Evaluation of Risk from Exposure to Nitrate Contamination in the Groundwater of the Lower Yakima Valley, Washington

Mallory Little
Site Assessment and Toxicology Section
Environmental Public Health

DOH 334-506 June 2023

To request this document in another format, call 1-800-525-0127. Deaf or hard of hearing customers, please call 711 (Washington Relay) or email doh.information@doh.wa.gov.

Table of Contents

List of Figures 3
List of Tables 3
Glossary 5
Foreword 7
Summary 8
Introduction 8
Conclusions 8
Next Steps 8
More Information 9
Purpose and Statement of Issues 9
Background 9
Historical Land Use 10
Previous Environmental Investigations and Regulatory History 11
Nitrate 15
Populations Evaluated in this Assessment 17
Exposure Pathways 18
Data Analysis 19
Yakima County 19
Benton County 22
Evaluating Non-cancer Hazards 24
Methemoglobinemia 25
Reproductive Effects 27
Thyroid 28
Evaluating Cancer Hazards 29
Discussion 31
Public Health Implications 31
Environmental Justice Implications 34
Historical Comparisons 34
Standard vs VanDerslice (2007) Risk Estimates 36
Conclusions 39

Recommendations 39
Public Health Action Plan 40
References 41
Appendix A 50
Appendix B 58
Appendix C 59
Derivation of RfD for Pregnant Individuals 59
VanDerslice (2007) Risk Estimates 59

List of Figures

Figure 1: Cattle and dairy cows in Yakima County from 1925 to 2012 (adapted from Figure 2 from WSDA, 2018) 11
Figure 2: Medium scenario for nitrogen availability (adapted from Figure 11 in WSDA, 2018) .. 14

List of Tables

Table 1: Urinary nitrate levels (mg/L) in the general population (adapted from CDC, 2016) 17
Table 2: Statistical summary of nitrate-N concentrations in private domestic wells in Yakima County 21
Table 3: Statistical summary of nitrate-N concentrations in public water system wells in Yakima County 22
Table 4: Statistical summary of nitrate-N concentrations in private domestic wells in Benton County 23
Table 5: Statistical summary of nitrate-N concentrations in public water system wells in Benton County 24
Table 6: RfDs used in this health assessment 25
Table 7: HQs calculated for adults and pregnant individuals ingesting water from public wells 31
Table 8: HQs calculated for infants ingesting water from public wells 32
Table 9: HQs calculated for infants and pregnant individuals ingesting water from private wells 32
Table 10: HQs calculated for adults ingesting water from private wells 33
Table 11: HQs calculated for infants and pregnant individuals hypothetically ingesting water from monitoring wells 33
Table 12: HQs calculated for adults hypothetically ingesting water from monitoring wells 34
Table 13: Statistical summary of nitrate-N concentrations in private domestic wells in Benton County 35

Table 14: Statistical summary of nitrate-N concentrations in private domestic wells in Yakima County 35
Table 15: Nitrate-N levels in tap water adapted from Table 5 of VanDerslice (2007) 36
Table 16: VanDerslice (2007) and EPA (1991) exposure parameters 38
Table 17: Comparison of infant methemoglobinemia HQs Using parameters from VanDerslice (2007) and EPA (1991) 38
Table 18: Exposure parameters used in this health assessment 50
Table 19: ADDs calculated based on private well data in this health assessment 52
Table 20: ADDs calculated based on public well data in this health assessment 54
Table 21: ADDs calculated based on monitoring well data in this health assessment 54
Table 22: HQs calculated based on private well data in this health assessment 55
Table 23: HQs calculated based on public well data in this health assessment 56
Table 24: HQs calculated based on monitoring well data in this health assessment 56
Table 25: Well water nitrate concentrations used in this health assessment 58
Table 26: Exposure parameters derived from VanDerslice (2007) used in this health assessment 59
Table 27: ADDs calculated based on VanDerslice (2007) exposure parameters in this health assessment 60
Table 28: HQs calculated using parameters from VanDerslice (2007) 61

Glossary

Acute - Occurring over a short time [compare with chronic].

Agency for Toxic Substances and Disease Registry (ATSDR) - The principal federal public health agency involved with hazardous waste issues, responsible for preventing or reducing the harmful effects of exposure to hazardous substances on human health and quality of life. ATSDR is part of the US Department of Health and Human Services.

Cancer Slope Factor - A number assigned to a cancer-causing chemical that is used to estimate its ability to cause cancer in humans.

Chronic - Occurring over a long time [compare with acute]. A chronic exposure is one that lasts for a year or longer.

Contaminant - A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.

Dose - The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.

Epidemiology - The study of the distribution and determinants of disease or health status in a population; the study of the occurrence and causes of health effects in humans.

Exposure - Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].

Groundwater - Water beneath the earth's surface in the spaces between soil particles and between rock surfaces.

Hazardous substance - Any material that poses a threat to public health and/or the environment. Typical hazardous substances are materials that are toxic, corrosive, ignitable, explosive, or chemically reactive.

Ingestion rate (IR) - The amount of an environmental medium that could be ingested typically on a daily basis. Units for IR are usually liter/day for water, and mg/day for soil.

Inorganic - Compounds composed of mineral materials, including elemental salts and metals such as iron, aluminum, mercury, and zinc.

Lower Yakima Valley (LYV) - Includes portions of Yakima County, Benton County, and the Yakama Reservation. The area of interest for this health assessment.

Lowest Observed Adverse Effect Level (LOAEL) - The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.

Maximum Contaminant Level (MCL) - A drinking water regulation established by the federal Safe Drinking Water Act. It is the maximum permissible concentration of a contaminant in water that is delivered to the free-flowing outlet of the ultimate user of a public water system. MCLs are enforceable standards.

Media - Soil, water, air, plants, animals, or any other part of the environment that can contain contaminants.

Minimal Risk Level (MRL) - An ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), noncancerous effects. MRLs are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic). MRLs should not be used as predictors of harmful (adverse) health effects.

No Observed Adverse Effect Level (NOAEL) - The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects on people or animals.

Reference Dose (RfD) - An amount of chemical ingested into the body (i.e., dose) below which health effects are not expected. RfDs are published by EPA.

Organic - Compounds composed of carbon, including materials such as solvents, oils, and pesticides that are not easily dissolved in water.

Parts per billion (ppb)/Parts per million (ppm) - Units of measurement expressing concentration of a contaminant in environmental media.

Route of exposure - The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].

U.S. Environmental Protection Agency (EPA) - Established in 1970 to bring together parts of various government agencies involved with the control of pollution.

Foreword

The Washington State Department of Health (DOH) has prepared this health assessment in accordance with approved methodologies and procedures for toxicological risk assessments first established by the National Research Council (NRC; 1983) and EPA (2004). A standard toxicological risk assessment evaluates the risk of a population from exposure to a contaminant in environmental media. It represents a scientific analysis of nitrates in groundwater in the Lower Yakima Valley (LYV). The findings in this report are relevant to conditions at the site during the time of this health assessment. It may not be appropriate to rely on this health assessment if site conditions or land use changes in the future.

Editorial review was completed by DOH.

Summary

Introduction

This health assessment evaluates potential human health hazards from nitrate contamination in Lower Yakima Valley (LYV) groundwater. The LYV includes parts of Yakima and Benton counties, and part of the Yakama Reservation. For this assessment, the area evaluated includes parts of Yakima and Benton counties that coincide with the LYV. This health assessment also evaluates potential human health hazards resulting from nitrate levels in public water systems in the LYV for comparison to nitrate levels in groundwater. At Washington State Department of Health (DOH), our top priority is to ensure communities have the best information to be healthy. We prepared this assessment at the request of the Center for Food Safety, Friends of Toppenish Creek, and Food & Water Watch (Petitioners).

Conclusions

For LYV drinking water systems, including public water systems and private wells, we conclude:

- Infants and pregnant people who consume water from private wells in Yakima and Benton counties may be at risk for adverse health effects.
- Adults who are not pregnant who consume water from private wells in Yakima and Benton counties are not at risk for adverse health effects.
- People who consume water from the public water systems in Yakima and Benton counties are not at risk for adverse health effects.

Next Steps

1. DOH strongly advises residents of Yakima and Benton counties that use private wells for drinking water to test nitrate levels at least once a year. If nitrate test results are 5 milligrams per liter (mg/L) or higher, re-sample in six months.
2. If drinking water concentrations exceed 10 mg/L nitrate-nitrogen, cease use and switch to bottled water for drinking and food preparation.
3. DOH will send this health assessment to the public water systems in Yakima and Benton counties, the local health districts and departments in the LYV, the Petitioners, and Ecology. This health assessment will also be publicly available on https://doh.wa.gov/community-and-environment/drinking-water/contaminants/nitrate.
4. DOH will send a fact sheet summarizing the results and recommendations of this health assessment to private well users and local health departments in the LYV. This fact sheet will also be publicly available on https://doh.wa.gov/community-and-environment/drinking-water/contaminants/nitrate.
5. As requested, DOH will review and evaluate any new data regarding contaminants in drinking water from the LYV.

More Information

Please feel free to contact DOH at 1-877-485-7316 or eha@doh.wa.gov or visit our website at https://doh.wa.gov/community-and-environment/drinking-water/contaminants/nitrate if you have any questions about this health assessment.

Purpose and Statement of Issues

DOH has prepared this health assessment at the request of the Center for Food Safety, Friends of Toppenish Creek, and Food & Water Watch (Petitioners). The purpose of this health assessment is to evaluate potential human health hazards posed by nitrate contamination in the groundwater of the LYV. It evaluates the drinking water drawn from public water systems and select private domestic wells in the area. This health assessment will also be used to recommend appropriate actions to protect the public health of residents of the LYV.

This health assessment is a current and historical review (2018 – 2022) of DOH's Washington State Water System Data (Sentry Internet) and the Department of Ecology's (Ecology's) Environmental Information Management System (EIM) (Sentry, 2022; Ecology, 2022a). The Sentry Internet database documents public drinking water systems whereas EIM documents private domestic wells and ambient groundwater monitoring wells.

This health assessment will be used in part to fulfill requests made by the Petitioners who petitioned the United States (US) Environmental Protection Agency (EPA) for Emergency Action under Section 1431 of the Safe Drinking Water Act (SDWA) on October 26, 2021 to address the groundwater contamination with nitrates in the LYV. The request for the health assessment was made during a meeting on December 9, 2021 between the Petitioners and the DOH Office of Drinking Water.

Background

The LYV is part of the Yakima Basin, a 6,200 square mile area in Washington state that begins on the upper eastern slope of the Cascades and includes the Yakima River (Vaccaro et al., 2009). The Yakima Basin is divided into three portions: the upper valley, the lower valley, and the upland benches (Foxworthy et al., 1962). The LYV includes the lower part of Ahtanum Creek and Ahtanum Ridge, and contains a broad alluvial plain for fourteen miles west of the Yakima River until it is met by bluffs and cliffs of lava rock, and is bounded by the Cascade Mountains to the west (Foxworthy et al., 1962; EPA, 2013). Basalt ridgelines surround the LYV to the north and south (EPA, 2013). The LYV includes portions of Yakima County to the north and northeast, Benton County to the southeast, and the Yakama Nation to the west.

The LYV contains two aquifer types: a surficial unconfined to semi-confined alluvial aquifer and a basalt aquifer under a sedimentary layer (EPA, 2013b). The basalt aquifer is located at greater depths than the alluvial aquifer, and generally flows from the northwest to the southeast parallel to the Yakima River (EPA, 2013b). The surficial aquifer discharges to the Yakima River whereas the basalt aquifer primarily discharges to the Columbia River, with some minor flow at shallower depths discharging to the Yakima River (EPA, 2013b). The LYV aquifers have a slow groundwater recharge rate of <12 mm/year because this area lies in a "rain-shadow" and receives limited precipitation (also known as the orographic effect); however, human activity has increased the recharge rate through increased rill irrigation and storage/diversion of snowmelt to the aquifer (Jensen & Gazis, 2018).

Yakima and Benton counties contain both Group A and Group B water service systems. Group A systems serve 15+ service connections or serve 25+ people 60+ days per year, whereas Group B systems serve fewer than 15 connections and fewer than 25 people per day (DOH, 2013; DOH, 2022).

Historical Land Use

Historically, the LYV was the site of wheat, corn, melon, potato, squash, pumpkin, and pea production in irrigated gardens created by the Yakama Tribe in the mid-1800s (Drennan, 2013). Over the following 50 years, ranching, farming, and irrigation were rapidly expanded in the area (Drennan, 2013). As of 1925, about 20,000 dairy cows were reported in the agricultural census of Yakima County (Drennan, 2013) as part of a growing milk producing region in Washington. The number of dairy cows in the region stayed mostly stable until about 1974, when numbers sharply increased, reaching about 90,000 dairy cows reported by the agricultural census (Drennan, 2013). As of 2012, 99,532 cows were counted in Yakima County on 97 farms, and the Yakima Valley contained over 110,000 cows (WSDA, 2018; Washington State Dairy Federation, 2014).

Figure 1 shows the trends in dairy cow numbers from 1925 to 2012.

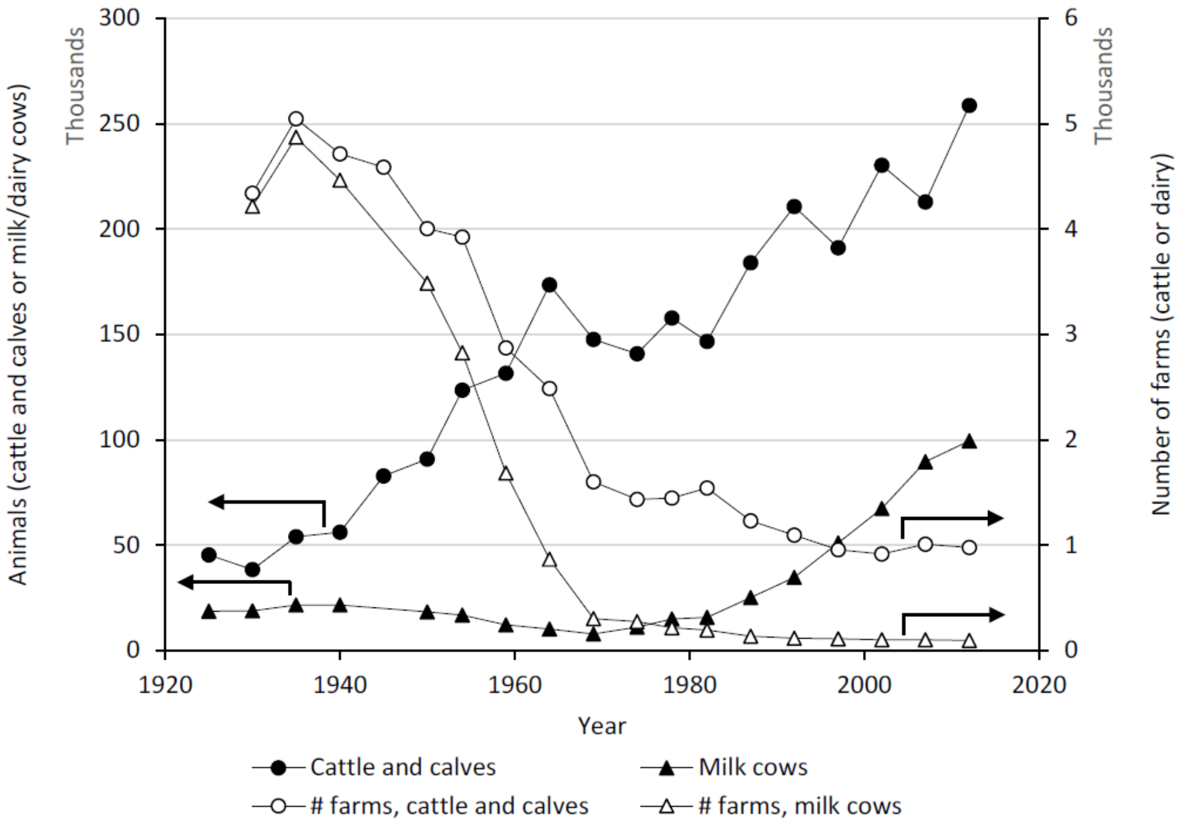

Figure 1: Cattle and dairy cows in Yakima County from 1925 to 2012 (adapted from Figure 2 from WSDA, 2018)

Today, Yakima County is the leading agricultural county in Washington State for production of apples, sweet cherries, pears, and is the leading county for hop production in the nation (WSU, 2022). Yakima County also leads the state in squash, pepper, and melon production (WSU, 2022). In addition to its agriculture, the Valley contains many dairies and concentrated animal feeding operations (Sell & Knutson, 2002). As of 2013, Yakima County has the highest milk production per cow ratio in the entire US (EPA, 2013b).

