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GROUNDWATER NITRATE CHARACTERIZATION REPORT
BENTON COUNTY, WASHINGTON

Prepared for:

Benton Conservation District
Benton County, Washington

Prepared by:
EA Engineering, Science, and Technology, Inc., PBC
8019 West Quinault Avenue, Suite 201
Kennewick, Washington 99336

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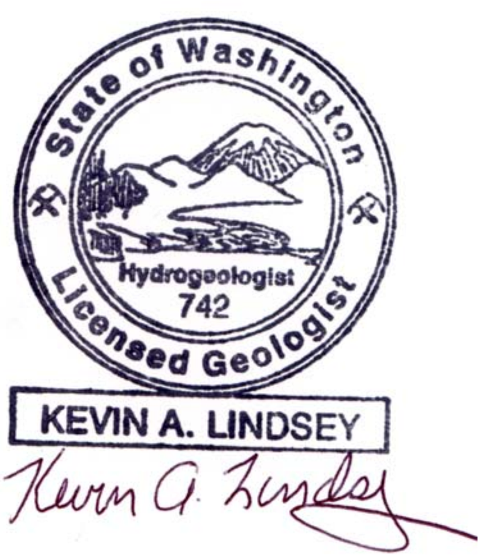

Executive Summary

Elevated nitrate concentrations in groundwater are a concern for Benton County, Washington. Practices in both urban and rural areas can contribute to the presence of nitrate in groundwater. In Benton County, the primary potential sources of nitrogen, and by association nitrate, are livestock agriculture, agricultural fertilization activities, urban wastewater, septic systems, and residential or urban landscape fertilization practices which includes large area commercial landscaping for golf courses and parks. Of these, crop agriculture generally covers the largest area and likely contributes the greatest amount of nitrogen. Croplands generally receive nitrogen from multiple inputs, including synthetic fertilizer, compost, solid and liquid animal manure, wastewater treatment plant and food processor effluent, wastewater treatment plant biosolids, atmospheric deposition, and nitrate in irrigation water sources. Animal agricultural facilities and areas of high density residential landscape, irrigation and septic systems may at least locally form elevated nitrogen sources. Although all these activities potentially contribute nitrate to groundwater they are also a part of Benton County's socio-economic fabric.

The Benton County Groundwater Nitrate Characterization Study was conducted to: (1) summarize the activities that potentially contribute to groundwater nitrate contamination in Benton County, (2) discuss the occurrence, movement, and potential sources of nitrate in groundwater, (3) identify and rank areas of high nitrate concentrations to be addressed by future actions, and (4) provide a baseline for community-wide efforts to improve groundwater quality. The study included a review of both the historic and recent nitrate groundwater data. The historic record spans from 1971 to 2011, and the recent record encompasses three monitoring events conducted in the fall of 2015, the spring of 2016, and the fall of 2016. The available groundwater monitoring data was evaluated in terms of hydrostratigraphy (water production zone), well location, and surrounding land use.

The basic distribution of groundwater nitrate in Benton County does not change significantly between the historic and recent data sets; however, the highest nitrate concentrations and average nitrate concentrations have increased over time. It seems likely that groundwater nitrate concentrations have increased in areas where anthropogenic activities introduce nitrate, in both urban and rural areas.

Both the historic and recent groundwater nitrate data were interpreted to indicate that irrigation and fertilization practices introduce some of the highest nitrate concentrations into groundwater. The urban areas, Benton City-Kiona, Richland Wye, and Finley had local spots of nitrate contamination, while mixed urban and rural areas and the rural areas of Prosser, Badger Coulee, and Horse Heaven Hills exhibited potentially larger areas of high nitrate. In both records, the available data in Horse Heaven Hills is sparse, and nitrate affected areas may not be well represented.

In Benton County, groundwater nitrate is generally: (1) above Background levels where there is anthropogenic development, including urban or rural residential or agricultural development, (2) highest in shallower water producing zones and lowest in deep zones, and (3) lower in alluvial and shallow basalt water producing zones near major surface water sources. Nitrate concentrations in most wells sampled in 2015 and 2016 showed relatively minor fluctuations. However, some sampled wells do display seasonal nitrate concentration variations interpreted to reflect irrigation season dilution of groundwater nitrate.

In the urbanized Richland Wye area and mixed residential and farming Finley area, Elevated and/or High groundwater nitrate was observed in individual wells which are separated by clusters of wells displaying Background and Anthropogenic effects. Much of the residential development in these areas is on ground converted from irrigated farming, and there is the potential that historical, no longer active sources, could have contributed to observed nitrate effects. In general, the wells in the Richland Wye and Finley areas had nitrate trends that were constant over the year, not showing seasonal fluctuations or increasing trends during the 2015 to 2016 sampling events.

In the Benton City-Kiona area, land use consists of a mix of small urban, rural residential, and irrigated farming. Active sources of nitrate in this setting are a mix of urban landscaping, irrigated farming, and variable density on-site waste water systems. Wells in the Benton City-Kiona area located near the Yakima River, display Background nitrate levels that are interpreted to be receiving significant low nitrate recharge water from nearby surface water nitrate conditions resulting in the dilution of groundwater nitrate.

Groundwater nitrate in sampled Prosser and Badger Coulee area wells range from Background to High nitrate concentrations in all water producing zones. The large range of observed groundwater nitrate effects in these two areas likely reflects a mix of very different and changing land uses. In addition, where Background effects are seen, wells are either near low nitrate surface water recharge sources or deep in the aquifer system. Generally, seasonal irrigation trends are seen in areas of moderate and low efficiency agricultural irrigation, including the Prosser the Badger Coulee areas. Irrigation practices in these areas introduce new water sources that dilute the groundwater nitrate concentrations, which then rebound when irrigation water is no longer being added to the system.

