Water Association<br>North Whatcom County Nitrates Feasibility Study | Mitigation for nitrates levels in exceedance of the MCL; install nitrates treatment system or install connection to the City Lynden source | DWSRF Loan: $540,350<br>Project Cost: $540,350 | County: Whatcom<br>Resident Population: 240 |
| 2007-052<br>Royal City, City of<br>Royal City Well No. 2 | Remove existing well due to high level of nitrate levels; install new well and generator | DWSRF Loan: $1,447,330<br>Project Cost: $1,447,330 | County: Grant<br>Resident Population: 1800 |
| 2011-025<br>Greater Bar Water District<br>Greater Bar Water District Compliance and Consolidation Project | Install service meters, source meters, new reservoir, distribution piping and security features (nitrate issues) | Project Cost: $2,722,800 | County: Douglas<br>Resident Population: 153 |

# Appendix B:  Nitrate Priority Area Candidate Inventory Table

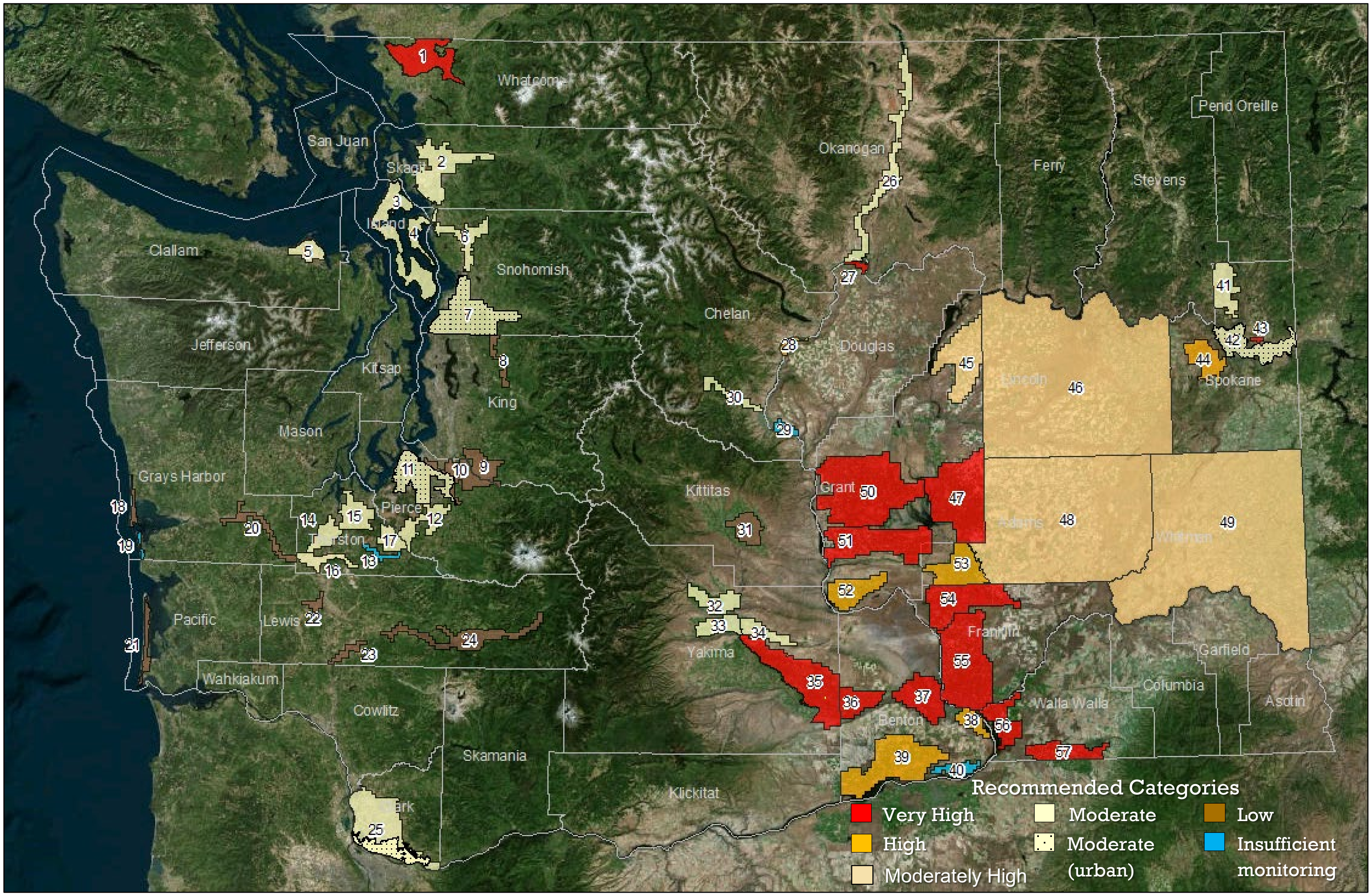


**Figure 25:  Recommended Nitrate Priority Areas with NPAC ID (Table B-2)**

**Table B-1: Key to Bin Category**

| Priority Bin | | Description |
|---|---|---|
| 1 | Very High | Top tier by number of well locations with maximum nitrate results over 10 mg/L |
| 2 | High | Next tier by number of well locations with maximum nitrate results over 10 mg/L |
| 3 | Moderately High | Lincoln, Adams, Whitman and part of Grant County outside of the Columbia Irrigation Project |
| 4 | Moderate | Vulnerable conditions, many results over 5 mg/L but few over 10 mg/L. |
| 5 | Moderate (Urban) | |
| 6 | Low | Few nitrate results over 5 mg/L |
| 7 | Insufficient Data | Vulnerable conditions, little monitoring |

The inventory of population, dairies, and cropland is a general guide and not a substitute for detailed inventories of nitrogen sources for each area. Other nitrogen sources (feedlots, swine, poultry, horses, septic systems, and biosolids) are not reflected in this initial inventory. The count of well locations may include wells that were sampled by more than one agency and so maybe over-counted. Only data available from USGS, Washington Dept. of Health, and the Washington Dept. of Ecology were used – Local jurisdictions may have sampling data not reflected in this report.

**Table B-2: Nitrate Priority Area Candidate Inventory Table – Nitrate Sample Result Counts**

Number of Well Locations in the database withMaximum Nitrate in these ranges, mg/L as N

| ID | Bin | Name | County | >= 10 | >= 5 and < 10 | >= 5 | >= 3 and < 5 | < 3 | Total | PCT Max >= 10 | PCT Max >= 5 | Total Number of Nitrate Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Sumas-Blaine | Whatcom | 188 | 123 | 311 | 90 | 334 | 735 | 25.6 | 42.3 | 2440 |
| 2 | 4 | Skagit River Valley | Skagit | 2 | 7 | 9 | 3 | 47 | 59 | 3.4 | 15.3 | 148 |
| 3 | 4 | Whidbey Island | Island | 11 | 38 | 49 | 62 | 689 | 800 | 1.4 | 6.1 | 4032 |
| 4 | 4 | Camano Island | Island | 0 | 15 | 15 | 16 | 246 | 277 | 0.0 | 5.4 | 1716 |
| 5 | 4 | Dungeness | Clallam | 4 | 21 | 25 | 36 | 317 | 378 | 1.1 | 6.6 | 1246 |
| 6 | 4 | Marysville Trough | Snohomish | 5 | 11 | 16 | 10 | 65 | 91 | 5.5 | 17.6 | 333 |
| 7 | 5 | Snohomish South | Snohomish | 3 | 7 | 10 | 10 | 108 | 128 | 2.3 | 7.8 | 346 |
| 8 | 6 | King North Valley | King | 0 | 1 | 1 | 1 | 34 | 36 | 0.0 | 2.8 | 120 |
| 9 | 6 | Enumclaw Plateau | King | 2 | 5 | 7 | 7 | 108 | 122 | 1.6 | 5.7 | 344 |
| 10 | 6 | Pierce North | Pierce | 3 | 8 | 11 | 9 | 186 | 206 | 1.5 | 5.3 | 904 |
| 11 | 5 | Central Pierce County Sole Source Aquifer Urban | Pierce | 3 | 26 | 29 | 62 | 212 | 303 | 1.0 | 9.6 | 2019 |
| 12 | 4 | Central Pierce County Sole Source Aquifer Rural | Pierce | 4 | 25 | 29 | 38 | 239 | 306 | 1.3 | 9.5 | 1424 |
| 13 | 7 | Deschutes Ruth Prairie | Thurston | 2 | 2 | 4 | 1 | 16 | 21 | 9.5 | 19.0 | 95 |
| 14 | 4 | Black River | Thurston | 1 | 13 | 14 | 21 | 123 | 158 | 0.6 | 8.9 | 764 |
| 15 | 4 | Thurston Central | Thurston | 1 | 27 | 28 | 50 | 264 | 342 | 0.3 | 8.2 | 1476 |
| 16 | 4 | Scatter Creek | Thurston | 3 | 43 | 46 | 74 | 102 | 222 | 1.4 | 20.7 | 1340 |
| 17 | 4 | Yelm Smith Prairie | Thurston | 3 | 22 | 25 | 28 | 54 | 107 | 2.8 | 23.4 | 621 |
| 18 | 6 | Ocean Shores | Grays Harbor | 0 | 0 | 0 | 0 | 54 | 54 | 0.0 | 0.0 | 324 |
| 19 | 7 | Westport | Grays Harbor | 0 | 0 | 0 | 0 | 14 | 14 | 0.0 | 0.0 | 65 |
| 20 | 6 | Chehalis River Valley | Grays Harbor | 0 | 3 | 3 | 5 | 33 | 41 | 0.0 | 7.3 | 168 |
| 21 | 6 | Long Beach Peninsula | Pacific | 1 | 4 | 5 | 7 | 76 | 88 | 1.1 | 5.7 | 255 |
| 22 | 6 | Chehalis Adna | Lewis | 1 | 0 | 1 | 1 | 24 | 26 | 3.8 | 3.8 | 80 |