Previous Environmental Investigations and Regulatory History

The following environmental investigations have occurred in the LYV and are listed in chronological order.

In 1991, the US Geological Survey (USGS) conducted a groundwater study in the Toppenish Creek Basin of the LYV assessing the drinking water quality of almost 500 wells. Only about 0.4% of these wells had nitrate levels above EPA's Maximum Contaminant Level (MCL) of 10 mg/L. Small seasonal variations in groundwater quality were linked to fertilizer use in the basin; however, the overall health of the groundwater was not considered degraded (Sumioka, 1998).

The LYV aquifer has had areas with nitrate concentrations greater than the MCL since at least 2002 (Jensen & Gazis, 2018). In 2002, the non-profit Valley Institute for Research and Education

(VIRE) tested private wells in the LYV and was the first study to assess the quality of the groundwater in private wells in the LYV outside of the Toppenish Creek Basin. At this time, the LYV also contained major agricultural operations growing corn, hops, apples, grapes, alfalfa, asparagus, cherries, pears, spearmint, hay, wheat, and other grains, and 60 dairies with about 100,000 animals (Sell & Knutson, 2002). VIRE recommended the creation of a Groundwater Management Area (GWMA) after a large proportion of wells in the southern section of the LYV reported nitrate at concentrations greater than the MCL. VIRE linked the overuse of nitrogen fertilizer as the main cause of nitrate contamination in the groundwater (Sell & Knutson, 2002).

RCW 90.44.400 and WAC 173-100, in 1985 and 1988 respectively, established the authority to create a groundwater management area to address nitrate contamination greater than drinking water standards in private domestic wells.

In 1998, the Dairy Nutrient Management Act (DNMA, Chapter 90.64 RCW) was enacted, giving Ecology regulatory authority to address pollutant discharge from dairy farms (Drennan, 2013). Ecology developed an inspection program under the DNMA which required licensed dairy producers to develop a dairy nutrient management plan certified by their local conservation district (Drennan, 2013). The legislature transferred the powers, duties, and functions of the DNMA to WSDA in 2003. Under the DNMA, all licensed dairies are required to undergo inspections, complaint investigations, and ensure that the dairy operation does not cause a discharge of pollution to waters of the state, including groundwater. Dairy producers are also required to keep records to show that use of nutrients, including but not limited to nitrogen fertilizers, are applied at agronomic rates for the crops being grown, as well as annual records of all nutrient and irrigation water applied (Drennan, 2013).

A cross-sectional epidemiological study was conducted in the LYV assessing the association between methemoglobinemia in infants and nitrate levels in the drinking water (VanDerslice, 2007). Nitrate intake greater than 5 milligrams per kilograms per day (mg/kg-d) was positively associated with methemoglobin levels greater than 3% in infants (VanDerslice, 2007). While VanDerslice (2007) considered methemoglobin levels greater than 3% in infants to be “physiologically significant,” symptoms of methemoglobinemia usually present when methemoglobin levels elevate to at least 10% of total hemoglobin (California Office of Environmental Health Hazard Assessment (OEHHA), 2018). None of the infants analyzed in VanDerslice (2007) exhibited symptoms of methemoglobinemia.

The Groundwater Management Advisory Committee (GWAC) first met in 2012, and was comprised of local community members, local health officials, EPA, WSDA, Ecology, DOH, USGS, the Yakama Nation, the Dairy Federation, local conservation members, local university representatives, and agricultural representatives (Yakima County, 2022a). GWAC established the GWMA Program in 2012, which met for seven years and established 64 recommended actions to reduce nitrate concentrations in groundwater. These actions were approved by GWAC and were certified as a plan by Ecology in 2019 (Yakima County, 2022b). An implementation committee was established and currently oversees the implementation of the 64 recommended actions under the GWMA program.

EPA conducted a study examining potential sources of nitrate contamination in the groundwater of the LYV which culminated in 2013. EPA measured nitrate concentrations from residential drinking water wells, dairy supply wells, and wastewater treatment influent (as surrogate for septic systems), as well as potential sources of nitrates including dairy lagoons, dairy application fields, irrigated and fertilized crop fields, and dairy manure piles. EPA concluded that dairies are a major source and that irrigated crop fields are a likely source of nitrate contamination in the groundwater (EPA, 2013b). High nitrate levels were detected in the drinking water wells downgradient of the dairies, and few nitrate sources were identified upgradient of the dairies. Additionally, EPA concluded that dairy lagoons were likely leaking large quantities of nitrogen into subsurface water, and WSDA reported high levels of residual soil nitrogen in crop fields which use manure as part of their fertilizer regimen. EPA also concluded that irrigated crop fields are a likely source of nitrate contamination in the groundwater, because 30% of the nitrogen available for land application was accounted for from the total acreage of irrigated crop fields in Yakima County. This study also identified septic systems as a likely source of nitrate contamination in groundwater. Analysis of hormone and pharmaceutical contamination in WWTP influent and residential wells showed that septic systems impact the water quality of wells but did not provide evidence specific to nitrate contamination (EPA, 2013b).

In 2013, a Consent Order was issued by the EPA under the SDWA to address nitrate contamination originating from several dairy farms in the area. The Consent Order required Respondents to supply residents with a safe, permanent source of drinking water if their well tested at concentrations greater than the MCL, further control nitrate contamination sources at the dairies, establish a network of monitoring wells to monitor nitrate source reduction, and reduce nitrate contamination of the groundwater resulting from the dairies, or face financial penalty (EPA, 2013a).

There is also a history of technical assistance provided to the agricultural sector in the region from local conservation and university extension programs. For example, South Yakima Conservation District and Whatcom County conducted dairy nutrient management training programs in 2015, which taught best management practices for manure and other nutrient application management to protect water quality (WSDA, 2016). Benton Conservation District in collaboration with Benton-Franklin Health District, Benton County Commissioners, and the Benton County Groundwater Stakeholder Committee also released a Groundwater Nitrate Community Action Plan. This plan included irrigation water management guidelines, nutrient application management guidelines, and urban and rural residential water and fertilizer management recommendations intended to prevent further nitrate contamination of the groundwater (Benton County, 2018). Washington State University Extension regularly publishes best management practice and other technical assistance guides designed to improve nutrient management in the agricultural sector. For example, WSU published guidance for fertilizing with manure and other organic amendments to assist with improving soil quality and protecting groundwater quality (WSU, 2016).

In 2015, the Yakima County Public Services Department, GWAC, and WSDA conducted an extensive nitrogen availability study in the GWMA of the LYV. The study assessed the potential amount of nitrogen available for transport from activities within the LYV, with sources divided between WSDA and Yakima County. WSDA evaluated concentrated animal feeding operations (CAFOs), irrigated agriculture, and atmospheric sources. Yakima County evaluated residential, commercial, and industrial sources, consisting of residential, commercial, and large on-site sewage systems, small-scale farms, and residential fertilizer. The study assessed nitrogen availability under three scenarios (low, medium, and high rates of transport for all sources), and used data specific to the region. Irrigated agriculture was identified as the primary source of nitrogen in all three scenarios. Irrigated agriculture, CAFO lagoons, and CAFO pens comprised 80 – 96% of the total nitrogen available, with irrigated agriculture comprising 47 – 73% of this total across all three scenarios. Atmospheric deposition was a notable source of nitrogen in the low scenario, comprising of 11% of the nitrogen available. This study did not measure nitrate or total nitrogen concentrations in groundwater (WSDA, 2018).

Figure 2 contains a chart illustrating estimated nitrogen availability in the medium scenario from all sources. This chart shows that irrigated agriculture is the primary source of nitrogen. The charts for the low and high scenarios can be viewed in WSDA (2018).

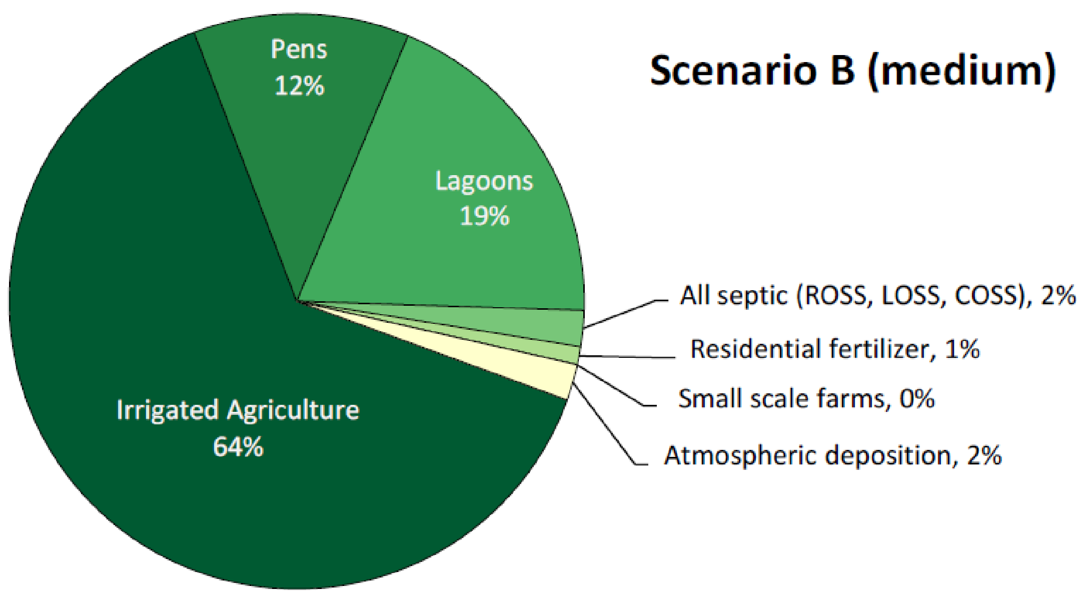

Figure 2: Medium scenario for nitrogen availability (adapted from Figure 11 in WSDA, 2018)

In 2017, USGS assessed the groundwater of the LYV in partnership with GWMA by sampling wells and surface-water drains. More than 20% of the groundwater samples collected from wells and 12% of the water samples collected from surface-water drains contained nitrate-N concentrations greater than 10 mg nitrate-N/L. This study was intended to form a baseline of nitrate concentrations in GWMA for comparison with future assessments, with a mean concentration of 6.1 mg nitrate-N/L detected from groundwater samples collected from wells (USGS, 2017).

DOH investigated a cluster of neural tube defects in infants in 2017 in part of the LYV, including Yakima, Benton, and Franklin counties. Seventy cases of anencephaly, spina bifida, and encephalocele were reported from 2010 – 2017. Fifty-three of these cases were from residences served by public water systems, for which the mean nitrate concentration was 1.8 mg/L. Data from the private wells serving the remaining cases were not available, and so nitrate levels in these wells were estimated. The combined mean public water system and private well nitrate concentration serving the neural tube defect-impacted residences was 2.1 mg/L. DOH did not find evidence that drinking water contaminated with nitrates caused the cluster of neural tube defects detected in the LYV (DOH, 2017).

Nitrate

Nitrate (NO_3^-) is a naturally occurring form of nitrogen and is commonly detected in shallow groundwater at concentrations up to 1.1 mg/L in the US (EPA, 2013b). Nitrite (NO_2^-) is also naturally occurring, and both nitrate and nitrite are formed when microbes or lightning oxidize nitrogen in soil, water, sewage, or the digestive tract (OEHHA, 2018; Fan et al., 1987). Specifically, bacteria in the mouth convert nitrate into nitrite, but these bacteria are not able to survive in the acidic conditions of the stomach (ATSDR, 2017a). Nitrate-N concentrations in water above 1.1 – 3.0 mg/L indicate contamination from human activity (EPA, 2021a). An estimated 8% of Washington state groundwater exceeds 5 mg/L nitrate-N (EPA, 2021a). Nitrite converts to nitrate in the environment and so is uncommon in groundwater (Sigler & Bauder, nd).

Nitrate results are typically reported by laboratories as either the nitrate ion or nitrate-nitrogen (nitrate-N). Nitrate-N results generally represent the amount of nitrogen that is present, excluding the oxygen in the nitrate ion. To calculate nitrate-N from results presented as the nitrate ion, multiply the nitrate ion concentration by 0.226 (Anderson, 2016).

Manure, compost, and synthetic products are applied as fertilizer to supply crops with nitrogen in its plant-available forms including ammonia, ammonium, and nitrate (WSDA, 2018). Ammonia and ammonium are converted to nitrate via microbial metabolism (EPA, 2013b). Ammonia is oxidized to nitrite and then nitrate at a rate that is reduced with low levels of dissolved oxygen in the water (EPA, 2012). Nitrate is highly soluble, and so excess nitrate not absorbed by plant roots may migrate to underlying groundwater via runoff or through the soil when driven by downward force or capillary action in a process called leaching, thus contaminating groundwater (Sell & Knutson, 2002; EPA, 2013a). Furthermore, nitrite and ammonia are unstable, especially in oxygenated water, and so are easily converted to nitrate (Yu et al., 2020; Fan et al., 1987). Nitrate can also leach from leaky lagoons (EPA, 2013a), transferring to surface water and eventually to groundwater, although there is insufficient evidence to conclude that this is happening at significant rates (WSDA, 2018; personal communication with WSDA). Effluent flowing from septic system drain fields contains nitrate, which can reach and contaminate groundwater (DOH, 2014). Irrigated crop fields, atmospheric deposition, natural soil organic matter, and application of commercial fertilizers to residential lawns are other potential major sources of nitrate contamination in groundwater (Ecology, 2022b; WSDA, 2018).

Nitrates were officially identified as contaminants of concern in drinking water in 1945 when cases of cyanosis were linked to nitrate contamination in well water (Comly, 1945). Comly suggested drinking water for infants should contain nitrate at concentrations no higher than 10 mg/L, or at the most 20 mg/L (Comly, 1945). In 1962, the US Public Health Service recommended 10 mg/L nitrate-nitrogen and 45 mg/L nitrate as the maximum permissible concentrations in drinking water (Fan et al., 1987). In 1991, the EPA set the MCL for nitrate at 10 mg/L nitrate-nitrogen, the MCL for nitrite at 1 mg/L as nitrite-nitrogen, and the MCL for total nitrate-nitrite (expressed as nitrogen, or nitrate-nitrogen) as 10 mg/L (Fan & Steinberg, 1996). The MCL is a legally enforceable standard that sets the maximum allowable level of a contaminant in drinking water under the National Primary Drinking Water Regulations (EPA, 2022).

Nitrate is naturally present in its inorganic form in many foods such as leafy green vegetables, radishes, beets, and carrots (Fan et al., 1987). Nitrite, commonly as sodium nitrite, is added to meat as a preservative and curing agent (Fan et al., 1987). Sodium nitrite is regulated under 21 CFR 172.175, which allows the compound to be added as a color fixative in tuna up to 10 ppm and in other fish up to 200 ppm. 21CFR172.175 also allows sodium nitrite to be added as a preservative and color fixative to meat products up to 200 ppm. Sodium nitrate is also regulated under 21CFR172.175 when added in combination with sodium nitrite, and is permissible up to 500 ppm when added to fish and cured meat as a preservative and color fixative (21CFR172.175). The intake of nitrates from food in the US is estimated to range from 40 – 100 mg/day, with a much lower intake rate of nitrite estimated to range from 0.3 – 2.6 mg/day (OEHHA, 2018). A systematic review assessing global dietary intake of nitrates, including through both food and water, estimated the median daily nitrate intake at 108 mg/day (Babateen et al., 2018).

Ingestion of nitrate from drinking water and food results in urinary nitrate levels in a dose-dependent manner (van Maanen et al., 1996). After ingestion, nitrate is excreted in the urine as the nitrate anion. Table 1 shows urinary nitrate anion levels in the general population for 2015 – 2016 reported by the National Health and Nutrition Examination Survey (NHANES).

Table 1: Urinary nitrate levels (mg/L) in the general population (adapted from CDC, 2016)

Population	Geometric mean (95% CI)	50th percentile (95% CI)	95th percentile (95% CI)
Total population	44.5 (42.4-46.7)	48.6 (44.9-50.6)	140 (125-155)
Age 3-5 years	46.6 (42.4-51.2)	48.1 (43.0-53.1)	147 (127-209)
Age 20+ years	43.2 (40.7-45.9)	46.8 (43.4-49.9)	139 (123-165)

CI – confidence interval

Populations Evaluated in this Assessment

This health assessment focuses on characterizing potential exposures to populations that could be exposed to nitrate-contaminated groundwater in the LYV. Several populations were selected to represent a range of potential exposures. The populations evaluated in this health assessment are:

- Infants of 0 to 3 months. This is the most sensitive population for methemoglobinemia, and the first three months is when methemoglobinemia is most likely to occur (OEHHA, 2018; EPA, 1991).
- Pregnant individuals with a gestation period of 40 weeks. After infants, pregnant individuals are the populations most at risk for health effects from elevated nitrate exposure in drinking water (US Agency for Toxic Substances and Disease Registry (ATSDR), 2014b).
- Adults with an average lifespan of the general population of 78 years (EPA, 2011). Adults can be susceptible to methemoglobinemia from elevated nitrate ingestion, but aren't as sensitive as infants (OEHHA, 2018). The full lifespan of the general population was assessed to be health protective.

The elderly population, defined as individuals 65 years and older, was not assessed as a population of concern in this risk assessment. The age range of the adult population included in this assessment is inclusive of the elderly population. No research has been conducted examining the deleterious health effects of elevated nitrate levels in drinking water on the elderly population. Most of the literature available examines the positive impacts of nitrate supplementation on this age range. Nitrate and nitrite are metabolized in the body into nitric oxide, and this process declines with age (Torregrossa et al., 2011). Decreased nitric oxide production has been linked to multiple age-related diseases, and so nitrate supplementation is thought to improve health outcomes in the elderly through this metabolic pathway (Torregrossa et al., 2011). For example, older women who consume ≥89.0 mg/day nitrate exhibited greater muscle strength and physical function compared to older women who consume less nitrate (Sim et al., 2019). A high nitrate diet can also improve blood flow in the brain areas involved in executive functioning in older adults (Presley et al., 2011). Additionally, supplementation with nitrates may help prevent senescence-related liver function decline, as shown in animal studies (Wang et al., 2018).

There is limited evidence that children are a vulnerable population from elevated nitrate exposure from drinking water. Drinking water containing up to 111 mg/L nitrate-nitrogen did not result in methemoglobinemia in children in an epidemiological study conducted in the US (Craun et al., 1981). Several studies found that children may be at elevated risk for hypothyroidism, and more specifically goiter, from nitrate levels in drinking water of at least 51 mg/L or 75 mg/L (reported as nitrate, equivalent to 11.5 nitrate-nitrogen and 16.9 nitrate-nitrogen, respectively) (Tajtakova et al., 2006; Gatseva and Argirova, 2008). However, an analysis of these studies by OEHHA (2018) revealed multiple issues that disrupt interpretation of the results, including lack of adjustment for confounders (such as nitrates in food, diet, age, tobacco status), iodine status, potential measurement bias, lack of information about the wells, and lack of information of other sources of nitrate exposure (OEHHA, 2018). Given the uncertainty in these studies, the risk for children from the ingestion of nitrate in drinking water was not calculated in this health assessment.

No studies were located examining the effects of nitrate ingestion in immunocompromised individuals. Therefore, the immunocompromised were not assessed in this health assessment. Furthermore, ATSDR (2017a) determined there is no significant evidence indicating immunological or lymphoreticular effects in humans or animals following oral exposure to nitrate or nitrite (ATSDR, 2017a).

While not examined in this health assessment, other health factors can increase an individual's vulnerability to methemoglobinemia from elevated nitrate ingestion. Anemia, cardiovascular disease, lung disease, and sepsis all increase risk for methemoglobinemia (ATSDR, 2014b). Additionally, genetic factors such as a deficiency in nicotinamide adenine dinucleotide (NAD) + hydrogen (H) diaphorase, cytochrome b5 reductase, pyruvate kinase, red blood cell (RBC) methemoglobin reductase, and/or glucose-6-phosphate dehydrogenase can lead to methemoglobinemia (OEHHA, 2018; ATSDR, 2014b). Reduced gastric acidity can also increase risk for methemoglobinemia, and infants suffering from diarrhea are also at increased risk for methemoglobinemia (OEHHA, 2018). Substance abuse, such as with cocaine or drugs taken with volatile nitrite inhalers, can also lead to methemoglobinemia (ATSDR, 2014b).

Exposure Pathways

For any contaminant to be a human health concern, the contaminant must be present at a high enough concentration to cause adverse health effects, and there must be a defined route of exposure. The exposure to contaminants in drinking water where someone has swallowed (ingestion), breathed (inhalation), or had contact with their skin (dermal) would be a defined route of exposure. This health assessment was conducted to respond to Petitioners who petitioned the EPA for Emergency Action under Section 1431 of the SDWA to address the nitrate-contaminated groundwater in the LYV. To address the concerns of the Petitioners, the ingestion route of exposure will be assessed in this health assessment. As described previously, nitrate is highly soluble in water, and has been well characterized as a groundwater contaminant in the LYV through multiple previous environmental investigations. Therefore, the primary route of exposure is ingestion of drinking water.

A previous study conducted in the LYV reported that very few infants (14 out of 677), which are the most vulnerable population to adverse health effects from nitrate exposure, consumed high nitrate-containing foods (VanDerslice, 2007). Therefore, this health assessment does not include ingestion of nitrates through food as an exposure pathway.

Inhalation of nitrates is not considered a significant route of exposure, unless the individual is using inhalant drugs that contain nitrates. Dermal contact is also not considered a significant route of exposure, unless the individual is using topical medications that contain nitrates (ATSDR, 2014a). As drug use is not connected to groundwater contamination, this health assessment will only address risk from nitrate exposure through ingestion.

Data Analysis

To assess risk for residents of the LYV from groundwater contaminated with nitrates, data representing drinking water for Yakima and Benton counties was analyzed. This assessment does not calculate risk for individual domestic drinking water wells but gives a more general assessment of risk for Yakima and Benton counties for the populations of concern discussed in the previous section. For each county, data from both public water systems and private domestic wells was collected. While not representative of groundwater conditions, the nitrate levels detected in public water systems were included to represent reference levels and compare the resulting health risk estimates with those calculated from nitrate levels detected in private domestic wells. Additionally, nitrate concentrations were available from groundwater monitoring wells located in GWMA in Yakima County. Data statistics were calculated using a widely accepted statistics calculation software product provided by the EPA, ProUCL (version 5.1) (EPA, 2016). To be health protective, the 95th percentile (upper bound) of the nitrate concentration data for groundwater collected from wells is used in this health assessment.

Appendix B contains a summary of the nitrate concentrations for groundwater samples collected from wells used in this health assessment.

Yakima County

Ecology's EIM database was utilized to find data that characterizes nitrate concentrations in Yakima County private domestic wells (Ecology, 2022a). Specifically, well data from the Ambient Groundwater Monitoring Network (AGMN) was used. The AGMN was recommended by GWAC and established by Ecology to evaluate the effectiveness of nitrate reduction practices in Yakima County. The AGMN includes 34 groundwater monitoring wells that were installed for ambient groundwater sample collection in GWMA in Yakima County. The AGMN also sampled 136 private domestic wells available for sampling in the area. These combined wells that make up the AGMN provide data to assess the ongoing health of the aquifer. The AGMN was initially utilized to collect water quality measurements quarterly over two years and has been used annually since to monitor groundwater quality.

Residents of the LYV do not consume water from the monitoring wells and are not expected to drink this water in the future. Still, these samples were included to give a snapshot of potential future impacts to groundwater and to private domestic well water quality. Water may travel from the aquifer sampled by the monitoring wells to the groundwater that serves private domestic wells. The monitoring wells are evenly distributed across the LYV GWMA, and so give a broad snapshot of the health of the aquifer. Additionally, these wells sample water that is impacted by surface activities that may contribute to nitrate contamination as it transitions into the ground (Redding, 2021). Therefore, the monitoring wells can serve as an early warning system for groundwater contamination for the private domestic wells.

Monitoring wells are constructed differently than private domestic drinking water wells. The monitoring wells in this study are screened across the top of the aquifer, which allows detection of nitrate concentrations as it enters groundwater. Impacts from land use activities are observed sooner in monitoring wells than in the private domestic wells, which are usually drilled deeper and screened across a wider depth of the aquifer. Water collected from private domestic wells indicates the quality of the water that the residents are currently drinking. The monitoring wells act as an indicator of the health of the aquifer and will likely show improvements or deleterious impacts to groundwater quality sooner than the private domestic wells.

The following filtering criteria were used in this dataset:

- Private domestic well samples and monitoring well samples were separated into their own respective datasets. Monitoring well samples were identified according to “MW” or “PS” in their location ID.
- Data were separated by season. July through September 2021 represents summer, October through December 2021 represents fall, and January through April 2022 represents winter.
- Field replicates were removed.
- Result parameter was listed as “Nitrate + Nitrite as N.”
- Samples with comments including, “Well observed dry upon arrival” and “Listed as SS-162 on LAR” were removed.
- Samples with U data qualifiers were included.
- Sample LYV-ZI-052 was removed because it is an irrigation well.

This resulted in data with characteristics captured in Table 2.

Table 2: Statistical summary of nitrate-N concentrations in private domestic wells in Yakima County

Season	Type of well	Number of samples	Minimum (mg/L)	Mean (mg/L)	95th percentile (mg/L)	Maximum (mg/L)
Summer	Private domestic	136	0.01	5.54	15.2	39.9
Summer	Monitoring	32	0.01	16.03	39.1	96.4
Fall	Private domestic	136	0.01	5.28	13.8	42.0
Fall	Monitoring	32	0.01	16.3	38.7	90.4
Winter	Private domestic	136	0.01	5.56	14.3	40.6
Winter	Monitoring	32	0.01	14.9	36.2	76.4

DOH's Sentry database was utilized to find data that characterizes nitrate concentrations in Yakima County public water system (Sentry, 2022). "Water Quality Data By County, Year And Analyte Group" was downloaded for Yakima County for the years 2021 – 2022, and "IOC – Inorganic Contaminants" was specified as the analyte group.

The following filtering criteria were used in this dataset:

- Transient Non-Community (TNC) water system results were removed. A TNC is "a public water system that provides water in a place such as a gas station or campground where people do not remain for long periods of time" (EPA, 2021b). Therefore, these data ware removed because it characterizes water in areas where people do not remain for long periods of time. Therefore, the exposure duration (ED) would not represent the actual duration of exposure to this water system type.
- Both Group A and B water systems were included.
- Data were separated by season to match seasonal delineations in GWMA's AGMN private domestic well data. July through September 2021 represents summer, October through December 2021 represents fall, and January through April 2022 represents winter.
- Result parameters included "Nitrate-suite" and "Total nitrate/nitrite."
- Pre-Treatment / Raw (PT/R) results were removed because this represents water that will not be consumed.

This resulted in data with characteristics captured in Table 3.

Table 3: Statistical summary of nitrate-N concentrations in public water system wells in Yakima County

Season	Number of samples	Minimum (mg/L)	Mean (mg/L)	95th percentile (mg/L)	Maximum (mg/L)
Summer	53	0.07	2.47	8.45	9.05
Fall	23	0.06	2.31	7.18	8.10
Winter	20	0.10	2.35	7.15	7.76

Benton County

Ecology's EIM database was utilized to find data that characterizes nitrate concentrations in Benton County private domestic wells (Ecology, 2022a). Search criteria included: only locations that have groundwater data, field collection dates from 2015 – 2022, and result parameter is in the parameter group nutrients. 11 groundwater studies resulted from this search. Studies were excluded if they used a small sampling area (such as one property), had fewer than 10 samples, or assessed pretreated water. The only study remaining was the Groundwater Nitrate Characterization, Monitoring and Stakeholder Engagement study (2015 – 2018). This study was designed to characterize the nitrate concentrations, distribution, and extent in Benton County groundwater (Ecology, 2015).

The following filtering criteria were used in this dataset:

- Result parameters and method included "Nitrogen (as Nitrate, NO_3^-)."
- Sample replicates were removed.
- Field replicates were removed.
- Sample composites were removed.
- Data qualifiers included J ("Analyte was positively identified. The reported result is an estimate") and E ("Reported result is an estimate because it exceeds the calibration range") (Ecology, 2022c).
- Dissolved-only fraction samples were removed. Total fraction samples, which are unfiltered and so reflect total nitrate concentration (Ecology, 2015), remained.
- Samples with comments including, "analyzed outside of 48 hr holding time," were removed.
- Samples collected prior to 2018, the last year of the study, were removed.

2021 and 2022 samples were available for Benton County and Yakima County public water systems, as well as Yakima County private domestic wells and groundwater monitoring wells. Additionally, these samples were evenly distributed between the seasons, allowing risk to be calculated by season. Samples only up to 2018 were available in this Benton County Groundwater Nitrate Characterization, Monitoring and Stakeholder Engagement study dataset, and they were not evenly distributed by season. Therefore, risk was calculated for the year 2018 only, rather than by season.

This resulted in data with characteristics captured in Table 4.

Table 4: Statistical summary of nitrate-N concentrations in private domestic wells in Benton County

Number of samples	Minimum (mg/L)	Mean (mg/L)	95th percentile (mg/L)	Maximum (mg/L)
33	0.10	6.0	21.1	26.6

DOH's Sentry database was utilized to find data that characterizes nitrate concentrations in Benton County public water system (Sentry, 2022). "Water Quality Data By County, Year And Analyte Group" was downloaded for Benton County for the years 2021 – 2022, and "IOC – Inorganic Contaminants" was specified as the analyte group.