| ID | Bin | Name | County | >= 10 | >= 5 and < 10 | >= 5 | >= 3 and < 5 | < 3 | Total | PCT Max >= 10 | PCT Max >= 5 | Total Number of Nitrate Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 6 | Cowlitz River Valley Toledo | Lewis | 0 | 0 | 0 | 1 | 29 | 30 | 0.0 | 0.0 | 147 |
| 24 | 6 | Cowlitz River Valley Mossyrock | Lewis | 1 | 6 | 7 | 6 | 112 | 125 | 0.8 | 5.6 | 674 |
| 25 | 4 | Troutdale | Clark | 1 | 14 | 15 | 38 | 298 | 351 | 0.3 | 4.3 | 1641 |
| 26 | 4 | Okanogan River Valley | Okanogan | 5 | 10 | 15 | 13 | 119 | 147 | 3.4 | 10.2 | 637 |
| 27 | 1 | Douglas Chief Joseph | Douglas | 6 | 5 | 11 | 1 | 1 | 13 | 46.2 | 84.6 | 88 |
| 28 | 2 | Columbia River NE of Waterville | Douglas | 9 | 10 | 19 | 4 | 13 | 36 | 25.0 | 52.8 | 399 |
| 29 | 7 | E Wenatchee Rock Island | Douglas | 4 | 7 | 11 | 3 | 9 | 23 | 17.4 | 47.8 | 119 |
| 30 | 4 | Wenatchee River Valley | Chelan | 5 | 20 | 25 | 38 | 65 | 128 | 3.9 | 19.5 | 523 |
| 31 | 6 | Kittitas Valley | Kittitas | 0 | 4 | 4 | 5 | 42 | 51 | 0.0 | 7.8 | 187 |
| 32 | 4 | Upper Yakima Valley Selah | Yakima | 1 | 57 | 58 | 57 | 119 | 234 | 0.4 | 24.8 | 807 |
| 33 | 4 | Upper Yakima Valley West | Yakima | 4 | 14 | 18 | 32 | 78 | 128 | 3.1 | 14.1 | 568 |
| 34 | 4 | Upper Yakima Valley Moxee | Yakima | 5 | 11 | 16 | 15 | 71 | 102 | 4.9 | 15.7 | 425 |
| 35 | 1 | Lower Yakima Valley | Yakima | 24 | 38 | 62 | 27 | 119 | 208 | 11.5 | 29.8 | 1017 |
| 36 | 1 | Benton West | Benton | 18 | 33 | 51 | 11 | 32 | 94 | 19.1 | 54.3 | 564 |
| 37 | 1 | Benton East | Benton | 33 | 51 | 84 | 36 | 145 | 265 | 12.5 | 31.7 | 857 |
| 38 | 2 | Benton Kennewick Highlands | Benton | 16 | 45 | 61 | 32 | 80 | 173 | 9.2 | 35.3 | 509 |
| 39 | 2 | Benton South | Benton | 16 | 4 | 20 | 4 | 17 | 41 | 39.0 | 48.8 | 391 |
| 40 | 7 | Benton Southeast | Benton | 1 | 0 | 1 | 0 | 1 | 2 | 50.0 | 50.0 | 62 |
| 41 | 4 | Spokane North | Spokane | 2 | 19 | 21 | 4 | 9 | 34 | 5.9 | 61.8 | 242 |
| 42 | 5 | Spokane Aquifer | Spokane | 4 | 26 | 30 | 45 | 275 | 350 | 1.1 | 8.6 | 2353 |
| 43 | 1 | Spokane External North of Spokane Aquifer | Spokane | 5 | 8 | 13 | 0 | 6 | 19 | 26.3 | 68.4 | 78 |
| 44 | 2 | Spokane West Airway Heights | Spokane | 12 | 21 | 33 | 25 | 18 | 76 | 15.8 | 43.4 | 661 |
| 45 | 3 | East of Banks Lake | Grant | 12 | 7 | 19 | 4 | 6 | 29 | 41.4 | 65.5 | 82 |
| 46 | 3 | Lincoln County | Lincoln | 12 | 20 | 32 | 21 | 99 | 152 | 7.9 | 21.1 | 722 |

| ID | Bin | Name | County | >= 10 | >= 5 and < 10 | >= 5 | >= 3 and < 5 | < 3 | Total | PCT Max >= 10 | PCT Max >= 5 | Total Number of Nitrate Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47 | 1 | East of Moses Lake | Grant | 35 | 71 | 106 | 76 | 94 | 276 | 12.7 | 38.4 | 1326 |
| 48 | 3 | Adams Dryland | Adams | 39 | 28 | 67 | 15 | 117 | 199 | 19.6 | 33.7 | 618 |
| 49 | 3 | Whitman County | Whitman | 24 | 42 | 66 | 32 | 148 | 246 | 9.8 | 26.8 | 1190 |
| 50 | 1 | Quincy Basin | Grant | 31 | 82 | 113 | 57 | 49 | 219 | 14.2 | 51.6 | 973 |
| 51 | 1 | Royal Slope | Grant | 29 | 62 | 91 | 14 | 30 | 135 | 21.5 | 67.4 | 770 |
| 52 | 2 | Mattawa | Grant | 8 | 13 | 21 | 5 | 31 | 57 | 14.0 | 36.8 | 216 |
| 53 | 2 | Adams Irrigated | Adams | 12 | 28 | 40 | 10 | 59 | 109 | 11.0 | 36.7 | 621 |
| 54 | 1 | Franklin Northwest | Franklin | 32 | 17 | 49 | 17 | 32 | 98 | 32.7 | 50.0 | 422 |
| 55 | 1 | Pasco Basin | Franklin | 219 | 129 | 348 | 35 | 120 | 503 | 43.5 | 69.2 | 1843 |
| 56 | 1 | Walla Walla West | Walla Walla | 43 | 16 | 59 | 6 | 20 | 85 | 50.6 | 69.4 | 1212 |
| 57 | 1 | Walla Walla | Walla Walla | 18 | 24 | 42 | 21 | 61 | 124 | 14.5 | 33.9 | 441 |

**Table B-3: Nitrate Priority Area Candidate Inventory Table – Population**

| ID | Bin | Name | County | Population 2010 | Sq Miles | Population per Sq Mi |
|---|---|---|---|---|---|---|
| 1 | 1 | Sumas-Blaine | Whatcom | 39058 | 149.8 | 260.7 |
| 2 | 4 | Skagit River Valley | Skagit | 42761 | 166.5 | 256.8 |
| 3 | 4 | Whidbey Island | Island | 62289 | 168.7 | 369.3 |
| 4 | 4 | Camano Island | Island | 15661 | 39.2 | 399.5 |
| 5 | 4 | Dungeness | Clallam | 21335 | 42.4 | 503.3 |
| 6 | 4 | Marysville Trough | Snohomish | 69813 | 77.4 | 901.7 |
| 7 | 5 | Snohomish South | Snohomish | 448667 | 208.0 | 2,157.5 |
| 8 | 6 | King North Valley | King | 8344 | 29.2 | 286.2 |
| 9 | 6 | Enumclaw Plateau | King | 22564 | 61.1 | 369.3 |
| 10 | 6 | Pierce North | Pierce | 83059 | 78.0 | 1,065.2 |
| 11 | 5 | Central Pierce County Sole Source Aquifer Urban | Pierce | 428815 | 140.5 | 3,053.0 |
| 12 | 4 | Central Pierce County Sole Source Aquifer Rural | Pierce | 29771 | 72.7 | 409.4 |
| 13 | 7 | Deschutes Ruth Prairie | Thurston | 1935 | 16.4 | 117.6 |
| 14 | 4 | Black River | Thurston | 12912 | 50.0 | 258.1 |
| 15 | 4 | Thurston Central | Thurston | 112229 | 75.3 | 1,490.2 |
| 16 | 4 | Scatter Creek | Thurston | 13278 | 44.5 | 298.2 |
| 17 | 4 | Yelm Smith Prairie | Thurston | 15830 | 43.0 | 367.8 |
| 18 | 6 | Ocean Shores | Grays Harbor | 5926 | 14.7 | 403.5 |
| 19 | 7 | Westport | Grays Harbor | 3163 | 6.6 | 477.5 |
| 20 | 6 | Chehalis River Valley | Grays Harbor | 4884 | 50.0 | 97.7 |
| 21 | 6 | Long Beach Peninsula | Pacific | 6870 | 31.8 | 216.1 |
| 22 | 6 | Chehalis Adna | Lewis | 1379 | 15.7 | 87.7 |
| 23 | 6 | Cowlitz River Valley Toledo | Lewis | 2457 | 22.9 | 107.4 |
| 24 | 6 | Cowlitz River Valley Mossyrock | Lewis | 5437 | 145.8 | 37.3 |
| 25 | 4 | Troutdale | Clark | 381276 | 267.4 | 1,426.1 |
| 26 | 4 | Okanogan River Valley | Okanogan | 21646 | 169.9 | 127.4 |