The following filtering criteria were used in this dataset:

- Transient Non-Community (TNC) water system results were removed. A TNC is "a public water system that provides water in a place such as a gas station or campground where people do not remain for long periods of time" (EPA, 2021b). Therefore, this data was removed because it characterizes water in areas where people do not remain for long periods of time. Therefore, the exposure duration (ED) would not represent the actual duration of exposure to this water system type.
- Both Group A and B water systems were included.
- Data were separated by season to match seasonal delineations in GWMA's AGMN private domestic well data. July through September 2021 represents summer, October through December 2021 represents fall, and January through April 2022 represents winter.
- Result parameters included "Nitrate-suite" and "Total nitrate/nitrite."
- Pre-Treatment / Raw (PT/R) results were removed because this represents water that will not be consumed.

This resulted in data with characteristics captured in Table 5.

Table 5: Statistical summary of nitrate-N concentrations in public water system wells in Benton County

Season	Number of samples	Minimum (mg/L)	Mean (mg/L)	95^{th} percentile (mg/L)	Maximum (mg/L)
Summer	27	0.05	3.66	5.40	32.2
Fall	17	0.05	3.03	8.67	9.01
Winter	40	0.50	3.53	7.77	8.80

Evaluating Non-cancer Hazards

To evaluate the potential for non-cancer adverse health effects that may result from exposure to contaminated water or other media (i.e., soil, air), a dose is estimated for the contaminant. These doses are calculated for exposure scenarios in which a person might be exposed to the contaminated media. The formula for this dose is included in Appendix A.

The estimated dose for each exposure scenario is then compared to the minimal risk level (MRL). MRLs are an estimate of the daily human exposure to a contaminant that is likely to be without considerable risk of adverse health effects during a specified duration of exposure. If MRLs have not been established for a contaminant, DOH uses EPA's reference dose (RfD). RfDs are doses below which non-cancer adverse health effects are not expected to occur.

MRLs and RfDs are derived from toxic effect thresholds obtained from epidemiological and animal studies. These thresholds are derived from either the lowest-observed adverse effect level (LOAEL), or preferably the no-observed adverse effect level (NOAEL) for the contaminant. In human and animal studies, the LOAEL is the lowest dose of a contaminant that results in adverse health effects, and the NOAEL is the highest dose of a contaminant that does not result in any adverse health effects. To help account for uncertainty present in the epidemiological and animal studies, the NOAEL or LOAEL is divided by uncertainty factors (UFs) to produce the lower and more health protective MRL or RfD. The equation for an MRL or RfD is shown below.

$$MRL\ or\ RfD = \frac{NOAEL\ or\ LOAEL}{UF}$$

If an exposure dose exceeds the MRL or RfD of that contaminant, it does not necessarily mean that adverse health effects will occur, only that further toxicological evaluation is warranted. This evaluation includes comparing the site-specific estimated exposure dose to doses from animal and human studies that showed either an effect level or a no effect level. This comparison, combined with other toxicological information, such as sensitive populations and metabolism, is used to determine the risk for specific harmful effects. When the exposure dose exceeds the MRL or RfD, this results in a hazard quotient (HQ) greater than one. The equation for the HQ is shown below.

$$HQ = \frac{Exposure\ dose}{RfD}$$

Exposure assumptions, estimated exposure doses, and hazard quotients for estimating nitrate exposures for drinking water sourced from the LYV are found in Appendix A.

A summary of the RfDs used in this health assessment are included in Table 6.

Table 6: RfDs used in this health assessment

Population	RfD	Unit	Reference
Infant	1.6	mg nitrate-nitrogen/kg-d	EPA, 1991
Adult	1.6	mg nitrate-nitrogen/kg-d	EPA, 1991
Pregnant individuals	0.267	mg nitrate-nitrogen/kg-d	Calculated, see section titled Derivation of RfD for Pregnant Individuals

Methemoglobinemia

Methemoglobinemia, which is frequently referred to as blue baby syndrome, is characterized by elevated levels of methemoglobin in the blood. Methemoglobin is a type of hemoglobin in which the iron is reduced to its ferric (3+) valence state, rendering it unable to transport oxygen and leading to cyanosis and hypoxia (Avery, 1999). Cyanosis is a bluish color in the skin and indicates hypoxia, which is when the blood contains insufficient levels of oxygen to support function. Symptoms of methemoglobinemia usually present when methemoglobin levels elevate to at least 10 to 20% of total hemoglobin (OEHHA, 2018). Infants are at particular risk for methemoglobinemia because their stomachs are less acidic than adult stomachs (Ward et al., 2018). The elevated pH of infant stomachs supports the growth of nitrate-reducing bacteria, leading to increased levels of nitrites (OEHHA, 2018). Nitrite can then bind to hemoglobin and convert it to methemoglobin (Ward et al., 2018). Additionally, infants have lower nicotinamide adenine dinucleotide phosphate (NADP) (H+)-cytochrome b5 reductase activity, which converts methemoglobin to hemoglobin, leading to reduced methemoglobin to hemoglobin metabolism in infants (Johnson, 2019). Infants under three months of age also have increased susceptibility to methemoglobinemia because fetal hemoglobin is more readily oxidized to methemoglobin than adult hemoglobin during this age range (OEHHA, 2018).

The presence of nitrate in drinking water has been shown to increase the risk for the development of methemoglobinemia in infants at levels above 10 mg/L, which is the current federal MCL established by the EPA for nitrate-nitrogen. Fan et al. (1987) reviewed the toxicological literature to examine the adequacy of the MCL for nitrate to protect against methemoglobinemia. Fan et al. (1987) reaffirmed that the MCL of 10 mg nitrate-N/L (and 45 mg nitrate/L) is protective of infants against methemoglobinemia, with the observation that no clinical methemoglobinemia was observed in populations with drinking water concentrations less than 10 mg nitrate-N/L, and only 2.3% of the cases reviewed concerned infants consuming water with 10 – 20 mg nitrate-N/L. Furthermore, Fan et al. (1987) found that neither nitrate nor nitrite were detected in breast milk (Fan et al., 1987). EPA converted the MCL of 10 mg nitrate-N/L to an RfD for methemoglobinemia of 1.6 mg nitrate-N/kg-d for infants (EPA, 1991). This RfD is defined for nitrate-nitrogen, which is inclusive of nitrite.

A negligible amount of nitrates are transferred from mother to baby via breastfeeding, especially if the mother is consuming water with a concentration of 100 mg NO_3^-/L or less (Dusdieker et al., 1996). Therefore, infant risk calculations will assume 100% of infants in the LYV are formula-fed, and the drinking water intake rate will not be adjusted to account for breastfeeding.

Methemoglobinemia can also occur in adults. About 1% of adult hemoglobin exists as methemoglobin under normal physiological conditions; as with infants, levels of 10 to 20% methemoglobin circulating in blood produce symptoms of methemoglobinemia (Fan et al., 1987). For adults, this corresponds to daily doses estimated to be in the range of 33 - 150 mg/kg-body weight, as determined by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (Sadler et al., 2016). JECFA determined an acceptable daily intake (ADI) of 3.7 mg nitrate ion/kg-body weight-day is protective against methemoglobinemia caused by salivary nitrite converted from nitrate added to food (European Food Safety Authority (EFSA), 2017). The ADI is the amount of a compound that can be ingested either by food or in drinking water over a lifetime without causing health effects. ADIs can only be derived for compounds without genotoxic or carcinogenic effects; EFSA did not find evidence for genotoxicity or carcinogenicity in *in vitro* and animal studies for nitrate, respectively (Mortensen et al., 2017). As the EPA RfD for methemoglobinemia is specific to nitrate-nitrogen in drinking water, whereas the ADI is specific to nitrate ion added to food, the RfD was used to characterize risk to the adult population.

Estimated exposure doses, exposure assumptions, and hazard quotients for populations of interest vulnerable to methemoglobinemia from nitrate ingestion are presented in Appendix A. Based on exposure estimates calculated in Appendix A, infants are expected to be at risk for methemoglobinemia by consuming drinking water from private domestic wells in either Yakima or Benton County. However, infants are not expected to be at risk for methemoglobinemia by ingesting water from public water systems in either Yakima or Benton counties. Risk estimates for infants calculated using exposure parameters derived from VanDerslice (2007), a previous study conducted in the LYV, are shown in the VanDerslice (2007) Risk Estimates section**.** This study is described more in depth in the Standard vs VanDerslice (2007) Risk Estimates section.

Additionally, as mentioned previously, samples from groundwater monitoring wells in Yakima County were included to give a snapshot of and assess risk for future private domestic well conditions. While infants are not expected to directly consume water from these monitoring wells, hazard quotients indicate the concentrations in the groundwater would constitute increased risk to infants for methemoglobinemia.

Exposure estimates and risk for methemoglobinemia were also calculated for adults exposed to drinking water in Yakima and Benton counties. For all seasons and all types of wells, adults are not expected to experience methemoglobinemia from exposure to nitrate.

Reproductive Effects

The ingestion of drinking water containing elevated levels of nitrate during pregnancy has been considered a risk factor for adverse pregnancy outcomes such as birth defects, premature births, and low birth weight in epidemiological studies (Ward et al., 2018). However, several reviews examining these relationships have found issues in the currently available epidemiological studies, such as multiple confounding factors, the absence of dose-response relationships, unsubstantiated self-reports of water ingestion, inadequate analysis of potentially confounding toxicants other than nitrates/nitrites, and lack of accounting for dietary nitrate/nitrite ingestion (OEHHA, 2018; ATSDR, 2017a). Therefore, ATSDR determined the results of these studies are not adequate to be used for quantitative risk assessment (ATSDR, 2017a).

Pregnant individuals are expected to be most at risk for health effects from nitrate exposure around the 30th week of pregnancy due to several reasons. Around the 30th week of pregnancy, blood volume peaks where plasma concentrations are greater than red blood cells, resulting in anemia (ATSDR, 2017c). Additionally, oxidative stress peaks at the 30th week, and because pregnancy increases oxygen demand in the body, reduces the rates of methemoglobin to hemoglobin conversion (ATSDR, 2017c).

Due to inadequate data concerning whether levels of nitrates less than the federal MCL of 10 mg/L nitrate-nitrogen can cause adverse pregnancy outcomes, Manassaram et al. (2010) conducted a longitudinal study examining 357 pregnant women consuming water with nitrate levels less than the MCL in Minnesota. The authors did not find any association between methemoglobin levels in pregnant women and exposure to nitrate in drinking water at levels less than 10 mg/L nitrate-nitrogen. Additionally, the pregnant women followed throughout pregnancy showed a decrease in methemoglobin levels with increasing gestational duration, providing counterevidence to the hypothesis that methemoglobin levels increase throughout pregnancy and peaking at the 30th week (Manassaram et al., 2010).

Despite the inconsistencies between the studies examining adverse reproductive outcomes from elevated nitrate ingestion, to be health protective, pregnant individuals were considered a vulnerable population for this health assessment. Additionally, due to the equivocal evidence concerning whether increased susceptibility for health effects occurs at the 30th week, the entire gestational period of 40 weeks was assessed for risk in this health assessment.

EPA and ATSDR have not developed MCLs or MRLs for reproductive effects from nitrates, respectively. Therefore, an RfD was calculated for pregnant individuals based on the MCL of 10 mg/L nitrate-N. This calculation is shown in the Derivation of RfD for Pregnant Individuals section.

Estimated exposure doses, exposure assumptions, and hazard quotients for populations of interest vulnerable to reproductive effects from nitrate ingestion are presented in Appendix A.

Based on exposure estimates calculated in Appendix A, pregnant individuals are expected to be at risk for reproductive effects by consuming drinking water from private domestic wells in either Yakima or Benton County. Additionally, as mentioned previously, samples from groundwater monitoring wells in Yakima County were included to give a snapshot of and assess risk from future private domestic well conditions. While pregnant individuals are not expected to directly consume water from these monitoring wells, hazard quotients indicate the concentrations in the groundwater would constitute increased risk to pregnant individuals for adverse reproductive effects.

Exposure estimates and risk were also calculated for pregnant individuals exposed to drinking water from public water systems in Yakima and Benton counties. For all seasons, pregnant individuals are not expected to experience adverse reproductive effects from exposure to nitrate from public water systems.

Thyroid

Nitrate may impact thyroid function by competitively inhibiting iodide uptake by the sodium-iodide symporter (NIS) (Ward et al., 2018). Uptake of iodide by the NIS results in the production of triiodothyronine (T3) and thyroxine (T4) thyroid hormones, and disruption of this uptake can lead to hypothyroidism (OEHHA, 2018). Indeed, a study concerning children consuming nitrate-contaminated water with levels ranging from 11 to 61 mg/L nitrate-nitrogen showed an increased prevalence of hypothyroidism (Rádiková et al., 2008). However, epidemiological studies such as Rádiková et al. (2008) and others examining the impact of elevated nitrate intake via drinking water have been shown to contain issues such as a lack of adjustment for iodine status, lack of adjustment for confounders such as dietary intake of nitrate or iodine, and lack of adjustment for individual well contamination with nitrate, making interpretation difficult (OEHHA, 2018).

To remove the impact of dietary iodine intake on the effect of nitrate ingestion via drinking water on the thyroid, volunteers consumed an iodine-restricted diet in a study by Hunault et al. (2007). After exposure to 380 mg/L nitrate (85 mg/L nitrate-nitrogen) a day, no evidence of uptake inhibition of radioactive iodine was observed, and T3, T4, and other thyroid hormone levels were not impacted (Hunault et al., 2007). Levels as low as 2.46 mg/L nitrate-nitrogen in drinking water, in a study in which dietary nitrate intake was accounted for, have been shown to have no association with hypothyroidism or hyperthyroidism (Ward et al., 2010).

EPA and ATSDR have not developed MCLs or MRLs, respectively, for adverse effects on the thyroid from nitrate ingestion. As nitrate levels less than the MCL have not been shown to impact thyroid function, this health assessment does not estimate risk for health effects on the thyroid from nitrate contamination in the LYV.

Evaluating Cancer Hazards

The consumption of processed meats is considered to increase the risk for gastric cancer due to the formation of carcinogenic nitrosamines, such as N-nitrosodimethylamine (NDMA) (Song et al., 2015). Nitrosamines are formed in processed foods through a reaction of secondary or tertiary amines with a metabolite of nitrite, nitrous anhydride (Scanlan, 1983). The addition of nitrates to processed foods can also lead to nitrosamine formation (Song et al., 2015). Nitrosamines can also form in the gastric environment after the addition of nitrates and foods such as milk, cheese, and slurried meals of fried eggs, bread, butter, cheese, biscuits, milk, and luncheon meat (OEHHA, 2018).

The carcinogenicity of ingested nitrate has been assessed by multiple public health agencies and in epidemiological studies. According to a recent assessment of health effects from ingested nitrates, JECFA does not consider nitrate to be genotoxic nor carcinogenic (EFSA, 2017). EPA considers the literature showing an association between exposures to nitrate and cancer in adults and children to be conflicting and inadequate (ATSDR, 2017b). Specifically, the literature examining cancer risk from nitrate exposure via drinking water is also considered inadequate (Fan & Steinberg (1996). IARC also concluded there is inadequate evidence for the carcinogenicity of nitrate in food or drinking water, but that the ingestion of nitrate under endogenous nitrosating conditions is probably carcinogenic to humans (2A) (IARC, 2010). EPA has not determined a cancer slope factor for nitrate. The NRC Subcommittee on Nitrate and Nitrite in Drinking Water concluded that nitrate (and nitrite) in drinking water is unlikely to increase risk for cancer (NRC, 1995). Their conclusion was based on the inadequate evidence from epidemiological studies, as well as a lack of evidence from animal studies when the carcinogenicity of nitrate was assessed in the absence of exposure to nitrosatable amines (NRC, 1995).

The association between stomach cancer and ingestion of nitrates has been examined. A meta-analysis of 19 studies examining the carcinogenicity of nitrates did not find a significant association between nitrate ingestion and stomach cancer (Song et al., 2015). A dose-response analysis indicated reduced risk for stomach cancer from ingestion of nitrate concentrations ranging from about 66.4 to 220 mg/day (about 15 to 49 mg/day nitrate-nitrogen) (Song et al., 2015). Another meta-analysis of 48 studies found a positive association with stomach cancer and nitrate in drinking water; however, this significance disappeared when the odds ratios were pooled (Essien et al., 2022). Temkin et al. (2019) conducted a meta-analysis of eight studies assessing the association between nitrate-contaminated drinking water and colorectal cancer, and found a positive association corresponding to a one-in-one million cancer risk level at 0.14

mg/L nitrate in water. A dose-response analysis was conducted using the studies in the meta-analysis, resulting in a relative risk (RR) of 1.04 (95% CI 1.01-1.07). However, this meta-analysis included studies (Espejo-Herrera et al., 2016; De Roos et al., 2003) that did not control for red meat consumption, which is a known risk factor for colorectal cancer. These two studies conveyed the highest study weights in the overall risk estimate of the meta-analysis (10.28% and 14.77%, respectively). As the RR was close to one, and the two studies that included consumers of red meat carried the most weight in the meta-analysis, this indicates the RR for drinking water contaminated with nitrate and colorectal cancer may drop to less than one if the two studies were removed from the analysis (Temkin et al., 2019). Taken together, the results of these meta-analyses indicate the association between drinking water contaminated with nitrate and colorectal cancer is inconclusive. Additionally, JECFA concluded that there is no evidence for a positive association between ingestion of nitrate and esophageal cancer, gastric cancer, and colorectal or colon or rectum cancer (Mortensen et al., 2017).

The literature examining risk for bladder cancer from exposure to nitrates is also inconclusive. Jones et al. (2016) analyzed a cohort of postmenopausal women who consumed nitrate above 5 mg/L in drinking water for over 10 years and found an increased risk for bladder cancer. However, Jones et al. (2016) did not find an increased risk of bladder cancer from the ingestion of dietary nitrate (Jones et al., 2016). Espejo-Herrera et al. (2015) conducted a case-control study examining the association of bladder cancer in residents of Spain with nitrate levels from 2.1 mg/L to 12.0 mg/L in drinking water, and did not find a positive association (Espejo-Herrera et al, 2015). A recent study examining ingested nitrate from drinking water and bladder cancer in New England also observed a positive association of increased risk of bladder cancer with nitrate concentrations above 2.07 mg/L; however, this was not significant (OR = 1.5, 95% CI = 0.97, 2.3) (Barry et al., 2020). A meta-analysis of five studies found no association between bladder cancer and chronic exposure to nitrate concentrations ranging from 0.21 to 3.09 mg/L (Arafa et al., 2022). JECFA concluded that there is insufficient evidence for a positive association between ingested nitrate and bladder cancer, and there is no evidence for a positive association between ingested nitrate and renal cancer (Mortensen et al., 2017).

The risk for thyroid cancer has also been examined. A meta-analysis of three studies found no association between thyroid cancer and nitrate ingestion above 5 mg/L nitrate-nitrogen in drinking water and food (Bahadoran et al., 2015). Interestingly, a recent geospatial analysis in California found a positive association between thyroid cancer and contaminated wells containing above 5 mg/L nitrate-nitrogen (Tariqi et al., 2021). JECFA concluded there is insufficient evidence for a positive association between ingested nitrate and thyroid cancer (Mortensen et al., 2017).

Overall, the literature is inconsistent or insufficient to conclude that ingesting nitrate in drinking water will increase risk of cancer. Additionally, a cancer slope factor established by a public health agency was not located for nitrate. EPA has not determined a cancer slope factor for nitrate. Therefore, this health assessment does not calculate the risk for cancer from ingesting nitrate-contaminated groundwater in the LYV.

Discussion

Public Health Implications

This health assessment calculated risk for vulnerable populations exposed to nitrate contamination in the groundwater of the LYV. Specifically, risks for methemoglobinemia to infants and adults, as well as adverse reproductive outcomes in pregnant individuals were calculated. Nitrate concentrations from private domestic wells and public wells in Yakima and Benton counties were used. Additionally, nitrate concentrations for groundwater samples collected from monitoring wells, which may predict private well water quality in the future, in Yakima County were also used. While residents of the LYV are not expected to ever consume water from the groundwater monitoring wells, these samples were included to give a snapshot of potential future private domestic well conditions as well as context on the health implications of the aquifer.

Exposure assumptions were used to estimate exposure doses and hazard quotients from the LYV. These are found in Appendix A.

Hazard quotients were calculated for adults and pregnant individuals drinking water from public water systems in Yakima and Benton counties using standard exposure parameters. They indicate that there is no risk for adverse health effects for these residents drinking water from the public water system for all seasons sampled (summer, fall, winter) (see the table below and Table 23, in Appendix A).

Table 7: HQs calculated for adults and pregnant individuals ingesting water from public wells

County	Season	Population	HQ
Yakima	Summer	Adults	0.15
	Fall	Adults	0.13
	Winter	Adults	0.13
	Summer	Pregnant individuals	0.85
	Fall	Pregnant individuals	0.72
	Winter	Pregnant individuals	0.72
Benton	Summer	Adults	0.09
	Fall	Adults	0.15
	Winter	Adults	0.14
	Summer	Pregnant individuals	0.54
	Fall	Pregnant individuals	0.87
	Winter	Pregnant individuals	0.78

Infant risk estimates were calculated in this health assessment using the standard exposure parameters used to derive the EPA RfD (EPA, 1991). These risk estimates indicate no adverse health risks are expected for infants exclusively drinking water from public water systems in Yakima and Benton counties (see the table below and Table 23, in Appendix A). For comparison, hazard quotients for infants for methemoglobinemia were estimated using alternative exposure parameters derived from the VanDerslice (2007) study in the LYV. Further discussion of this study is included in the Standard vs VanDerslice (2007) Risk Estimates section, and hazard quotients are shown in VanDerslice (2007) Risk Estimates section.

Table 8: HQs calculated for infants ingesting water from public wells

County	Season	Population	HQ
Yakima	Summer	Infants	0.85
	Fall	Infants	0.72
	Winter	Infants	0.72
Benton	Summer	Infants	0.54
	Fall	Infants	0.87
	Winter	Infants	0.78

Hazard quotients calculated for infants and pregnant individuals for methemoglobinemia and adverse reproductive outcomes, respectively, using standard exposure parameters for residents drinking water from private domestic wells in Yakima and Benton counties indicate increased risk for these health effects, for all seasons sampled (summer, fall, winter) (see the table below and Table 22, in Appendix A).

Table 9: HQs calculated for infants and pregnant individuals ingesting water from private wells

County	Season	Population	HQ
Yakima	Summer	Infants	1.52
	Fall	Infants	1.38
	Winter	Infants	1.43
	Summer	Pregnant individuals	1.52
	Fall	Pregnant individuals	1.38
	Winter	Pregnant individuals	1.43
Benton	All seasons	Infants	2.11
	All seasons	Pregnant individuals	2.11

Hazard quotients calculated for adults drinking water from private domestic wells in Yakima and Benton counties indicate no risk for methemoglobinemia, for all seasons sampled (summer, fall, winter) (See the table below and Table 22, Appendix A).

Table 10: HQs calculated for adults ingesting water from private wells

County	Season	Population	HQ
Yakima	Summer	Adults	0.27
	Fall	Adults	0.25
	Winter	Adults	0.26
Benton	All seasons	Adults	0.38

Hazard quotients calculated for infants and pregnant individuals for methemoglobinemia and adverse reproductive outcomes, respectively, using standard exposure parameters for hypothetical water consumption from groundwater monitoring wells in Yakima County for all seasons sampled (summer, fall, winter) indicate elevated risk for adverse health effects for these populations (see the table below and Table 24, Appendix A). The sample results from the groundwater monitoring wells resulted in the highest risk estimates calculated in this health assessment for infants and pregnant individuals. As discussed previously, the monitoring wells sample from a depth that is shallower than the depth that private domestic wells are located, and so don't necessarily represent future private well conditions. Still, these results indicate that users of private domestic wells, particularly vulnerable populations, in the LYV should closely monitor the water quality for increasing nitrate concentrations.

Table 11: HQs calculated for infants and pregnant individuals hypothetically ingesting water from monitoring wells

County	Season	Population	HQ
Yakima	Summer	Infants	3.91
	Fall	Infants	3.87
	Winter	Infants	3.62
	Summer	Pregnant individuals	3.91
	Fall	Pregnant individuals	3.87
	Winter	Pregnant individuals	3.62

Hazard quotients calculated for adults hypothetically drinking water from groundwater monitoring wells in Yakima County indicate no risk for methemoglobinemia, for all seasons sampled (summer, fall, winter) (see the table below and Table 24, Appendix A).

Table 12: HQs calculated for adults hypothetically ingesting water from monitoring wells

County	Season	Population	HQ
Yakima	Summer	Adults	0.69
	Fall	Adults	0.69
	Winter	Adults	0.65

Overall, DOH concludes that using water from the public water systems in Yakima and Benton counties is not expected to cause health effects. DOH also concludes that using water from private domestic wells in Yakima and Benton counties may cause adverse health effects in infants and pregnant individuals.

Environmental Justice Implications

As of 2013, over 20% of the population of Yakima County was at or above the poverty level, and at least 41% of the population identified as Hispanic/Latino (EPA, 2013b). The proportion of the population at or above the poverty level is now at least 14%, and the proportion has increased to at least 51% of the population that identifies as Hispanic/Latino in Yakima County in 2021 (United States Census Bureau, 2021). In Benton County, at least 9% of residents are below the poverty level, and 24% identifies as Hispanic/Latino (United States Census Bureau, 2021).

Residents living in rural areas of the counties are more likely to be served by private domestic wells rather than public water systems. Indeed, 34% of residents in the LYV use private well water (VanDerGeest et al., 2020) for domestic water uses, including drinking. A recent study found that private well water users of the LYV, who are predominantly Latino, were concerned about well water contamination but were also unaware of the current government nitrate/total coliform testing recommendations (VanDerGeest et al., 2020). Specifically, residents were unaware of the recommended testing frequency, testing costs, who to contact for testing, and how to test on their own without the aid of a government agency (VanDerGeest et al., 2020). Given the results of this health assessment indicating that private well users are at increased risk for methemoglobinemia, increased and robust outreach needs to be conducted within these communities to educate and assist residents on how to deal with the contamination.

As shown by the risk estimates calculated in this health assessment, vulnerable populations such as infants and pregnant individuals consuming water from private domestic wells are at increased risk for adverse health effects. Combined with the high proportions of minorities residing in the LYV, and the high proportion of residents living below the poverty level, this indicates the groundwater contamination likely constitutes a matter of environmental injustice for these populations.

Historical Comparisons

Nitrate concentrations were assessed in private well samples taken from Yakima and Benton counties in this health assessment. Nitrate concentrations were also assessed in samples collected from groundwater monitoring wells in Yakima County. The statistical summaries of these samples are included in the tables below for comparison with results from previous environmental studies conducted in the LYV.

Table 13: Statistical summary of nitrate-N concentrations in private domestic wells in Benton County

Number of samples	Minimum (mg/L)	Mean (mg/L)	95th percentile (mg/L)	Maximum (mg/L)
33	0.10	6.0	21.1	26.6

Table 14: Statistical summary of nitrate-N concentrations in private domestic wells in Yakima County

Season	Type of well	Number of samples	Minimum (mg/L)	Mean (mg/L)	95th percentile (mg/L)	Maximum (mg/L)
Summer	Private domestic	136	0.01	5.54	15.2	39.9
Summer	Monitoring	32	0.01	16.03	39.1	96.4
Fall	Private domestic	136	0.01	5.28	13.8	42.0
Fall	Monitoring	32	0.01	16.3	38.7	90.4
Winter	Private domestic	136	0.01	5.56	14.3	40.6
Winter	Monitoring	32	0.01	14.9	36.2	76.4

Previous environmental investigations have detected nitrate levels in the groundwater of the LYV.

VanDerslice (2007) assessed the association between methemoglobinemia in infants and nitrate-N levels in the drinking water of the LYV (VanDerslice, 2007). Table 5 of this study includes tap water nitrate-N levels for private wells, small water systems, and community systems. 95th percentile nitrate-N concentrations were not calculated in this study. Average and maximum nitrate-N levels reproduced from Table 5 of VanDerslice (2007) are shown in Table 15.

Table 15: Nitrate-N levels in tap water adapted from Table 5 of VanDerslice (2007)

Source of water	n	Mean (mg/L)	Maximum (mg/L)
Private well	399	4.6	35.6
Small water system	190	2.8	15.3
Community system	129	1.2	14.8

By comparing the nitrate-N levels in VanDerslice (2007) and this health assessment, it becomes clear that average and maximum nitrate-N levels in private domestic wells are similar between the two analyses, with slightly elevated nitrate-N levels in this health assessment. This health assessment did not separate nitrate-N levels in public water systems by small water system or community water system, so these concentrations cannot be compared.

EPA (2013b) conducted a study examining potential sources of nitrate contamination in the groundwater of the LYV. EPA measured nitrate concentrations from multiple land use areas. Samples were taken from two residential wells, from which nitrate-nitrogen was detected at concentrations of 23.4 and 72.2 mg/L nitrate-nitrogen (Table A1 in EPA, 2013b). The second sample concentration is much higher than the greatest maximum nitrate concentration detected in this health assessment a private domestic well of 42 mg/L for Yakima County in the Fall. However, comparison is difficult due to the small sample size taken in EPA, (2013b). Table A1 in EPA (2013b) also includes results of samples taken from wells upgradient of dairies, downgradient of dairies, dairy supply wells, downgradient of septic tanks, and downgradient of farms. These concentrations range from 0.05 to 72.2 mg/L nitrate-nitrogen.

USGS (2017) measured nitrate concentrations from 892 samples taken from 156 domestic drinking water wells in GWMA of Yakima County. Table 6 shows the concentrations in these wells ranged from 0.4 to 45.2 mg/L nitrate-nitrite. Further summary statistics aren't provided in USGS (2017). For comparison, the nitrate concentrations sampled from private domestic wells in Yakima County in this health assessment produced a range of 0.01 to 42 mg/L, which is about equivalent to the range produced in USGS (2017). This indicates nitrate concentrations have not changed much in scope between 2017 and the present in Yakima County.

Standard vs VanDerslice (2007) Risk Estimates

EPA used a standard drinking water ingestion rate and standard body weight in their derivation of the RfD (1.6 mg nitrate-nitrogen/kg-d) for methemoglobinemia in infants less than 3 months of age (EPA, 1991). This health assessment uses these exposure parameters to calculate the estimated daily dose of exposure to infants from nitrate-N.

A previous epidemiological study was conducted in the LYV assessing the association between methemoglobinemia in infants and nitrate-N levels in the drinking water (VanDerslice, 2007). VanDerslice (2007) includes exposure parameters derived from survey data focused on infants living in the LYV from September, 2004 to October, 2005. For comparison's sake, this health assessment also calculated risk for infant methemoglobinemia using the exposure parameters described in VanDerslice (2007).