| ID | Bin | Name | County | Population 2010 | Sq Miles | Population per Sq Mi |
|---|---|---|---|---|---|---|
| 27 | 1 | Douglas Chief Joseph | Douglas | 820 | 11.0 | 74.5 |
| 28 | 2 | Columbia River NE of Waterville | Douglas | 1094 | 16.7 | 65.6 |
| 29 | 7 | E Wenatchee Rock Island | Douglas | 8717 | 19.2 | 454.2 |
| 30 | 4 | Wenatchee River Valley | Chelan | 13558 | 38.8 | 349.5 |
| 31 | 6 | Kittitas Valley | Kittitas | 19631 | 64.1 | 306.2 |
| 32 | 4 | Upper Yakima Valley Selah | Yakima | 25167 | 72.9 | 345.4 |
| 33 | 4 | Upper Yakima Valley West | Yakima | 104252 | 60.1 | 1,733.8 |
| 34 | 4 | Upper Yakima Valley Moxee | Yakima | 10566 | 56.4 | 187.5 |
| 35 | 1 | Lower Yakima Valley | Yakima | 55565 | 273.7 | 203.0 |
| 36 | 1 | Benton West | Benton | 10978 | 80.0 | 137.3 |
| 37 | 1 | Benton East | Benton | 74893 | 130.1 | 575.8 |
| 38 | 2 | Benton Kennewick Highlands | Benton | 49029 | 44.1 | 1,111.6 |
| 39 | 2 | Benton South | Benton | 564 | 278.0 | 2.0 |
| 40 | 7 | Benton Southeast | Benton | 21 | 40.5 | 0.5 |
| 41 | 4 | Spokane North | Spokane | 11059 | 86.3 | 128.1 |
| 42 | 5 | Spokane Aquifer | Spokane | 275837 | 129.8 | 2,124.4 |
| 43 | 1 | Spokane External North of Spokane Aquifer | Spokane | 627 | 4.8 | 131.8 |
| 44 | 2 | Spokane West Airway Heights | Spokane | 17818 | 85.9 | 207.3 |
| 45 | 3 | East of Banks Lake | Grant | 777 | 197.7 | 3.9 |
| 46 | 3 | Lincoln County | Lincoln | 10570 | 2,339.6 | 4.5 |
| 47 | 3 | East of Moses Lake | Grant | 38566 | 331.4 | 116.4 |
| 48 | 3 | Adams Dryland | Adams | 4303 | 1,732.2 | 2.5 |
| 49 | 3 | Whitman County | Whitman | 44776 | 2,177.3 | 20.6 |
| 50 | 1 | Quincy Basin | Grant | 15511 | 458.0 | 33.9 |
| 51 | 1 | Royal Slope | Grant | 6158 | 247.9 | 24.8 |
| 52 | 2 | Mattawa | Grant | 7870 | 104.5 | 75.3 |
| 53 | 2 | Adams Irrigated | Adams | 14059 | 130.9 | 107.4 |

| ID | Bin | Name | County | Population 2010 | Sq Miles | Population per Sq Mi |
|---|---|---|---|---|---|---|
| 54 | 1 | Franklin Northwest | Franklin | 4407 | 195.5 | 22.5 |
| 55 | 1 | Pasco Basin | Franklin | 69742 | 351.7 | 198.3 |
| 56 | 1 | Walla Walla West | Walla Walla | 3739 | 92.7 | 40.3 |
| 57 | 1 | Walla Walla | Walla Walla | 13046 | 94.0 | 138.8 |

**Table B-4: Nitrate Priority Area Candidate Inventory Table – Crop and Irrigated Acreage**

| ID | Bin | Name | County | Total Crop Acres | Irrigated Acres | Un-Irrigated Acres | Total Acres | PCT Irrigated |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | Sumas-Blaine | Whatcom | 44,603.0 | 32,495 | 12,108 | 95,876 | 33.9 |
| 2 | 4 | Skagit River Valley | Skagit | 56,927.6 | 32,368 | 24,559 | 106,554 | 30.4 |
| 3 | 4 | Whidbey Island | Island | 16,316.4 | 402 | 15,914 | 107,944 | 0.4 |
| 4 | 4 | Camano Island | Island | 2,754.2 | 557 | 2,197 | 25,092 | 2.2 |
| 5 | 4 | Dungeness | Clallam | 10,982.0 | 2,383 | 8,599 | 27,131 | 8.8 |
| 6 | 4 | Marysville Trough | Snohomish | 12,429.7 | 5,060 | 7,370 | 49,552 | 10.2 |
| 7 | 5 | Snohomish South | Snohomish | 13,237.3 | 4,211 | 9,027 | 133,091 | 3.2 |
| 8 | 6 | King North Valley | King | 5,911.2 | 855 | 5,056 | 18,656 | 4.6 |
| 9 | 6 | Enumclaw Plateau | King | 10,999.4 | 257 | 10,743 | 39,105 | 0.7 |
| 10 | 6 | Pierce North | Pierce | 2,805.4 | 1,274 | 1,531 | 49,904 | 2.6 |
| 11 | 5 | Central Pierce County Sole Source Aquifer Urban | Pierce | 2,645.8 | 1,579 | 1,067 | 89,893 | 1.8 |
| 12 | 4 | Central Pierce County Sole Source Aquifer Rural | Pierce | 1,724.4 | 416 | 1,309 | 46,545 | 0.9 |
| 13 | 7 | Deschutes Ruth Prairie | Thurston | 2,525.4 | 82 | 2,444 | 10,527 | 0.8 |
| 14 | 4 | Black River | Thurston | 2,421.0 | 1,184 | 1,237 | 32,013 | 3.7 |
| 15 | 4 | Thurston Central | Thurston | 2,869.7 | 863 | 2,006 | 48,199 | 1.8 |
| 16 | 4 | Scatter Creek | Thurston | 4,757.8 | 392 | 4,365 | 28,493 | 1.4 |
| 17 | 4 | Yelm Smith Prairie | Thurston | 1,753.4 | 106 | 1,648 | 27,548 | 0.4 |

| ID | Bin | Name | County | Total Crop Acres | Irrigated Acres | Un-Irrigated Acres | Total Acres | PCT Irrigated |
|---|---|---|---|---|---|---|---|---|
| 18 | 6 | Ocean Shores | Grays Harbor | 17,809.8 | 0 | 17,810 | 9,399 | 0.0 |
| 19 | 7 | Westport | Grays Harbor | 5,551.7 | 263 | 5,289 | 4,239 | 6.2 |
| 20 | 6 | Chehalis River Valley | Grays Harbor | 11,313.0 | 2,577 | 8,736 | 31,981 | 8.1 |
| 21 | 6 | Long Beach Peninsula | Pacific | 7,252.5 | 422 | 6,830 | 20,350 | 2.1 |
| 22 | 6 | Chehalis Adna | Lewis | 2,471.4 | 1,374 | 1,098 | 10,062 | 13.7 |
| 23 | 6 | Cowlitz River Valley Toledo | Lewis | 2,536.1 | 726 | 1,810 | 14,639 | 5.0 |
| 24 | 6 | Cowlitz River Valley Mossyrock | Lewis | 3,659.0 | 569 | 3,090 | 93,312 | 0.6 |
| 25 | 4 | Troutdale | Clark | 10,758.8 | 1,659 | 9,100 | 171,112 | 1.0 |
| 26 | 4 | Okanogan River Valley | Okanogan | 25,714.2 | 25,014 | 700 | 108,722 | 23.0 |
| 27 | 1 | Douglas Chief Joseph | Douglas | 1,138.7 | 1,064 | 74 | 7,047 | 15.1 |
| 28 | 2 | Columbia River NE of Waterville | Douglas | 4,415.9 | 4,409 | 7 | 10,681 | 41.3 |
| 29 | 7 | E Wenatchee Rock Island | Douglas | 3,878.8 | 3,829 | 50 | 12,282 | 31.2 |
| 30 | 4 | Wenatchee River Valley | Chelan | 6,630.3 | 6,541 | 90 | 24,827 | 26.3 |
| 31 | 6 | Kittitas Valley | Kittitas | 25,358.5 | 25,044 | 314 | 41,027 | 61.0 |
| 32 | 4 | Upper Yakima Valley Selah | Yakima | 15,954.4 | 15,878 | 76 | 46,635 | 34.0 |
| 33 | 4 | Upper Yakima Valley West | Yakima | 8,147.1 | 8,128 | 20 | 38,483 | 21.1 |
| 34 | 4 | Upper Yakima Valley Moxee | Yakima | 16,088.7 | 15,907 | 182 | 36,075 | 44.1 |
| 35 | 1 | Lower Yakima Valley | Yakima | 91,814.8 | 88,954 | 2,861 | 175,152 | 50.8 |
| 36 | 1 | Benton West | Benton | 31,205.7 | 31,035 | 171 | 51,189 | 60.6 |
| 37 | 1 | Benton East | Benton | 21,152.5 | 20,652 | 501 | 83,245 | 24.8 |
| 38 | 2 | Benton Kennewick Highlands | Benton | 3,760.7 | 3,310 | 451 | 28,228 | 11.7 |
| 39 | 2 | Benton South | Benton | 117,126.4 | 106,049 | 11,077 | 177,926 | 59.6 |
| 40 | 7 | Benton Southeast | Benton | 15,620.9 | 15,621 | 0 | 25,951 | 60.2 |
| 41 | 4 | Spokane North | Spokane | 16,415.1 | 1,427 | 14,988 | 55,234 | 2.6 |
| 42 | 5 | Spokane Aquifer | Spokane | 3,631.3 | 1,941 | 1,690 | 83,100 | 2.3 |
| 43 | 1 | Spokane External North of Spokane Aquifer | Spokane | 966.8 | 1 | 966 | 3,045 | 0.0 |

| ID | Bin | Name | County | Total Crop Acres | Irrigated Acres | Un-Irrigated Acres | Total Acres | PCT Irrigated |
|---|---|---|---|---|---|---|---|---|
| 44 | 2 | Spokane West Airway Heights | Spokane | 7,790.7 | 140 | 7,651 | 55,008 | 0.3 |
| 45 | 3 | East of Banks Lake | Grant | 98,166.6 | 6,085 | 92,081 | 126,535 | 4.8 |
| 46 | 3 | Lincoln County | Lincoln | 682,661.6 | 49,650 | 633,012 | 1,497,340 | 3.3 |
| 47 | 3 | East of Moses Lake | Grant | 140,233.0 | 113,865 | 26,368 | 212,093 | 53.7 |
| 48 | 3 | Adams Dryland | Adams | 578,473.6 | 105,888 | 472,586 | 1,108,580 | 9.6 |
| 49 | 3 | Whitman County | Whitman | 840,771.1 | 5,479 | 835,292 | 1,393,495 | 0.4 |
| 50 | 1 | Quincy Basin | Grant | 187,007.2 | 185,707 | 1,301 | 293,150 | 63.3 |
| 51 | 1 | Royal Slope | Grant | 99,685.2 | 99,238 | 447 | 158,635 | 62.6 |
| 52 | 2 | Mattawa | Grant | 47,025.2 | 47,020 | 6 | 66,883 | 70.3 |
| 53 | 2 | Adams Irrigated | Adams | 56,066.9 | 53,986 | 2,080 | 83,758 | 64.5 |
| 54 | 1 | Franklin Northwest | Franklin | 69,548.9 | 66,060 | 3,489 | 125,114 | 52.8 |
| 55 | 1 | Pasco Basin | Franklin | 146,317.1 | 145,989 | 328 | 225,112 | 64.9 |
| 56 | 1 | Walla Walla West | Walla Walla | 36,017.4 | 35,422 | 595 | 59,312 | 59.7 |
| 57 | 1 | Walla Walla | Walla Walla | 42,093.4 | 35,045 | 7,049 | 60,172 | 58.2 |