Specifically, VanDerslice (2007) provided body weight for infants living in the LYV. Table 9 in VanDerslice (2007) provides body weights per month of age for a total sample size of 632 infants. The vulnerable age range for methemoglobinemia is the first three months of an infant's life (OEHHA, 2018; EPA, 1991). Therefore, an average body weight was calculated for infants aged 0 to 3 months using the data in Table 9 of VanDerslice (2007) for use in this health assessment. Table 9 includes mean body weights for infants aged 1 - <2 months, and 2 - <3 months (5.1 and 5.9 kilograms (kg), respectively), and a weighted average body weight of 5.58 kg was calculated. While body weights were not provided for infants aged 0 - <1 months to include in this calculation, 5.58 kg was considered proxy for the 0 to 3 months age range. This resulted in an average body weight of 5.58 kg for infants (0 to 3 months) residing in the LYV for this health assessment. This value is higher than the infant body weight used by EPA to calculate the RfD for infant methemoglobinemia (EPA, 1991).

VanDerslice (2007) also provided drinking water ingestion rates for infants living in the LYV. Table 10 in VanDerslice (2007) provides data on water consumption by month of age in 677 infants. Notably, while VanDerslice (2007) did survey if infants were breastfed in the LYV, only water that was in ingested food or formula was included in the drinking water ingestion rate. While it is never directly stated in this report, it does not appear that nitrates transferred via breastfeeding were accounted for in drinking water ingestion rates in Table 10. It has been shown that elevated levels of nitrate in drinking water do not transfer to breast milk (Dusdieker et al., 1996). Therefore, it is safe to assume that nitrate transfer via breastfeeding is an insignificant pathway and does not need to be accounted for in the derivation of drinking water ingestion rates for infants. The average drinking water ingestion rate for infants up to 3 months of age was calculated using data found in Table 10 of VanDerslice (2007). Table 10 includes mean ingestion rates for infants aged 1 - <2 months, and 2 - <3 months (0.27 and 0.35 L/d, respectively), resulting in a weighted average ingestion rate of 0.32 L/d. While ingestion rates were not provided for infants aged 0 - <1 months to include in this calculation, 0.32 L/d was considered proxy for the 0 to 3 months age range. For context, this value is lower than the drinking water ingestion rate for infants used by EPA to calculate the RfD for infant methemoglobinemia (EPA, 1991).

A comparison between VanDerslice (2007) and the standard exposure parameters used by EPA (1991) is included in Table 16.

Table 16: VanDerslice (2007) and EPA (1991) exposure parameters

Parameter	VanDerslice (2007)	EPA (1991)
Ingestion rate (L/d)	0.32	0.64
Body weight (kg)	5.58	4

These two sets of exposure parameters were used to calculate estimates of risk for infants for methemoglobinemia in the LYV. A comparison of these risk estimates is included in Table 17.

Table 17: Comparison of infant methemoglobinemia HQs Using parameters from VanDerslice (2007) and EPA (1991)

County	Description	VanDerslice (2007) HQs	EPA (1991) HQs
Yakima	Summer private wells	0.547147	1.518
	Fall private wells	0.498487	1.383
	Winter private wells	0.516509	1.433
	Summer monitoring wells	1.409317	3.91
	Fall monitoring wells	1.393818	3.867
	Winter monitoring wells	1.305871	3.623
	Summer public wells	0.304715	0.8454
	Fall public wells	0.258795	0.718
	Winter public wells	0.257786	0.7152
Benton	Private domestic wells	0.759085	2.106
	Summer public wells	0.194637	0.54
	Fall public wells	0.312645	0.8674
	Winter public wells	0.280061	0.777

As shown in the table above, risk estimates for infant methemoglobinemia are lower when calculated using parameters derived from the VanDerslice (2007) study, compared to risk estimates using the EPA (1991) exposure parameters. To provide context for this comparison, VanDerslice (2007) was a cross-sectional epidemiological study which surveyed families with infants aged 6 months or younger who lived in the LYV. Due to the cross-sectional nature of this study, exposure parameters were taken during the survey period of September 2004 to October 2005 and are representative of that period of time. Additionally, the study was conducted fifteen years ago. Therefore, the exposure parameters of the infants surveyed in this study do not necessarily represent the exposure parameters of infants residing in the LYV today.

The ingestion rate used by EPA (1991) is referenced from Davidson (1975). Specifically, the body weight and ingestion rate are derived from “an infant's normal requirements” of formula or breast milk, which is 160 mL/kg-d (Davidson, 1975). EPA (1991) assumes a standard 4 kg body weight, which when applied to 160 milliliters per kilogram per day (mL/kg-d) results in an ingestion rate of 0.64 L/d. While the 160 mL/kg-d of formula in Davidson (1975) is referred to as "an infant's normal requirement," it is not specifically stated to be an average, so it is not directly comparable to the average ingestion rate calculated from VanDerslice (2007).

Ultimately, the exposure parameters used by EPA (1991) are more conservative than those derived from VanDerslice (2007). This resulted in higher HQs calculated using the EPA (1991) parameters. Additionally, the use of these exposure parameters stays consistent with the values used to calculate the RfD for infant methemoglobinemia. Therefore, the HQs calculated using EPA (1991) parameters were used in this health assessment.

Conclusions

DOH concludes that consuming water from private domestic wells in the LYV may increase risk for methemoglobinemia in infants and adverse reproductive outcomes in pregnant individuals. Current nitrate levels in public water systems in Yakima and Benton counties are not expected to harm people's health. Additionally, nitrate levels in all well types in the LYV are not expected to increase risk for methemoglobinemia in adults.

Recommendations

DOH has several public health recommendations resulting from this health assessment to protect and improve the health of the LYV.

- More source control actions should be implemented to address nitrate contamination of the groundwater originating from irrigated and fertilized agriculture, CAFOs, septic systems, and other sources in the LYV.
- We recommend residents of the LYV who use private domestic wells for drinking water to get them tested for nitrate every year. If nitrate test results are 5 mg/L or higher, we advise re-sampling in six months.
- We recommend users get wells tested for nitrate more frequently than once a year if well construction and maintenance standards (e.g. compromised casing or seal) that are outlined in WAC 173-160 are not met.
- Do not boil water if it contains elevated nitrates. This will increase nitrate concentrations.
- Vulnerable populations should not use water containing nitrate concentrations above the MCL of 10 mg/L for drinking or food preparation (e.g., cooking, produce washing). Vulnerable populations include infants and pregnant individuals.

- Individuals with reduced gastric acidity should avoid consuming water containing nitrate concentrations above the MCL of 10 mg/L for drinking or food preparation (e.g., cooking, produce washing).
- Individuals with genetic conditions such as reduced NADH diaphorase, cytochrome b5 reductase, pyruvate kinase, RBC methemoglobin reductase, and/or glucose-6-phosphate dehydrogenase should avoid consuming water containing nitrate concentrations above the MCL of 10 mg/L for drinking or food preparation (e.g., cooking, produce washing).
- We recommend more education and communication to be given to residents of the LYV concerning frequency and resources for testing well water, with increased and robust outreach to underserved communities.

Public Health Action Plan

There are several actions planned to follow the publication of this health assessment.

- DOH will send this health assessment to the public water systems in Yakima and Benton counties, the local health districts and departments in the LYV, the Petitioners, and Ecology. This health assessment will also be publicly available on https://doh.wa.gov/community-and-environment/drinking-water/contaminants/nitrate.
- DOH will send a fact sheet summarizing the results and recommendations of this health assessment to private well users and local health departments in the LYV. This fact sheet will also be publicly available on https://doh.wa.gov/community-and-environment/drinking-water/contaminants/nitrate.
- As requested, DOH will review and evaluate any new data regarding nitrate contamination in drinking water and/or groundwater in the LYV.

References

Agency for Toxic Substances and Disease Registry (ATSDR). (2014a). What Are Routes of Exposure to Nitrates and Nitrites? Retrieved from https://www.atsdr.cdc.gov/csem/nitrate-nitrite/what_are_routes.html.

Agency for Toxic Substances and Disease Registry (ATSDR). (2014b). Who Is at Most Risk of Adverse Health Effects from Overexposure to Nitrates and Nitrites? Retrieved from https://www.atsdr.cdc.gov/csem/nitrate-nitrite/who_risk.html.

Agency for Toxic Substances and Disease Registry (ATSDR). (2017a). Toxicological profile for nitrate and nitrite. Atlanta, GA: Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services, Public Health Service. Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp204.pdf

Agency for Toxic Substances and Disease Registry (ATSDR). (2017b). What Are U.S. Standards and Regulations for Nitrates and Nitrites Exposure? Atlanta, GA: Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services, Public Health Service. Retrieved from https://www.atsdr.cdc.gov/csem/nitrate-nitrite/standards.html

Agency for Toxic Substances and Disease Registry (ATSDR). (2017c). Who Is at Most Risk of Adverse Health Effects from Overexposure to Nitrates and Nitrites? Atlanta, GA: Agency for Toxic Substances and Disease Registry, U.S. Department of Health and Human Services, Public Health Service. Retrieved from https://www.atsdr.cdc.gov/csem/nitrate-nitrite/who_risk.html

Anderson, B. (2016). Nitrate nitrogen (NO3-N) or nitrate (NO3-) – Know the Difference! University of Nebraska-Lincoln. Retrieved from https://newsroom.unl.edu/announce/beef/5891/33379

Arafa, A., Ewis, A., & Eshak, E. (2022). Chronic exposure to nitrate in drinking water and the risk of bladder cancer: a meta-analysis of epidemiological evidence. Public health, 203, 123–129. https://doi.org/10.1016/j.puhe.2021.11.019

Avery A. A. (1999). Infantile methemoglobinemia: reexamining the role of drinking water nitrates. Environmental health perspectives, 107(7), 583–586. https://doi.org/10.1289/ehp.99107583

Babateen, Fornelli, G., Donini, L. M., Mathers, J. C., & Siervo, M. (2018). Assessment of dietary nitrate intake in humans: a systematic review. The American Journal of Clinical Nutrition, 108(4), 878–888. https://doi.org/10.1093/ajcn/nqy108

Bahadoran, Mirmiran, P., Ghasemi, A., Kabir, A., Azizi, F., & Hadaegh, F. (2015). Is dietary nitrate/nitrite exposure a risk factor for development of thyroid abnormality? A systematic review and meta-analysis. Nitric Oxide, 47, 65–76. https://doi.org/10.1016/j.niox.2015.04.002

Barry, K. H., Jones, R. R., Cantor, K. P., Beane Freeman, L. E., Wheeler, D. C., Baris, D., Johnson, A. T., Hosain, G. M., Schwenn, M., Zhang, H., Sinha, R., Koutros, S., Karagas, M. R., Silverman, D. T., & Ward, M. H. (2020). Ingested Nitrate and Nitrite and Bladder Cancer in Northern New England. Epidemiology (Cambridge, Mass.), 31(1), 136–144. https://doi.org/10.1097/EDE.0000000000001112

Benton County. (2018). Benton County Groundwater Nitrate Community Action Plan. Benton County, Benton Conservation District, EA Engineering, Science, and Technology, Inc. PBC., Benton County Groundwater Stakeholder Committee. Retrieved from https://bentoncountywa.municipalone.com//files/documents/GroundwaterNitrateCommunityActionPlan217101233112818AM.pdf

Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). (2016). National Health and Nutrition Examination Survey Data. Hyattsville, MD: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, https://www.cdc.gov/exposurereport/report/pdf/Perchlorate%20and%20Other%20Anions%20NHANES-p.pdf.

Comly, H. (1945). Cyanosis in infants caused by nitrates in well water. J. Am. Med. Assoc. 129, 122. Retrieved from https://jamanetwork.com/journals/jama/article-abstract/275699.

Craun, Greathouse, D. G., & Gunderson, D. H. (1981). Methaemoglobin Levels in Young Children Consuming High Nitrate Well Water in the United States. International Journal of Epidemiology, 10(4), 309–317. https://doi.org/10.1093/ije/10.4.309

Davidson. (1975). Human nutrition and dietetics (6th ed.). Churchill Livingstone.

De Roos, A. J., Ward, M. H., Lynch, C. F., & Cantor, K. P. (2003). Nitrate in public water supplies and the risk of colon and rectum cancers. *Epidemiology (Cambridge, Mass.)*, *14*(6), 640–649. https://doi.org/10.1097/01.ede.0000091605.01334.d3

Drennan, M. (2013). Agricultural History of Yakima County. Yakima County. Retrieved from https://www.yakimacounty.us/DocumentCenter/View/2375/Agricultural-History-of-Yakima-County-PDF.

Dusdieker, Stumbo, P. J., Kross, B. C., & Dungy, C. I. (1996). Does Increased Nitrate Ingestion Elevate Nitrate Levels in Human Milk? Archives of Pediatrics & Adolescent Medicine, 150(3), 311–314. https://doi.org/10.1001/archpedi.1996.02170280081015

Ecology. Washington State Department of Ecology (Ecology). (2015). Quality Assurance Project Plan, Benton County Groundwater Nitrate Monitoring Study, Grant Number: WQC-

2015-BentCD-00102. Retrieved from https://apps.ecology.wa.gov/publications/documents/1610028.pdf.

Ecology. Washington State Department of Ecology (Ecology). (2022a). Environmental Information Management System (EIM). Retrieved from https://ecology.wa.gov/Research-Data/Data-resources/Environmental-Information-Management-database.

Ecology. Washington State Department of Ecology (Ecology). (2022b). Lower Yakima Valley Groundwater Management Area. Retrieved from https://ecology.wa.gov/Water-Shorelines/Water-quality/Groundwater/Protecting-aquifers/Lower-Yakima-Valley-groundwater.

Ecology. Washington State Department of Ecology (Ecology). (2022c). Valid Values - Data Qualifiers. Retrieved from https://apps.ecology.wa.gov/eim/help/ValidValues/DataQualifiers

EPA. United States Environmental Protection Agency (EPA). (1991). Integrated Risk Information System (IRIS), Chemical Assessment Summary, Nitrate. United States Environmental Protection Agency. Washington, D.C. Retrieved from https://iris.epa.gov/static/pdfs/0076_summary.pdf

EPA. United States Environmental Protection Agency (EPA). (2004). An Examination of EPA Risk Assessment Principles and Practices. Staff Paper. EPA/100/B-04/001. Retrieved from http://www.epa.gov/OSA/pdfs/ratffinal.pdf.

EPA. United States Environmental Protection Agency (EPA). (2011). Exposure Factors Handbook. United States Environmental Protection Agency. Washington, D.C. Retrieved from https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252.

EPA. United States Environmental Protection Agency (EPA). (2012). Water: Monitoring & Assessment 5.7 Nitrates. Retrieved from https://archive.epa.gov/water/archive/web/html/vms57.html

EPA. United States Environmental Protection Agency (EPA). (2013a). EPA Region 10 Administrative Order on Consent in the Matter of Yakima Valley Dairies. Retrieved from http://nationalaglawcenter.org/wp-content/uploads/2015/07/AOC_yakima_valley_dairies_march2013.pdf

EPA. United States Environmental Protection Agency (EPA). (2013b). Relation Between Nitrate in Water Wells and Potential Sources in the Lower Yakima Valley, Washington. EPA-910-R-13-004.

EPA. United States Environmental Protection Agency (EPA). (2016). ProUCL: Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations. Version 5.1. https://www.epa.gov/land-research/proucl-software

EPA. United States Environmental Protection Agency (EPA). (2019). Update for Chapter 3 of the Exposure Factors Handbook: Ingestion of Water and Other Select Liquids. United States Environmental Protection Agency. Washington D.C. EPA/600/R-18-259F. Retrieved from https://www.epa.gov/sites/production/files/2019-02/documents/efh_-_chapter_3_update.pdf.

EPA. United States Environmental Protection Agency (EPA). (2021a). Estimated Nitrate Concentrations in Groundwater Used for Drinking. Retrieved from https://www.epa.gov/nutrient-policy-data/estimated-nitrate-concentrations-groundwater-used-drinking#:~:text=While%20nitrate%20does%20occur%20naturally,2010).

EPA. United States Environmental Protection Agency (EPA). (2021b). Information about Public Water Systems. Retrieved from https://www.epa.gov/dwreginfo/information-about-public-water-systems

EPA. United States Environmental Protection Agency (EPA). (2022). National Primary Drinking Water Regulations. Retrieved from https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

Espejo-Herrera, Cantor, K. P., Malats, N., Silverman, D. T., Tardón, A., García-Closas, R., Serra, C., Kogevinas, M., & Villanueva, C. M. (2015). Nitrate in drinking water and bladder cancer risk in Spain. Environmental Research, 137, 299–307. https://doi.org/10.1016/j.envres.2014.10.034

Essien, E. E., Said Abasse, K., Côté, A., Mohamed, K. S., Baig, M., Habib, M., Naveed, M., Yu, X., Xie, W., Jinfang, S., & Abbas, M. (2022). Drinking-water nitrate and cancer risk: A systematic review and meta-analysis. Archives of environmental & occupational health, 77(1), 51–67. https://doi.org/10.1080/19338244.2020.1842313

European Food Safety Authority (EFSA). (2017). EFSA explains risk assessment, Nitrites and nitrates added to food. Retrieved from https://www.efsa.europa.eu/sites/default/files/corporate_publications/files/nitrates-nitrites-170614.pdf

Fan, Willhite, C. C., & Book, S. A. (1987). Evaluation of the nitrate drinking water standard with reference to infant methemoglobinemia and potential reproductive toxicity. Regulatory Toxicology and Pharmacology, 7(2), 135–148. https://doi.org/10.1016/0273-2300(87)90024-9

Fan, & Steinberg, V. E. (1996). Health Implications of Nitrate and Nitrite in Drinking Water: An Update on Methemoglobinemia Occurrence and Reproductive and Developmental Toxicity. Regulatory Toxicology and Pharmacology, 23(1), 35–43. https://doi.org/10.1006/rtph.1996.0006

Fossen Johnson. (2019). Methemoglobinemia: Infants at risk. Current Problems in Pediatric and Adolescent Health Care, 49(3), 57–67. https://doi.org/10.1016/j.cppeds.2019.03.002.

Foxworthy, Geological Survey, & United States. Department of the Interior. (1962). Geology and ground-water resources of the Ahtanum Valley, Yakima County, Washington. U.S. G.P.O. Retrieved from https://pubs.usgs.gov/wsp/1598/report.pdf

Gatseva, & Argirova, M. D. (2008). Iodine status and goitre prevalence in nitrate-exposed schoolchildren living in rural Bulgaria. Public Health (London), 122(5), 458–461. https://doi.org/10.1016/j.puhe.2007.09.001

Hunault, Lambers, A., Mensinga, T., van Isselt, J., Koppeschaar, H. P., & Meulenbelt, J. (2007). Effects of sub-chronic nitrate exposure on the thyroidal function in humans. Toxicology Letters, 175(1), 64–70. https://doi.org/10.1016/j.toxlet.2007.09.010

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (IARC) (2010). IARC monographs on the evaluation of carcinogenic risks to humans. Ingested nitrate and nitrite, and cyanobacterial peptide toxins. IARC monographs on the evaluation of carcinogenic risks to humans, 94, v–412. Retrieved from https://monographs.iarc.who.int/wp-content/uploads/2018/06/mono94.pdf

Jensen, & Gazis, C. (2018). Isotope Investigation of Nitrate in Soils and Agricultural Drains of the Lower Yakima Valley, Washington. ACS Earth and Space Chemistry, 2(12), 1249–1255. https://doi.org/10.1021/acsearthspacechem.8b00086

Jones, R. R., Weyer, P. J., DellaValle, C. T., Inoue-Choi, M., Anderson, K. E., Cantor, K. P., Krasner, S., Robien, K., Freeman, L. E., Silverman, D. T., & Ward, M. H. (2016). Nitrate from Drinking Water and Diet and Bladder Cancer Among Postmenopausal Women in Iowa. Environmental health perspectives, 124(11), 1751–1758. https://doi.org/10.1289/EHP191

Manassaram, D.M., Backer, L.C., Messing, R. (2010). Nitrates in drinking water and methemoglobin levels in pregnancy: a longitudinal study. Environ Health 9, 60 (2010). https://doi.org/10.1186/1476-069X-9-60

Mortensen, Aguilar, F., Crebelli, R., Di Domenico, A., Dusemund, B., Frutos, M. J., Galtier, P., Gott, D., Gundert-Remy, U., Lambre, C., Leblanc, J.-C., Lindtner, O., Moldeus, P., Mosesso, P., Oskarsson, A., Parent-Massin, D., Stankovic, I., Waalkens-Berendsen, I., Woutersen, R. A., Younes, M. (2017). Re-evaluation of sodium nitrate (E 251) and potassium nitrate (E 252) as food additives. EFSA Journal, 15(6), e04787–n/a. https://doi.org/10.2903/j.efsa.2017.4787

National Research Council (US) Committee on the Institutional Means for Assessment of Risks to Public Health. (1983). Risk Assessment in the Federal Government: Managing the

Process. Washington (DC): National Academies Press (US); 1983. Available from: https://www.ncbi.nlm.nih.gov/books/NBK216620/ doi: 10.17226/366

National Research Council (US) Subcommittee on Nitrate and Nitrite in Drinking Water. (1995). Nitrate and Nitrite in Drinking Water. Washington (DC): National Academies Press (US). 5, Risk Characterization. Available from: https://www.ncbi.nlm.nih.gov/books/NBK231050/

Office of Environmental Health Hazard Assessment (OEHHA). (2018). Public Health Goals Nitrate and Nitrite in Drinking Water. Pesticide and Environmental Toxicology Branch, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. Retrieved from https://oehha.ca.gov/media/downloads/water/chemicals/phg/nitratephg051118.pdf.

Presley, T. D., Morgan, A. R., Bechtold, E., Clodfelter, W., Dove, R. W., Jennings, J. M., Kraft, R. A., King, S. B., Laurienti, P. J., Rejeski, W. J., Burdette, J. H., Kim-Shapiro, D. B., & Miller, G. D. (2011). Acute effect of a high nitrate diet on brain perfusion in older adults. Nitric oxide: biology and chemistry, 24(1), 34–42. https://doi.org/10.1016/j.niox.2010.10.002

Rádiková, Tajtáková, M., Kocan, A., Trnovec, T., Seböková, E., Klimes, I., & Langer, P. (2008). Possible effects of environmental nitrates and toxic organochlorines on human thyroid in highly polluted areas in Slovakia. Thyroid (New York, N.Y.), 18(3), 353–362. https://doi.org/10.1089/thy.2007.0182

Redding, M., (2021). Quality Assurance Project Plan: Lower Yakima Valley Groundwater Management Area (GWMA) Ambient Groundwater Monitoring Network. Publication 21-03-106. Washington State Department of Ecology, Olympia. https://apps.ecology.wa.gov/publications/SummaryPages/2103106.html.

Sadler, Maetam, B., Edokpolo, B., Connell, D., Yu, J., Stewart, D., Park, M.-J., Gray, D., & Laksono, B. (2016). Health risk assessment for exposure to nitrate in drinking water from village wells in Semarang, Indonesia. Environmental Pollution (1987), 216, 738–745. https://doi.org/10.1016/j.envpol.2016.06.041

Scanlan R. A. (1983). Formation and occurrence of nitrosamines in food. Cancer research, 43(5 Suppl), 2435s–2440s.

Sell, R. & Knutson, L. (2002). Quality of Groundwater in Private Wells in the Lower Yakima Valley. Washington State Department of Ecology. Publication No. 02-10-074. Retrieved from https://apps.ecology.wa.gov/publications/documents/0210074.pdf

Sentry. (2022). Washington State Water System Data. Sentry Internet database. Washington State Department of Health, Office of Drinking Water. Retrieved from https://doh.wa.gov/data-statistical-reports/environmental-health/drinking-water-system-data/sentry-internet.

Sigler, W.A. & Bauder, J. No date (nd). Nitrate and Nitrite. Montana State University Extension. Retrieved from https://waterquality.montana.edu/well-ed/interpreting_results/images-files/Nitrate.pdf

Sim, M., Lewis, J. R., Blekkenhorst, L. C., Bondonno, C. P., Devine, A., Zhu, K., Peeling, P., Prince, R. L., & Hodgson, J. M. (2019). Dietary nitrate intake is associated with muscle function in older women. Journal of cachexia, sarcopenia and muscle, 10(3), 601–610. https://doi.org/10.1002/jcsm.12413

Song, P., Wu, L., & Guan, W. (2015). Dietary Nitrates, Nitrites, and Nitrosamines Intake and the Risk of Gastric Cancer: A Meta-Analysis. Nutrients, 7(12), 9872–9895. https://doi.org/10.3390/nu7125505

Sumioka. (1998). A survey of ground-water quality in the Toppenish Creek basin, Yakama Indian Reservation, Washington, 1989-91. U.S. Geological Survey. Retrieved from https://pubs.usgs.gov/wri/1997/4194/report.pdf

Tajtáková, Semanová, Z., Tomková, Z., Szökeová, E., Majoroš, J., Rádiková, Ž., Šeböková, E., Klimeš, I., & Langer, P. (2006). Increased thyroid volume and frequency of thyroid disorders signs in schoolchildren from nitrate polluted area. Chemosphere (Oxford), 62(4), 559–564. https://doi.org/10.1016/j.chemosphere.2005.06.030

Tariqi, A. Q., & Naughton, C. C. (2021). Water, Health, and Environmental Justice in California: Geospatial Analysis of Nitrate Contamination and Thyroid Cancer. Environmental engineering science, 38(5), 377–388. https://doi.org/10.1089/ees.2020.0315

Temkin, Evans, S., Manidis, T., Campbell, C., & Naidenko, O. V. (2019). Exposure-based assessment and economic valuation of adverse birth outcomes and cancer risk due to nitrate in United States drinking water. Environmental Research, 176, 108442–. https://doi.org/10.1016/j.envres.2019.04.009

Title 21. Volume 3 CFR172.175 § 2022. Retrieved from https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=172.175.

Torregrossa, A. C., Aranke, M., & Bryan, N. S. (2011). Nitric oxide and geriatrics: Implications in diagnostics and treatment of the elderly. Journal of geriatric cardiology: JGC, 8(4), 230–242. https://doi.org/10.3724/SP.J.1263.2011.00230

United States Census Bureau. (2021). QuickFacts Yakima County, Benton County, Washington. Retrieved from https://www.census.gov/quickfacts/fact/table/yakimacountywashington,bentoncountywashington/PST045221

United States Geological Survey (USGS). (2017). Concentrations of Nitrate in Drinking Water in the Lower Yakima River Basin, Groundwater Management Area, Yakima County, Washington, 2017. Retrieved from https://pubs.usgs.gov/ds/1084/ds1084.pdf.

van Maanen, J. M., Welle, I. J., Hageman, G., Dallinga, J. W., Mertens, P. L., & Kleinjans, J. C. (1996). Nitrate contamination of drinking water: relationship with HPRT variant frequency in lymphocyte DNA and urinary excretion of N-nitrosamines. Environmental health perspectives, 104(5), 522–528. https://doi.org/10.1289/ehp.96104522

VanDerGeest, Ko, L. K., Karr, C., Torres, E., Drury, D., & Austin, E. (2020). Private well stewardship within a rural, agricultural Latino community: a qualitative study. BMC Public Health, 20(1), 1–11. https://doi.org/10.1186/s12889-020-08963-4

VanDerslice, J. (2007). Final Report: Dose-Response of Nitrate and Other Methemoglobin Inducers on Methemoglobin Levels of Infants. EPA Grant Number: R829781. Washington State Department of Health. Retrieved from https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract_id/5379/report/F

Wang, H., Hu, L., Li, L., Wu, X., Fan, Z., Zhang, C., Wang, J., Jia, J., & Wang, S. (2018). Inorganic nitrate alleviates the senescence-related decline in liver function. Science China. Life sciences, 61(1), 24–34. https://doi.org/10.1007/s11427-017-9207-x

Ward, Kilfoy, B. A., Weyer, P. J., Anderson, K. E., Folsom, A. R., & Cerhan, J. R. (2010). Nitrate Intake and the Risk of Thyroid Cancer and Thyroid Disease. Epidemiology (Cambridge, Mass.), 21(3), 389–395. https://doi.org/10.1097/EDE.0b013e3181d6201d

Ward, M. H., Jones, R. R., Brender, J. D., de Kok, T. M., Weyer, P. J., Nolan, B. T., Villanueva, C. M., & van Breda, S. G. (2018). Drinking water nitrate and human health: An updated review. *International Journal of Environmental Research and Public Health, 15*(7), 1557. https://doi.org/10.3390/ijerph15071557

Washington State Department of Agriculture (WSDA). (2016). Implementation of nutrient management training program for farmers. Washington State Department of Agriculture. AGR PUB 713-533 (N/6/16). Retrieved from https://app.leg.wa.gov/ReportsToTheLegislature/Home/GetPDF?fileName=533-DNMPReportToLegJune2016_e9a85fda-7303-4899-a2fb-c30aea1728df.pdf

Washington State Department of Agriculture (WSDA). (2018). Estimated Nitrogen Available for Transport in the Lower Yakima Valley Groundwater Management Area. Washington State Department of Agriculture & Yakima County. AGR PUB 103-691 (N/6/18). Retrieved from https://cms.agr.wa.gov/WSDAKentico/Imported/103-691YakimaGWMANitrogenTransportReport.pdf?/103-691YakimaGWMANitrogenTransportReport.pdf

Washington State Dairy Federation. (2014). Facts About Washington's Dairy Industry. Washington State Dairy Federation. Retrieved from http://wastatedairy.com/wp-content/uploads/2014/05/FACTS-ABOUT-THE-WASHINGTON-DAIRY-INDUSTRY1.pdf.

Washington State Department of Health (DOH). (2013). Owning and Managing a Group A Water System. DOH 331-084 Revised. Retrieved from https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs//331-084.pdf.

Washington State Department of Health (DOH). (2014). How Nitrogen from Septic Systems Can Harm Water Quality. DOH 337-142. Retrieved from https://doh.wa.gov/sites/default/files/legacy/Documents/4450/337-142-Nitrogen-Removal-from-OSS-FactSheet.pdf#:~:text=Wastewater%20treated%20by%20a%20properly%20functioning%20OSS%20generally,depending%20on%20site%20conditions.effects.%20Excess%20nitrate%20can%20also

Washington State Department of Health (DOH). (2017). Neural Tube Defect Investigation in Benton, Franklin and Yakima Counties, 2010-2016. Retrieved from https://doh.wa.gov/sites/default/files/legacy/Documents/Pubs/210-092-NTDReport.pdf.

Washington State Department of Health (DOH). (2022). Group B Public Water Systems. Retrieved from https://doh.wa.gov/community-and-environment/drinking-water/water-system-assistance/group-b.