**Table B-5: Nitrate Priority Area Candidate Inventory Table – Dairies**

NPAC = Nitrate Priority Area Candidate

| ID | Bin | Name | County | Total Dairies | Range reported if only one dairy in the NPAC (WAC 16-06-210) Total Dairy N Produced Tons | Dairy Total Owned/Rented Acres More acreage may be available for use than is reported here |
|---|---|---|---|---|---|---|
| 1 | 1 | Sumas-Blaine | Whatcom | 91 | 6,176 | 27297 |
| 2 | 4 | Skagit River Valley | Skagit | 28 | 2,025 | 10827 |
| 3 | 4 | Whidbey Island | Island | 0 | 0 | 0 |
| 4 | 4 | Camano Island | Island | 1 | 1 to 5,256 | 301 to 550 |
| 5 | 4 | Dungeness | Clallam | 2 | 101 | 563 |
| 6 | 4 | Marysville Trough | Snohomish | 13 | 814 | 5002 |
| 7 | 5 | Snohomish South | Snohomish | 9 | 754 | 3603 |
| 8 | 6 | King North Valley | King | 5 | 247 | 2075 |
| 9 | 6 | Enumclaw Plateau | King | 24 | 1,195 | 5581 |
| 10 | 6 | Pierce North | Pierce | 2 | 169 | 1070 |
| 11 | 5 | Central Pierce County Sole Source Aquifer Urban | Pierce | 0 | 0 | 0 |
| 12 | 4 | Central Pierce County Sole Source Aquifer Rural | Pierce | 0 | 0 | 0 |
| 13 | 7 | Deschutes Ruth Prairie | Thurston | 1 | 1 to 5,256 | 901 to 1,300 |
| 14 | 4 | Black River | Thurston | 2 | 372 | 1660 |
| 15 | 4 | Thurston Central | Thurston | 0 | 0 | 0 |
| 16 | 4 | Scatter Creek | Thurston | 6 | 319 | 2024.5 |
| 17 | 4 | Yelm Smith Prairie | Thurston | 0 | 0 | 0 |
| 18 | 6 | Ocean Shores | Grays Harbor | 0 | 0 | 0 |
| 19 | 7 | Westport | Grays Harbor | 0 | 0 | 0 |
| 20 | 6 | Chehalis River Valley | Grays Harbor | 7 | 205 | 2529 |

NPAC = Nitrate Priority Area Candidate

| ID | Bin | Name | County | Total Dairies | Total Dairy N Produced Tons | Dairy Total Owned/Rented Acres More acreage may be available for use than is reported here |
|---|---|---|---|---|---|---|
| | | | | | Range reported if only one dairy in the NPAC (WAC 16-06-210) | |
| 21 | 6 | Long Beach Peninsula | Pacific | 0 | 0 | 0 |
| 22 | 6 | Chehalis Adna | Lewis | 5 | 177 | 1792 |
| 23 | 6 | Cowlitz River Valley Toledo | Lewis | 0 | 0 | 0 |
| 24 | 6 | Cowlitz River Valley Mossyrock | Lewis | 4 | 47 | 1109 |
| 25 | 4 | Troutdale | Clark | 5 | 534 | 4882 |
| 26 | 4 | Okanogan River Valley | Okanogan | 0 | 0 | 0 |
| 27 | 1 | Douglas Chief Joseph | Douglas | 0 | 0 | 0 |
| 28 | 2 | Columbia River NE of Waterville | Douglas | 0 | 0 | 0 |
| 29 | 7 | E Wenatchee Rock Island | Douglas | 0 | 0 | 0 |
| 30 | 4 | Wenatchee River Valley | Chelan | 1 | 1 to 5,256 | 0 to 25 |
| 31 | 6 | Kittitas Valley | Kittitas | 0 | 0 | 0 |
| 32 | 4 | Upper Yakima Valley Selah | Yakima | 0 | 0 | 0 |
| 33 | 4 | Upper Yakima Valley West | Yakima | 0 | 0 | 0 |
| 34 | 4 | Upper Yakima Valley Moxee | Yakima | 1 | 1 to 5,256 | 1,801 to 2,500 |
| 35 | 1 | Lower Yakima Valley | Yakima | 60 | 17,814 | 33458.6 |
| 36 | 1 | Benton West | Benton | 3 | 566 | 689 |
| 37 | 1 | Benton East | Benton | 0 | 0 | 0 |
| 38 | 2 | Benton Kennewick Highlands | Benton | 0 | 0 | 0 |
| 39 | 2 | Benton South | Benton | 1 | 1 to 5,256 | 3,201 to 4,000 |
| 40 | 7 | Benton Southeast | Benton | 0 | 0 | 0 |
| 41 | 4 | Spokane North | Spokane | 4 | 88 | 1170 |

NPAC = Nitrate Priority Area Candidate

| ID | Bin | Name | County | Total Dairies | Range reported if only one dairy in the NPAC (WAC 16-06-210)<br>Total Dairy N Produced Tons | Dairy Total Owned/Rented Acres More acreage may be available for use than is reported here |
|---|---|---|---|---|---|---|
| 42 | 5 | Spokane Aquifer | Spokane | 0 | 0 | 0 |
| 43 | 1 | Spokane External North of Spokane Aquifer | Spokane | 0 | 0 | 0 |
| 44 | 2 | Spokane West Airway Heights | Spokane | 1 | 1 to 5,256 | 901 to 1,300 |
| 45 | 3 | East of Banks Lake | Grant | 0 | 0 | 0 |
| 46 | 3 | Lincoln County | Lincoln | 1 | 1 to 5,256 | 551 to 900 |
| 47 | 3 | East of Moses Lake | Grant | 6 | 1,373 | 14350 |
| 48 | 3 | Adams Dryland | Adams | 1 | 1 to 5,256 | 2,501 to 3,200 |
| 49 | 3 | Whitman County | Whitman | 1 | 1 to 5,256 | 551 to 900 |
| 50 | 1 | Quincy Basin | Grant | 9 | 2,090 | 4107 |
| 51 | 1 | Royal Slope | Grant | 4 | 1,660 | 3542 |
| 52 | 2 | Mattawa | Grant | 1 | 1 to 5,256 | 121 to 300 |
| 53 | 2 | Adams Irrigated | Adams | 4 | 874 | 3430 |
| 54 | 1 | Franklin Northwest | Franklin | 7 | 1,380 | 3686 |
| 55 | 1 | Pasco Basin | Franklin | 5 | 2,562 | 7715 |
| 56 | 1 | Walla Walla West | Walla Walla | 0 | 0 | 0 |
| 57 | 1 | Walla Walla | Walla Walla | 0 | 0 | 0 |

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## Appendix C: Top ten nitrate priority area candidates by count of wells with historical nitrate maximum greater than or equal to 10 mg/L as N

**Table C-1: Key to Bin Category**

| Priority Bin | | Description |
|---|---|---|
| 1 | Very High | Top tier by number of well locations with maximum nitrate results over 10 mg/L |
| 2 | High | Next tier by number of well locations with maximum nitrate results over 10 mg/L |
| 3 | Moderately High | Lincoln, Adams, Whitman and part of Grant County outside of the Columbia Irrigation Project |
| 4 | Moderate | Vulnerable conditions, many results over 5 mg/L but few over 10 mg/L. |
| 5 | Moderate (Urban) | |
| 6 | Low | Few nitrate results over 5 mg/L |
| 7 | Insufficient Data | Vulnerable conditions, little monitoring |

**Table C-2: Top ten nitrate priority area candidates by count of wells with historical nitrate maximum greater than or equal to 10 mg/L as N.**

| ID | Bin | Name | County | >= 10 | >= 5 and < 10 | >= 5 | >= 3 and < 5 | < 3 | Total | PCT Max >= 10 | PCT Max >= 5 | Total Number of Nitrate Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 55 | 1 | Pasco Basin | Franklin | 219 | 129 | 348 | 35 | 120 | 503 | 43.5 | 69.2 | 1843 |
| 1 | 1 | Sumas-Blaine | Whatcom | 188 | 123 | 311 | 90 | 334 | 735 | 25.6 | 42.3 | 2440 |
| 56 | 1 | Walla Walla West | Walla Walla | 43 | 16 | 59 | 6 | 20 | 85 | 50.6 | 69.4 | 1212 |
| 48 | 3 | Adams Dryland | Adams | 39 | 28 | 67 | 15 | 117 | 199 | 19.6 | 33.7 | 618 |
| 47 | 1 | East of Moses Lake | Grant | 35 | 71 | 106 | 76 | 94 | 276 | 12.7 | 38.4 | 1326 |
| 37 | 1 | Benton East | Benton | 33 | 51 | 84 | 36 | 145 | 265 | 12.5 | 31.7 | 857 |
| 54 | 1 | Franklin Northwest | Franklin | 32 | 17 | 49 | 17 | 32 | 98 | 32.7 | 50.0 | 422 |
| 50 | 1 | Quincy Basin | Grant | 31 | 82 | 113 | 57 | 49 | 219 | 14.2 | 51.6 | 973 |
| 51 | 1 | Royal Slope | Grant | 29 | 62 | 91 | 14 | 30 | 135 | 21.5 | 67.4 | 770 |
| 35 | 1 | Lower Yakima Valley | Yakima | 24 | 38 | 62 | 27 | 119 | 208 | 11.5 | 29.8 | 1017 |

As noted prior, a “well” is a well record from an agency database. WDOH, Ecology and USGS data – does not include local data.