Washington State University Extension (WSU). (2016). Fertilizing with Manure and other Organic Amendments. Retrieved from https://pubs.extension.wsu.edu/fertilizing-with-manure

Washington State University Extension (WSU). (2022). Crop Production. Retrieved from https://extension.wsu.edu/yakima/crop-production.

World Health Organization (WHO). (2003). Guidelines for drinking-water quality, Volume 1: Recommendations. Annex 3. World Health Organization.

Yakima County. (2022a). Committee Members. Retrieved from https://www.yakimacounty.us/576/Committee-Members

Yakima County. (2022b). Groundwater Management. Retrieved from https://www.yakimacounty.us/541/Groundwater-Management

Yu, Wang, J., Liu, L., Li, Y., Zhang, Y., & Wang, S. (2020). The analysis of groundwater nitrate pollution and health risk assessment in rural areas of Yantai, China. BMC Public Health, 20(1), 437–437. https://doi.org/10.1186/s12889-020-08583-y

Appendix A

To evaluate the potential for non-cancer adverse health effects that may result from exposure to contaminated water in the LYV, a dose is estimated for the contaminant (nitrate). These doses are calculated for exposure scenarios in which a person might be exposed to the contaminated media. This health assessment calculates doses, called average daily doses (ADDs) acquired through ingestion of drinking water. The formula for the ADD is shown below:

$$ADD = \frac{C_W \times IR \times EF \times ED}{AT \times BW}$$

Where:

ADD = Average daily dose; the average daily intake of the contaminant (mg/kg-d).

C_W = Concentration of nitrate in water (mg/L).

IR = Ingestion rate (L/d).

EF = Exposure frequency (d/yr).

ED = Exposure duration (yr).

AT = Averaging time (d).

BW = Body weight (kg).

The exposure parameters used in each exposure scenario of the health assessment are included in Table 18.

Table 18: Exposure parameters used in this health assessment

Symbol	Definition	Default	Mean	Maximum	Units	Reference
ED adults	Exposure duration for adults		78		yr	Average life expectancy of the general population (Table 18-1; EPA, 2011)
ED infants	Exposure duration for infants		0.25		yr	Equivalent to 3 months
ED pregnant individuals	Exposure duration for		0.77		yr	Equivalent to 40 weeks

	pregnant individuals					
IR adults & pregnant individuals	Daily water ingestion rate for adults	2			L/d	WHO, 2003
IR infants (VanDerslice)	Daily water ingestion rate for infants (VanDerslice, 2007)		0.317186441	1.53	L/d	Calculated from VanDerslice, 2007, for 1-<3 months.
IR infants (EPA, 1991)	Daily water ingestion rate for infants (EPA, 1991)		0.64		L/d	EPA, 1991
EF	Exposure frequency	365			d/yr	Constant
AT adults	Averaging time for adults	28470			d	Number of days in ED
AT infants	Averaging time for infants	91.25			d	Number of days in ED
AT pregnant individuals	Averaging time for pregnant individuals	281.05			d	Number of days in ED
BW infants (VanDerslice)	Body weight of infants (VanDerslice, 2007)		5.58		kg	Weighted average calculated from VanDerslice, 2007 for 1-<3 months
BW infants (EPA, 1991)	Body weight of infants (EPA, 1991)		4		kg	EPA, 1991

BW adults	Body weight of adults		70		kg	Table 8-1 in EPA, 2011
BW pregnant individuals	Body weight of pregnant individuals		75		kg	Table 8-29; EPA, 2011
ED – exposure duration; IR – ingestion rate; EF – exposure frequency; AT – averaging time; BW – body weight; yr – year; kg – kilogram; d – day; L – liter.						

The ingestion rate for adults (2L/d; WHO, 2003), is also used to estimate the average daily dose of pregnant individuals. The adult ingestion rate is inclusive of the EPA recommended average water ingestion rate for pregnant women, which is 0.731 L/d (EPA, 2019).

The ADDs calculated in this health assessment are included in Table 19, Table 20, and Table 21.

Table 19: ADDs calculated based on private well data in this health assessment

County	Description	Population	ADD	Unit
Yakima	Summer private wells	Adults	0.433714	mg/kg-d
	Fall private wells	Adults	0.395143	mg/kg-d
	Winter private wells	Adults	0.409429	mg/kg-d
	Summer private wells	VDS infants	0.875435	mg/kg-d
	Fall private wells	VDS infants	0.79758	mg/kg-d
	Winter private wells	VDS infants	0.826415	mg/kg-d
	Summer private wells	EPA infants	2.4288	mg/kg-d
	Fall private wells	EPA infants	2.2128	mg/kg-d
	Winter private wells	EPA infants	2.2928	mg/kg-d
	Summer private wells	Pregnant individuals	0.4048	mg/kg-d
	Fall private wells	Pregnant individuals	0.3688	mg/kg-d
	Winter private wells	Pregnant individuals	0.382133	mg/kg-d
Benton	Private wells	Adults	0.601714	mg/kg-d

	Private wells	VDS infants	1.214536	mg/kg-d
	Private wells	EPA infants	3.3696	mg/kg-d
	Private wells	Pregnant women	0.5616	mg/kg-d

VDS – VanDerslice (2007); EPA – EPA (1991); ADD – average daily dose; mg – milligram; kg – kilogram; d – day.

Table 20: ADDs calculated based on public well data in this health assessment

County	Description	Population	ADD	Unit
Yakima	Summer public wells	Adults	0.241543	mg/kg-d
	Fall public wells	Adults	0.205143	mg/kg-d
	Winter public wells	Adults	0.204343	mg/kg-d
	Summer public wells	VDS infants	0.487544	mg/kg-d
	Fall public wells	VDS infants	0.414072	mg/kg-d
	Winter public wells	VDS infants	0.412458	mg/kg-d
	Summer public wells	EPA infants	1.35264	mg/kg-d
	Fall public wells	EPA infants	1.1488	mg/kg-d
	Winter public wells	EPA infants	1.14432	mg/kg-d
	Summer public wells	Pregnant individuals	0.22544	mg/kg-d
	Fall public wells	Pregnant individuals	0.191467	mg/kg-d
	Winter public wells	Pregnant individuals	0.19072	mg/kg-d
Benton	Summer public wells	Adults	0.154286	mg/kg-d
	Fall public wells	Adults	0.247829	mg/kg-d
	Winter public wells	Adults	0.222	mg/kg-d
	Summer public wells	VDS infants	0.311419	mg/kg-d
	Fall public wells	VDS infants	0.500232	mg/kg-d
	Winter public wells	VDS infants	0.448098	mg/kg-d
	Summer public wells	EPA infants	0.864	mg/kg-d
	Fall public wells	EPA infants	1.38784	mg/kg-d
	Winter public wells	EPA infants	1.2432	mg/kg-d
	Summer public wells	Pregnant women	0.144	mg/kg-d
	Fall public wells	Pregnant women	0.231307	mg/kg-d
	Winter public wells	Pregnant women	0.2072	mg/kg-d

VDS – VanDerslice (2007); EPA – EPA (1991); ADD – average daily dose; mg – milligram; kg – kilogram; d – day.

Table 21: ADDs calculated based on monitoring well data in this health assessment

County	Description	Population	ADD	Unit
Yakima	Summer monitoring wells	Adults	1.117143	mg/kg-d
	Fall monitoring wells	Adults	1.104857	mg/kg-d
	Winter monitoring wells	Adults	1.035143	mg/kg-d

	Summer monitoring wells	VDS infants	2.254907	mg/kg-d
	Fall monitoring wells	VDS infants	2.230109	mg/kg-d
	Winter monitoring wells	VDS infants	2.089394	mg/kg-d
	Summer monitoring wells	EPA infants	6.256	mg/kg-d
	Fall monitoring wells	EPA infants	6.1872	mg/kg-d
	Winter monitoring wells	EPA infants	5.7968	mg/kg-d
	Summer monitoring wells	Pregnant individuals	1.042667	mg/kg-d
	Fall monitoring wells	Pregnant individuals	1.0312	mg/kg-d
	Winter monitoring wells	Pregnant individuals	0.966133	mg/kg-d
VDS – VanDerslice (2007); EPA – EPA (1991); ADD – average daily dose; mg – milligram; kg – kilogram; d – day.				

The HQs calculated in this health assessment are included in Table 22, Table 23, and Table 24.

Table 22: HQs calculated based on private well data in this health assessment

County	Description	Population	HQ
Yakima	Summer private wells	Adults	0.271
	Fall private wells	Adults	0.2469
	Winter private wells	Adults	0.2559
	Summer private wells	Infants	1.518
	Fall private wells	Infants	1.383
	Winter private wells	Infants	1.433
	Summer private wells	Pregnant individuals	1.518
	Fall private wells	Pregnant individuals	1.383
	Winter private wells	Pregnant individuals	1.433
Benton	Private wells	Adults	0.3761
	Private wells	Infants	2.106
	Private wells	Pregnant individuals	2.106

Table 23: HQs calculated based on public well data in this health assessment

County	Description	Population	HQ
Yakima	Summer public wells	Adults	0.1509
	Fall public wells	Adults	0.1282
	Winter public wells	Adults	0.1277
	Summer public wells	Infants	0.8454
	Fall public wells	Infants	0.718
	Winter public wells	Infants	0.7152
	Summer public wells	Pregnant individuals	0.8454
	Fall public wells	Pregnant individuals	0.718
	Winter public wells	Pregnant individuals	0.7152
Benton	Summer public wells	Adults	0.0964
	Fall public wells	Adults	0.1549
	Winter public wells	Adults	0.1388
	Summer public wells	Infants	0.54
	Fall public wells	Infants	0.8674
	Winter public wells	Infants	0.777
	Summer public wells	Pregnant individuals	0.54
	Fall public wells	Pregnant individuals	0.8674
	Winter public wells	Pregnant individuals	0.777

Table 24: HQs calculated based on monitoring well data in this health assessment

County	Description	Populations	HQ
Yakima	Summer monitoring wells	Adults	0.6982
	Fall monitoring wells	Adults	0.6905
	Winter monitoring wells	Adults	0.6469
	Summer monitoring wells	Infants	3.91
	Fall monitoring wells	Infants	3.867
	Winter monitoring wells	Infants	3.623
	Summer monitoring wells	Pregnant individuals	3.91

	Fall monitoring wells	Pregnant individuals	3.867
	Winter monitoring wells	Pregnant individuals	3.623

Appendix B

A summary of the well water nitrate concentrations used in this health assessment is included in Table 25.

Table 25: Well water nitrate concentrations used in this health assessment

County	Definition	95th percentile	Units	Reference
Yakima	Concentration of nitrates in private domestic wells in summer	15.18	mg/L	Ecology, 2022a
	Concentration of nitrates in private domestic wells in fall	13.83	mg/L	Ecology, 2022a
	Concentration of nitrates in private domestic wells in winter	14.33	mg/L	Ecology, 2022a
	Concentration of nitrates in monitoring wells in summer	39.1	mg/L	Ecology, 2022a
	Concentration of nitrates in monitoring wells in fall	38.67	mg/L	Ecology, 2022a
	Concentration of nitrates in monitoring wells in winter	36.23	mg/L	Ecology, 2022a
	Concentration of nitrates in public water system in summer	8.454	mg/L	Sentry, 2022
	Concentration of nitrates in public water system in fall	7.18	mg/L	Sentry, 2022
	Concentration of nitrates in public water system in winter	7.152	mg/L	Sentry, 2022
Benton	Concentration of nitrates in private domestic water system	21.06	mg/L	Ecology, 2022a
	Concentration of nitrates in public water system in summer	5.4	mg/L	Sentry, 2022
	Concentration of nitrates in public water system in fall	8.674	mg/L	Sentry, 2022
	Concentration of nitrates in public water system in winter	7.77	mg/L	Sentry, 2022

Mg – milligram; L – liter; Sentry – Washington State Department of Health Sentry Internet database.

Appendix C

Derivation of RfD for Pregnant Individuals

EPA and ATSDR have not developed MCLs or MRLs for reproductive effects from nitrates, respectively. Manassaram et al. (2010) did not find any association between methemoglobin levels in pregnant women and exposure to nitrate in drinking water at levels less than 10 mg/L nitrate-nitrogen. Therefore, an RfD was calculated for pregnant individuals based on the MCL of 10 mg/L nitrate-N. The following parameters were used to convert the MCL to an RfD:

- A default drinking water ingestion rate (IR) of 2 L/d (WHO, 2003).
- An average body weight (BW) of pregnant individuals of 75 kg (EPA, 2011).
- Uncertainty and modifying factors of 1.

The following formula was used to derive an RfD:

$$RfD = \frac{MCL \times IR}{BW}$$

Resulting in:

$$0.267\frac{mg}{kg-d} : \frac{10\frac{mg}{L} \times 2\frac{L}{d}}{75kg}$$

Therefore, the RfD used in this health assessment to calculate risk to pregnant individuals for adverse reproductive outcomes is 0.267 mg/kg-d.

VanDerslice (2007) Risk Estimates

The exposure parameters derived from the VanDerslice (2007) study are included in Table 26.

Table 26: Exposure parameters derived from VanDerslice (2007) used in this health assessment

Definition	Mean	Maximum	Units	Reference
Daily water ingestion rate for infants	0.317186441	1.53	L/d	Calculated using ingestion rates listed in Table 10 of VanDerslice, 2007, for infants aged 1-<3 months.
Body weight of infants	5.58	none	kg	Weighted average calculated from VanDerslice, 2007 for 1-<3 months
L - liter; d – day; kg – kilogram.				

The ADDs calculated in this health assessment using parameters derived from the VanDerslice (2007) study described in the Standard vs VanDerslice (2007) Risk Estimates section are included in Table 27.

Table 27: ADDs calculated based on VanDerslice (2007) exposure parameters in this health assessment

County	Description	Population	ADD	Unit
Yakima	Summer private wells	Infants	0.875435	mg/kg-d
	Fall private wells	Infants	0.79758	mg/kg-d
	Winter private domestic wells	Infants	0.826415	mg/kg-d
	Summer monitoring wells	Infants	2.254907	mg/kg-d
	Fall monitoring wells	Infants	2.230109	mg/kg-d
	Winter monitoring wells	Infants	2.089394	mg/kg-d
	Summer public wells	Infants	0.487544	mg/kg-d
	Fall public wells	Infants	0.414072	mg/kg-d
	Winter public wells	Infants	0.412458	mg/kg-d
Benton	Private wells	Infants	1.214536	mg/kg-d
	Summer public wells	Infants	0.311419	mg/kg-d
	Fall public wells	Infants	0.500232	mg/kg-d
	Winter public wells	Infants	0.448098	mg/kg-d

ADD – average daily dose; mg – milligram; kg – kilogram; d – day.

Included in Table 28 are hazard quotients calculated using parameters from the VanDerslice (2007) study described in the Standard vs VanDerslice (2007) Risk Estimates section.

Table 28: HQs calculated using parameters from VanDerslice (2007)

County	Description	Population	HQ
Yakima	Summer private wells	Infants	0.547147
	Fall private wells	Infants	0.498487
	Winter private wells	Infants	0.516509
	Summer monitoring wells	Infants	1.409317
	Fall monitoring wells	Infants	1.393818
	Winter monitoring wells	Infants	1.305871
	Summer public wells	Infants	0.304715
	Fall public wells	Infants	0.258795
	Winter public wells	Infants	0.257786
Benton	Private domestic wells	Infants	0.759085
	Summer public wells	Infants	0.194637
	Fall public wells	Infants	0.312645
	Winter public wells	Infants	0.280061