# Appendix D: Example data record

**Table D-1: Example data record from the statewide nitrate database (blended and treated samples are not included)**

| Data Source | LID (Linking ID) | Name | Sample Count | Min | Avg | Max | Date Max | StDev | Date Begin | Most Recent | Date Most Recent | County | Well Depth |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WDOH | 0635001 | BEVERLY WATER DISTRICT | 48 | 0.25 | 11.0 | 28.6 | 18-Mar-02 | 3.8 | 25-Jan-00 | 9.14 | 30-Nov-10 | Grant | 55 |
| ECY | WW32R1 | Walla Walla Pesticides | 2 | 23 | 25.8 | 28.6 | 14-Nov-94 | 4.0 | 18-Jan-94 | 28.6 | 14-Nov-94 | Walla Walla | 80 |
| ECY | N40214P1 | Sumas-Blaine Surficial Aquifer Nitrate Characterization | 1 | 29 | 28.6 | 28.6 | 10-Mar-97 | | 10-Mar-97 | 28.6 | 10-Mar-97 | Whatcom | 42 |
| WDOH | 7392005 | LAMB-WESTON PASCO | 105 | 0.1 | 9.8 | 28.5 | 17-Jun-03 | 10.1 | 08-Feb-00 | 0.69 | 07-Mar-11 | Franklin | 98 |
| WDOH | 0904401 | GOBLE WATER SYSTEM | 10 | 4.2 | 16.4 | 28.4 | 10-May-05 | 8.1 | 11-Apr-00 | 10.8 | 30-Mar-10 | Okanogan | 100 |
| ECY | G1701 | Central Columbia Basin GWMA - Nitrate Characterization Study | 1 | 28 | 28.3 | 28.3 | 10-Nov-98 | | 10-Nov-98 | 28.3 | 10-Nov-98 | Adams | 183 |
| WDOH | 0423601 | CANOE RIDGE VINEYARD | 5 | 17 | 25.1 | 28.2 | 08-Apr-10 | 4.5 | 22-Jan-07 | 27.7 | 07-Feb-11 | Benton | 324 |
| USGS | 461321120055601 | 09N/22E-32M01 | 2 | 28 | 28.0 | 28 | 22-May-74 | 0.0 | 01-Jun-73 | 28 | 22-May-74 | Yakima | 142 |
| USGS | 460912119043501 | 08N/30E-29A01 | 10 | 25 | 26.5 | 28 | 15-Sep-87 | 1.0 | 11-Sep-86 | 27 | 08-Sep-88 | Benton | 215 |
| WDOH | 0359701 | BOGART WATER SYSTEM | 9 | 16 | 21.6 | 27.7 | 02-Jul-02 | 4.8 | 18-Jul-00 | 17.4 | 29-Jul-08 | Walla Walla | 86 |

Notes: Latitude and Longitude are not included here to meet security and privacy requirements. A hyperlink field that links the well record to the original web page for the well is included in the database but is not shown here.

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# Appendix E:  Statewide Atlas

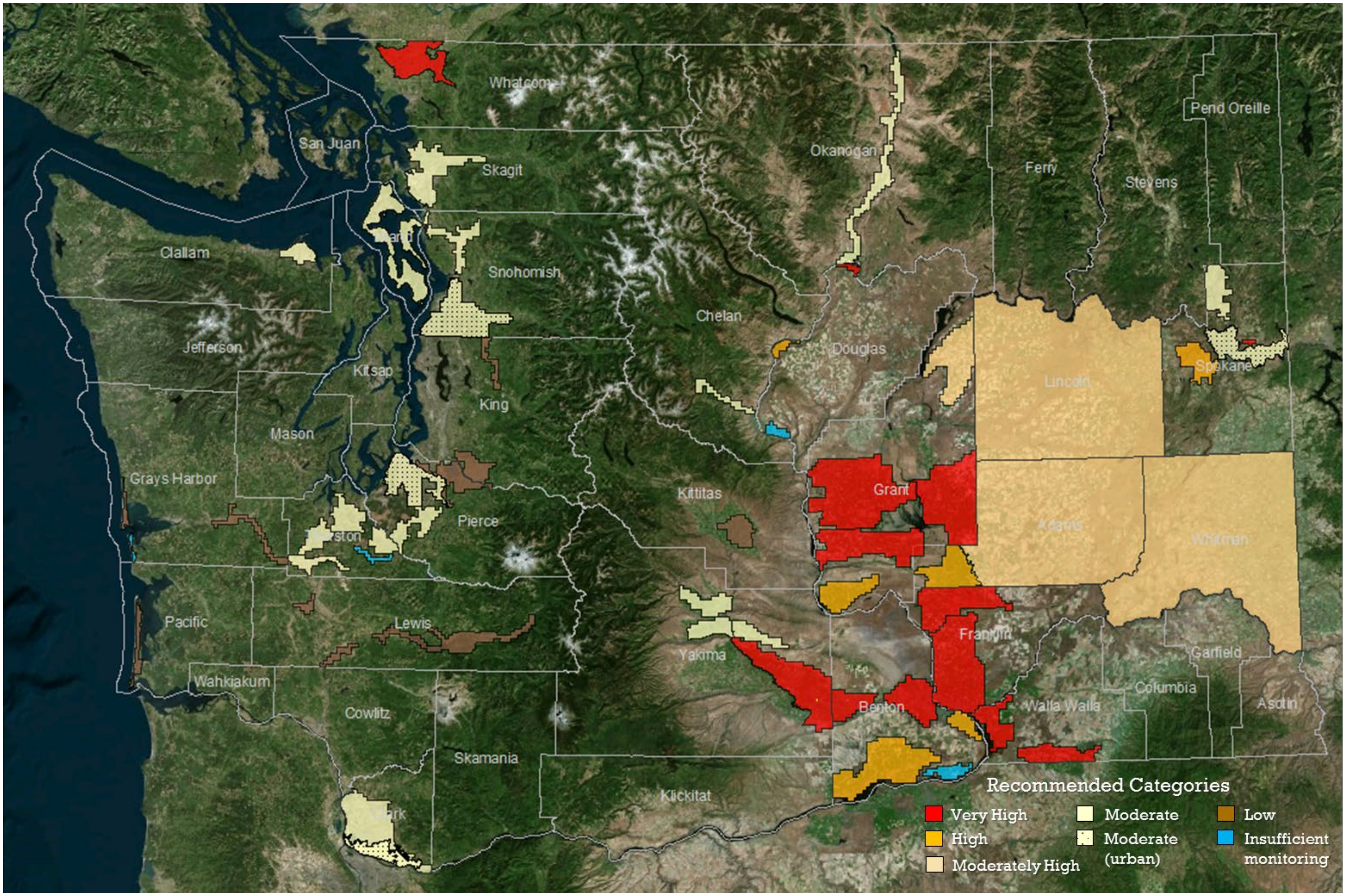


**Figure 26:  Recommended draft Nitrate Priority Areas and Categories**

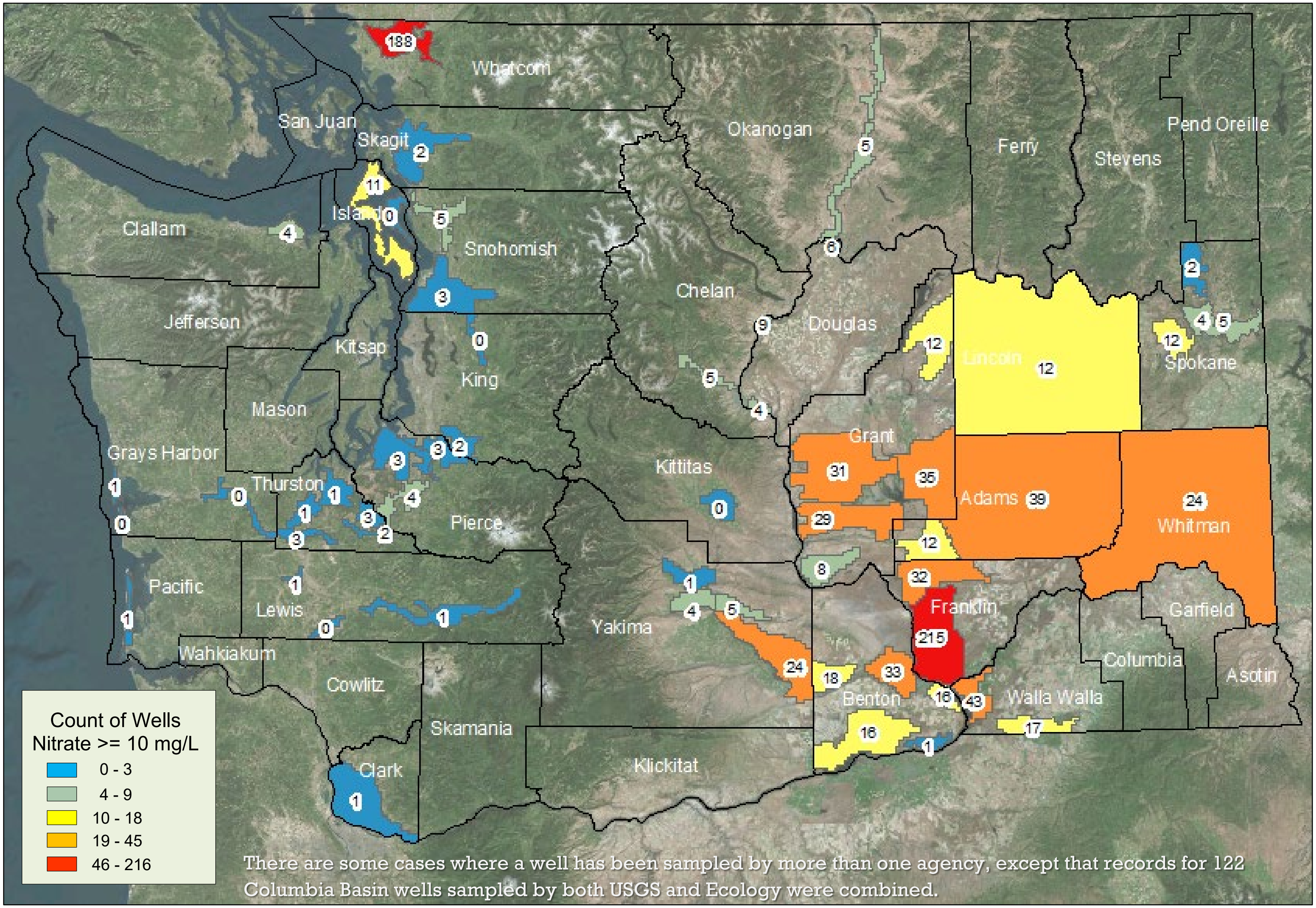


**Figure 27: Total number of wells for which the maximum nitrate level was greater than or equal to 10 mg/L as N within draft Nitrate Priority Areas**

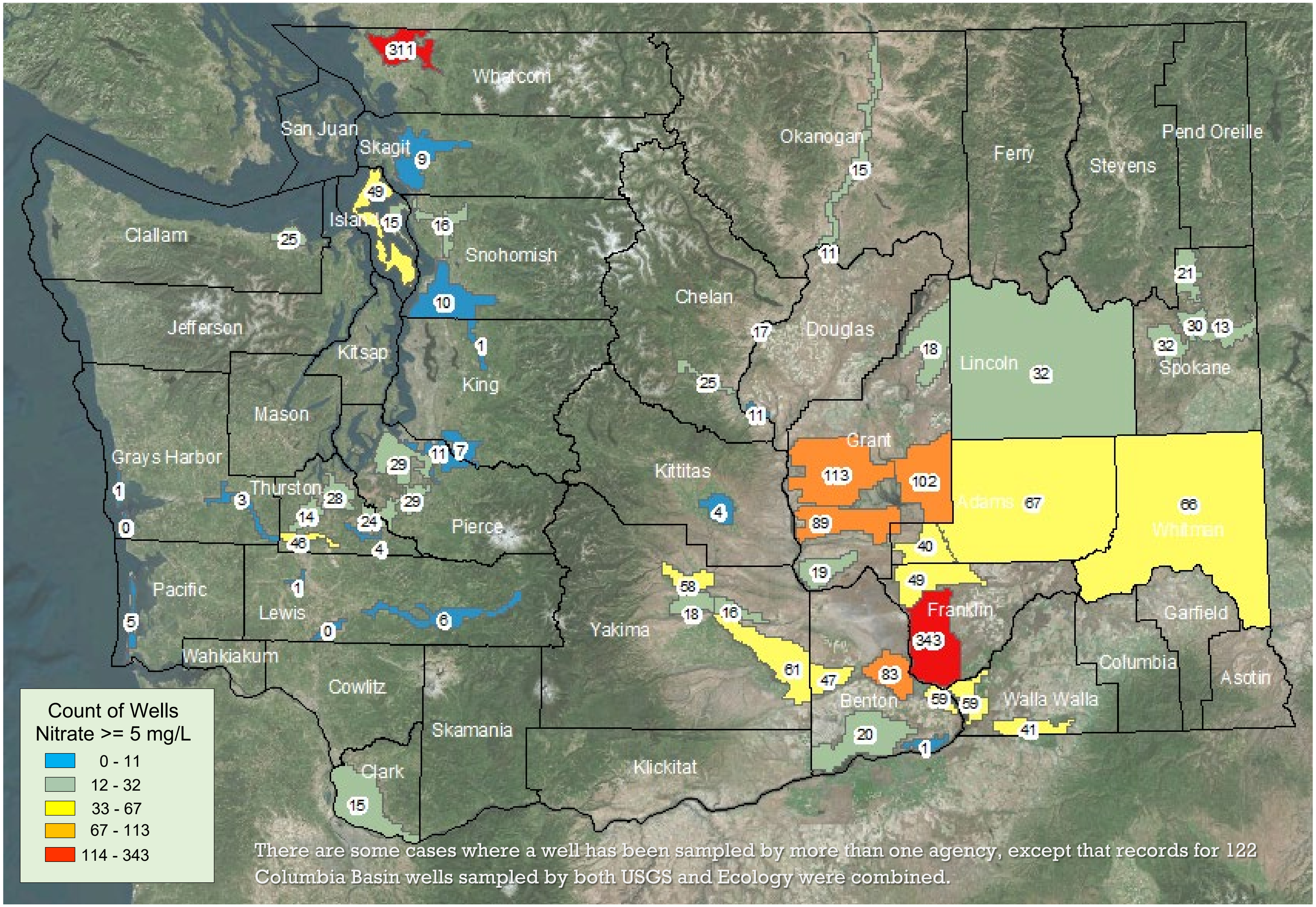


**Figure 28: Total number of wells for which the maximum nitrate level was greater than or equal to 5 mg/L as N within draft Nitrate Priority Areas**

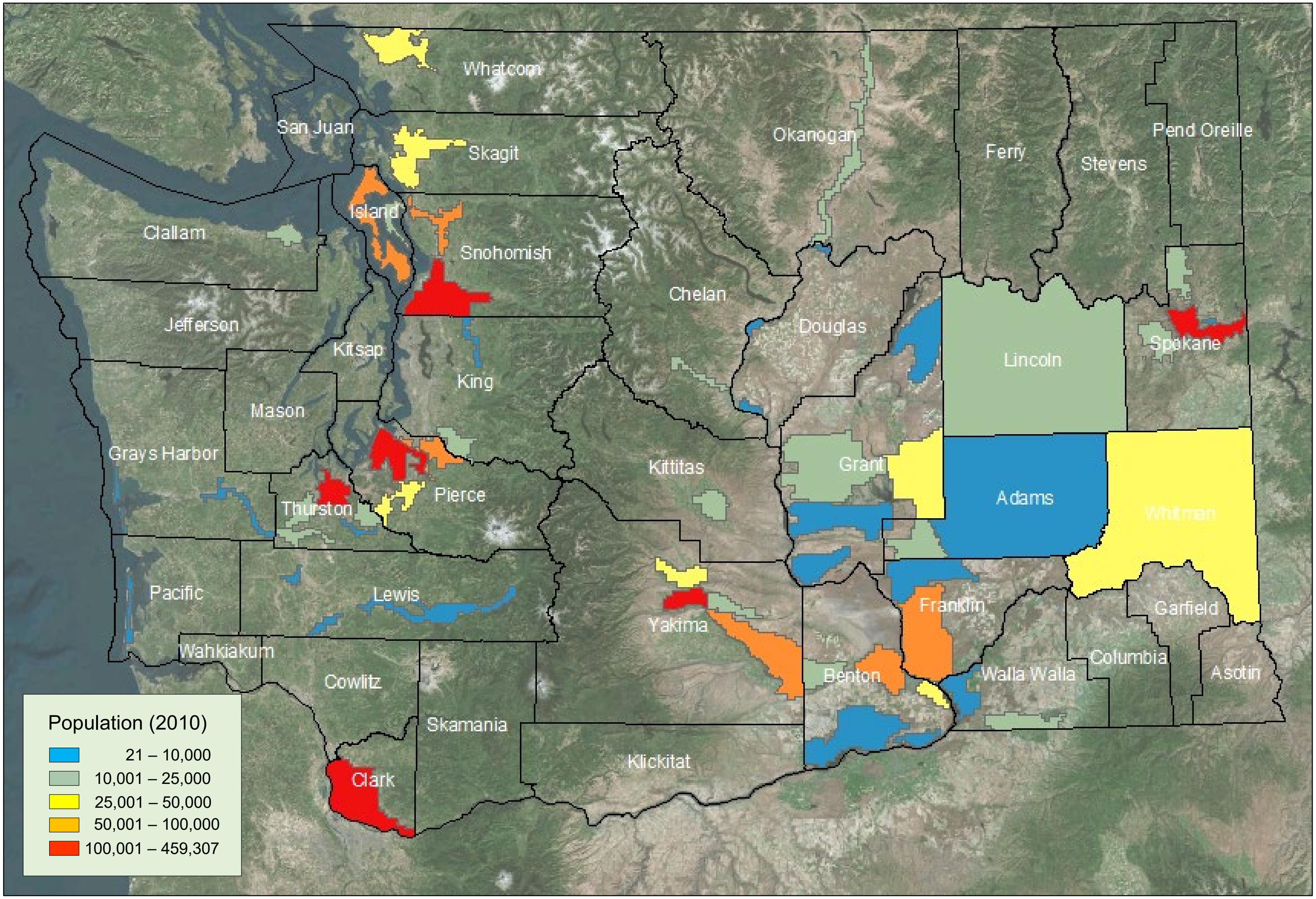


**Figure 29: U.S. Census Population of draft Nitrate Priority Areas**

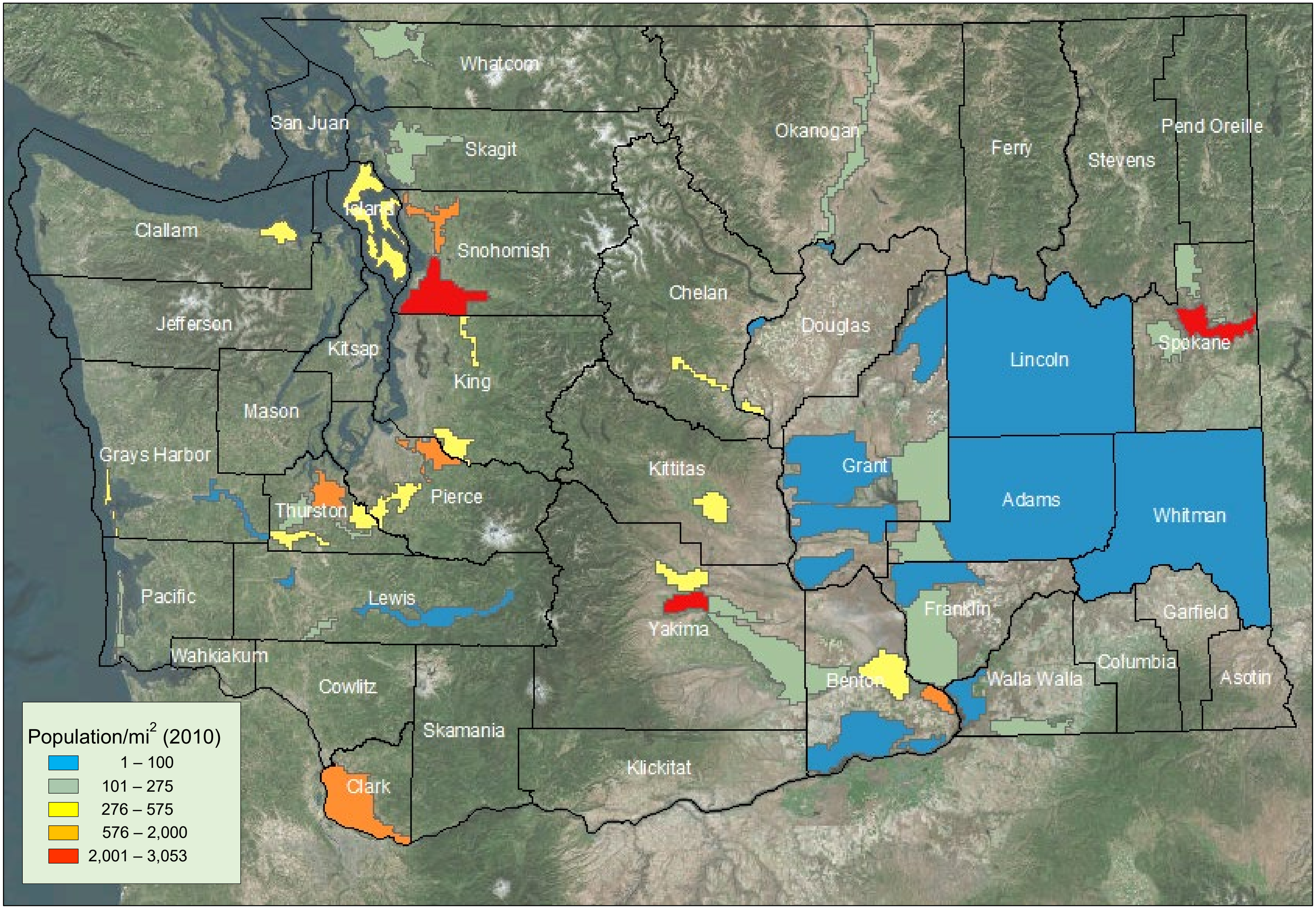


**Figure 30: U.S. Census 2010 Population per Square Mile of draft Nitrate Priority Areas**

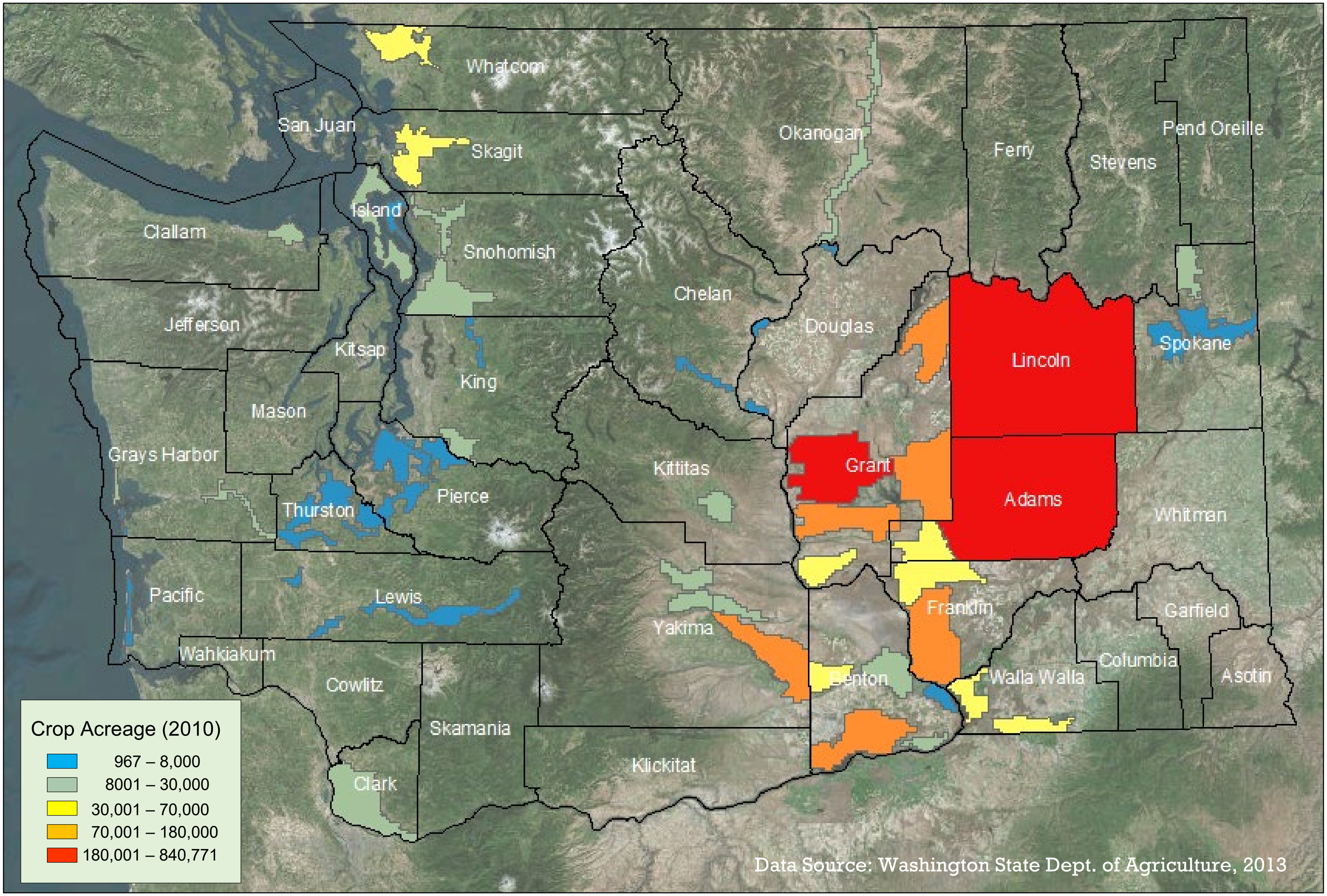


**Figure 31: 2010 Crop Acreage of draft Nitrate Priority Areas (WSDA 2013)**

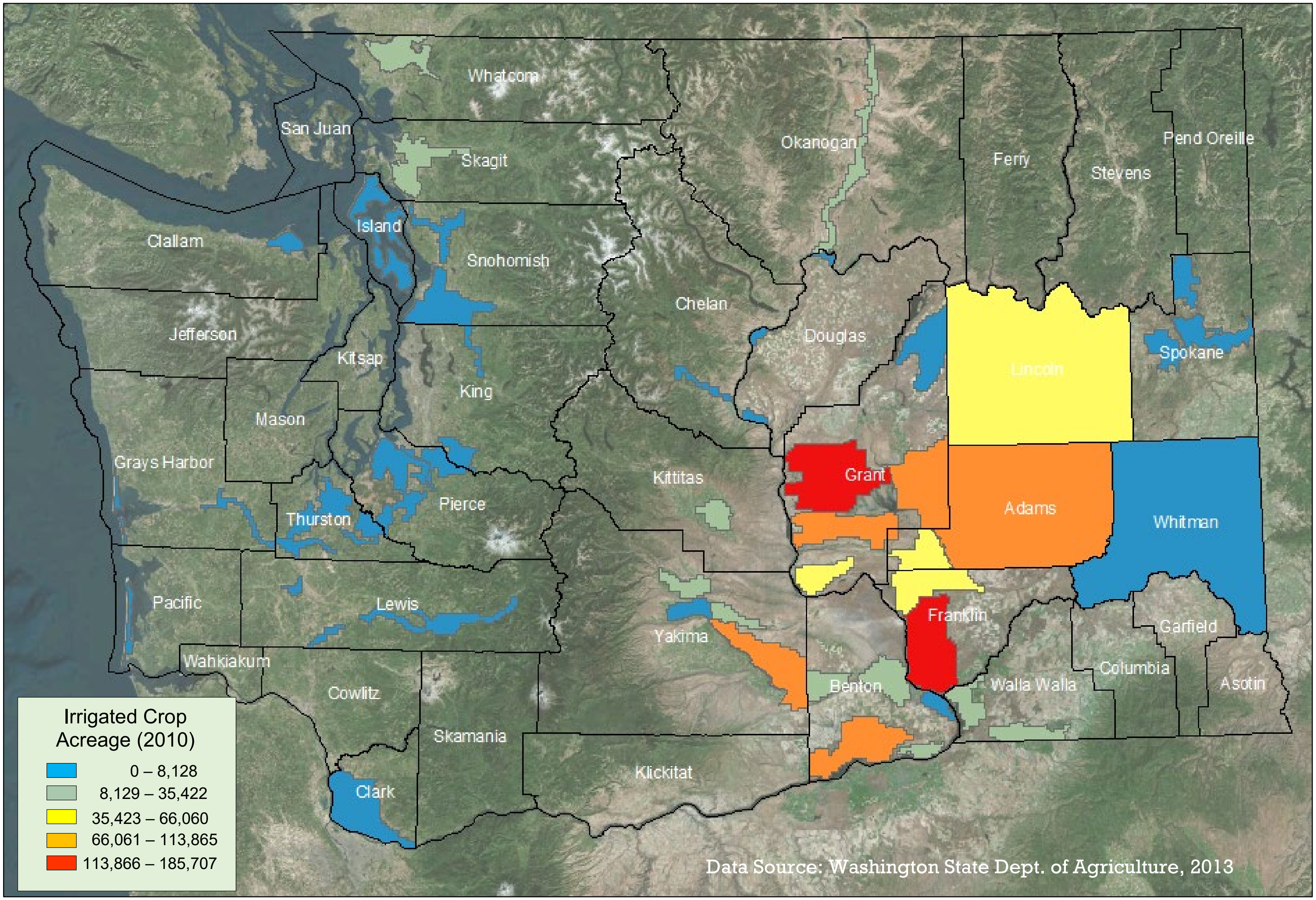


**Figure 32: 2010 Irrigated Crop Acreage of draft Nitrate Priority Areas (WSDA 2013)**

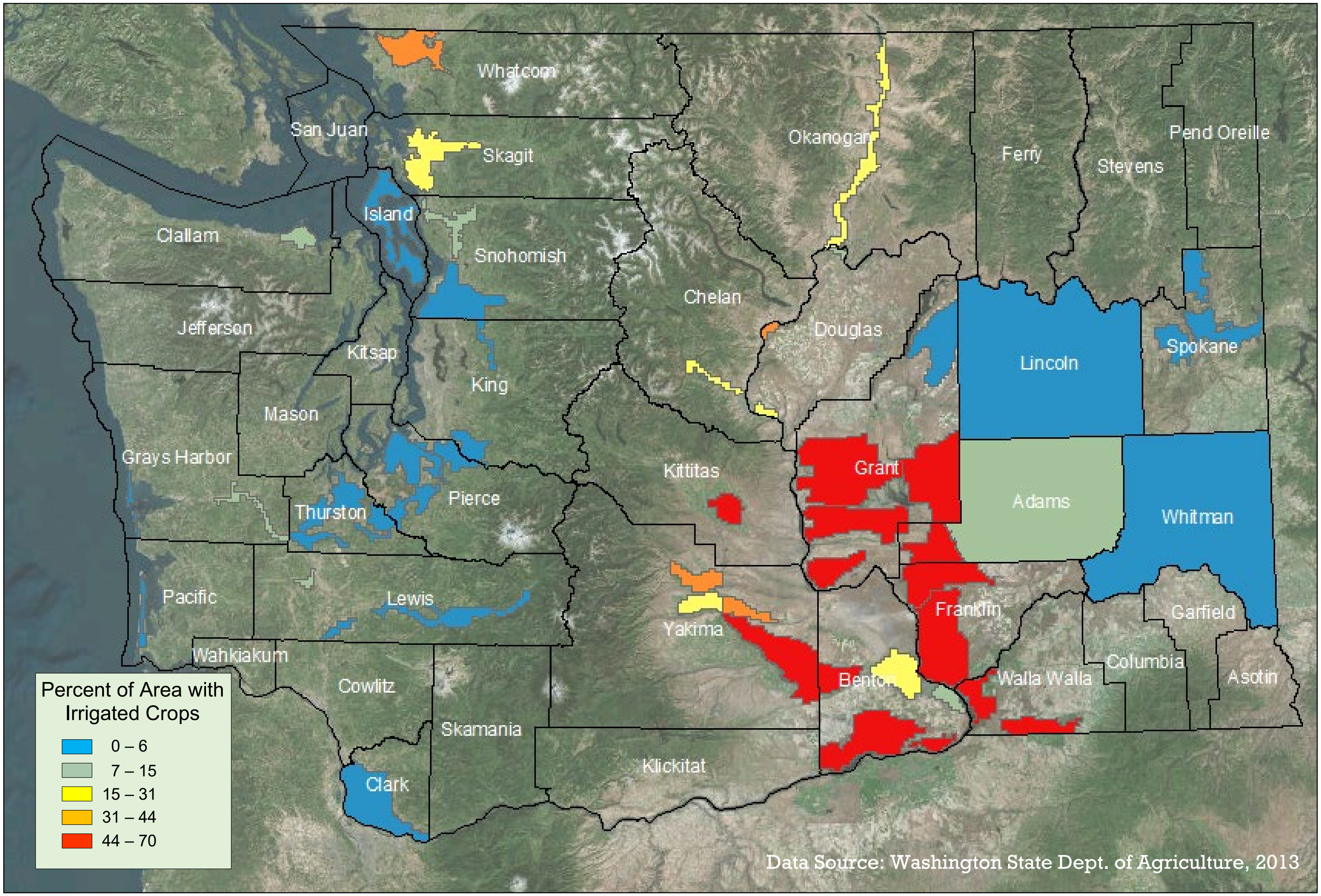


**Figure 33: Percent of draft Nitrate Priority Area with Irrigated Crops in 2010 (WSDA 2013)**

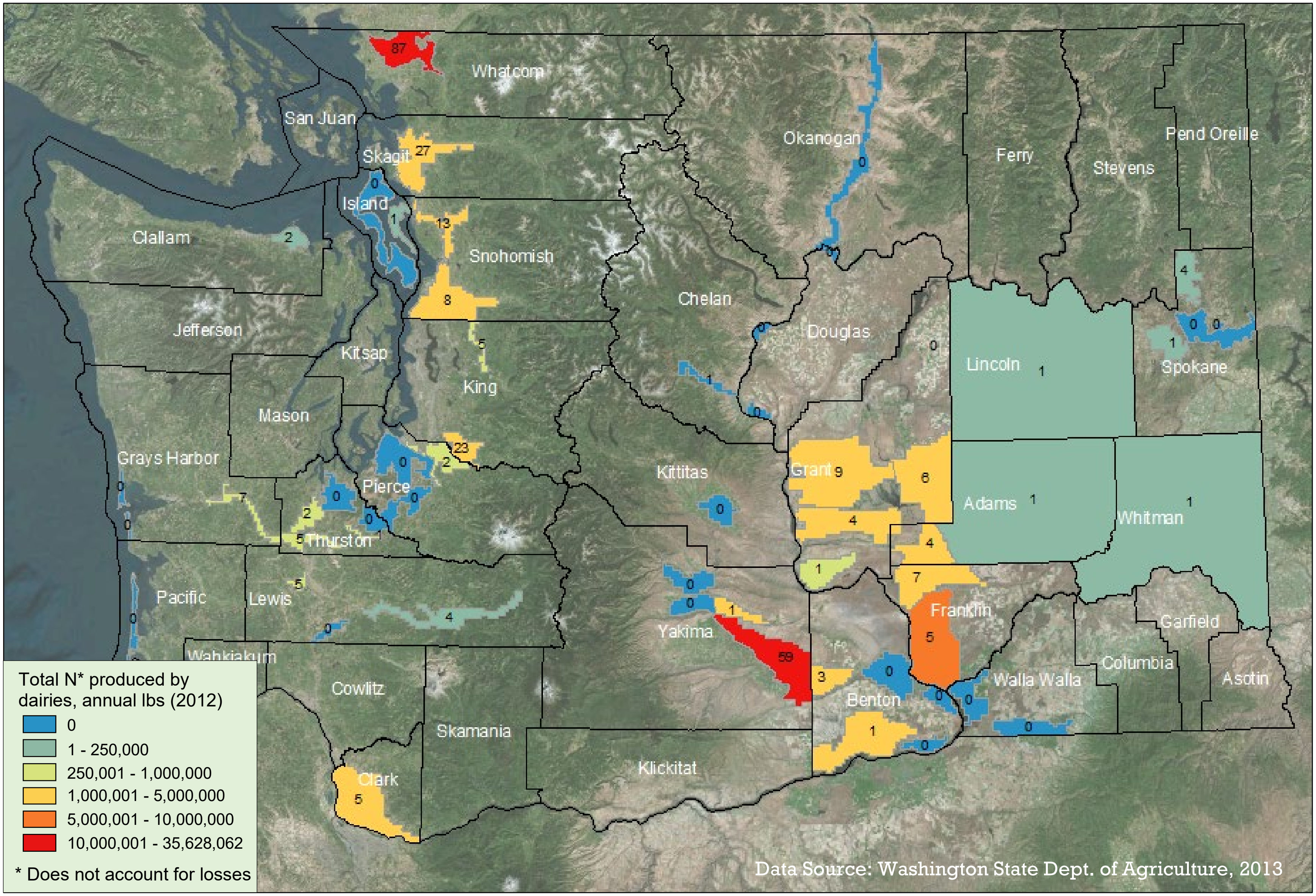


**Figure 34: Number of Dairies and Estimated Dairy Total N Produced (not accounting for losses of N), 2010 (WSDA 2012)**

# Appendix F

# Glossary, Acronyms, and Abbreviations

**Nonpoint source:** Pollution that enters any water from any dispersed land-based or water-based activity, including but not limited: to atmospheric deposition; surface-water runoff from agricultural lands, urban areas, or forest lands; subsurface or underground sources; or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

**Parameter:** Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

**Pathogen:** Disease-causing microorganisms such as bacteria, protozoa, viruses.

**Pollution:** Contamination or other alteration of the physical, chemical, or biological properties of any water. This includes change in temperature, taste, color, turbidity, or odor of the water. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any water. This definition assumes that these changes will,
or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

**Subaqueous**: Existing, formed, or taking place in or under water.

**Surface waters of the state:** Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

**Watershed:** A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

## Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

| | |
|---|---|
| BMP | Best management practices |
| Ecology | Washington State Department of Ecology |
| EIM | Environmental Information Management system |
| EPA | U.S. Environmental Protection Agency |
| GIS | Geographic Information System |
| USGS | U.S. Geological Survey |
| GWMA | Ground Water Management Area |
| WDOH | Washington State Department of Health |

| | |
|---|---|
| NRCS | National Resource Conservation Service |
| SSURGO | NRCS Soil Survey Geographic database |
| WSDA | Washington State Department of Agriculture |

**Units of Measurement**

| | |
|---|---|
| ft | feet |
| mg/L | milligrams per liter (parts per million |