In the Horse Heaven Hills area, which is dominated by dryland farming in the north and irrigated farming in the south, Elevated and High groundwater nitrate effects are spread out geographically. However, the available data in Horse Heaven Hills is sparse and lateral continuity of the High and Elevated nitrate effects are difficult to determine. Nitrate concentrations are higher and affect the intermediate basalt production zone to a greater degree. The occurrence(s) of nitrate in the intermediate basalt below the Horse Heaven Hills area may be due to wells completed in multiple water producing zones, including the intermediate basalt, and acting as preferential flow pathways. Horse Heaven Hills, unlike the Prosser and Badger Coulee areas, is high efficiency irrigation; therefore, large amounts of irrigation water are not available to infiltrate the groundwater and dilute nitrate concentrations. This lack of dilution in the Horse Heaven Hills area may be a contributing factor to elevated groundwater nitrate concentrations.

The available data do not indicate feedlots are a significant source of nitrate when compared to the contributions of the surrounding land use.

Although irrigation and fertilization occur in urban areas as residential landscaping, parks, and golf courses, they do not appear to produce short-term seasonal trends like irrigated agriculture. Further sampling will be needed to determine if any trend exists as a result of urban fertilization.

Based on the findings of this Groundwater Characterization Study, certain activities were recommended that might aid in the efforts to monitor and mitigate the effects of nitrate in groundwater. These recommendations include the development of a long-term groundwater monitoring program, the mitigation of nitrate in the alluvial and shallow basalt producing zones, the protection of the intermediate and deep basalt water producing zones, and the education and protection of the public from current groundwater nitrate conditions.

The anthropogenic processes that introduce nitrogen at the surface and result in groundwater nitrate are important to the local economy and the livelihood of Benton County residents. Therefore, a community effort is needed to make these processes more efficient while still being cost effective. This community effort should include education and incentives to educate the public on what they can do to protect their groundwater without significant impacts to their bottom line.

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1 INTRODUCTION

EA Engineering, Science, and Technology, Inc. (EA) prepared this Groundwater Nitrate Characterization Report (the Report) for Benton County, Washington in accordance with *Task 1 and Task 2* of the *Benton County Groundwater Nitrate Characterization, Monitoring, and Stakeholder Engagement Project (the Project).*

Elevated nitrate concentrations in groundwater are a concern for Benton County (Figure 1). Practices in both urban and rural areas can contribute to the presence of nitrate in Benton County's groundwater. The presence of nitrate in groundwater can come from irrigation processes, agricultural fertilization (both inorganic and organic), and lawn fertilization and watering practices for residential, community and recreational areas (e.g., golf courses and parks). Dairies, feedlots, and other livestock practices can also contribute to the presence of nitrate in the groundwater along with septic tanks and wastewater treatment. Although all these activities are capable of introducing nitrate to groundwater, they also are part of Benton County's socio-economic fabric.

Historical groundwater nitrate data was collected in Benton County from the 1970s through 2011 by several agencies, including the Washington State Department of Ecology (Ecology) and the U.S. Geological Survey (USGS). The U.S. Environmental Protection Agency (EPA) and Ecology have established a maximum contaminant level of nitrate in drinking water at 10 mg/L. Historical studies describing nitrate in Benton County groundwater include:

- Ebbert et al. (1993) found approximately 10% of the wells sampled in the Kennewick and Finley areas of Benton County during the mid-1980s had nitrate concentrations exceeding the maximum contaminant level (MCL) of 10 milligrams per liter (mg/L).
- EES (2003) focused on the entire Yakima River valley and reported the presence of nitrate in some wells in this region indicating elevated nitrate levels in portions of the basin impair local groundwater quality.
- WRIA 31 (2004), which focused on the Horse Heaven Hills (Glade/Fourmile Creeks sub-basin) and Kennewick portions of Benton County, summarized Washington State Department of Health (WDOH) data for alluvial and basalt public water systems with nitrate concentrations exceeding 10 mg/L in 10 public water systems.
- Jones et al. (2006) showed the presence of wells containing elevated nitrate concentrations above 20 mg/L in the lower Yakima River valley portion of Benton County.
- Ecology (2010), focused primarily on the Yakima County portion of the Yakima River Valley and found elevated nitrate concentrations (above 10 mg/L) in wells immediately up gradient of Benton County in the Yakima River Valley.

These previous studies show nitrate concentrations in groundwater above the Ecology and EPA MCL of 10 mg/L. They do not, however, evaluate groundwater quality for all of Benton County as a single database, or provide a comprehensive evaluation of the possible sources and extent of nitrate impacts to groundwater in Benton County. As a result of the concerns raised by these reports, Benton Conservation District (BCD) began a county-wide groundwater nitrate monitoring program in 2015 as a precursor to formation of a County stakeholder group. The Benton County stakeholder group is tasked with addressing groundwater nitrate issues in Benton County.

The ***objective*** of this Project is to summarize the activities that potentially contribute to groundwater nitrate contamination in Benton County, discuss the occurrence, movement, and potential sources of nitrate contamination, identify and rank areas of high nitrate contamination to be addressed by future actions, and provide a baseline for community-wide efforts to improve groundwater quality. This was done for Benton County south of the Hanford Site. The Hanford Site and the far northwest corner of the County are not discussed in this report.

To address the Project objectives, the following topics are covered in this report:

- Summarize common nitrate sources and the nitrogen cycle.
- Examine the hydrogeologic setting of Benton County.
- Perform a review and analysis of historic and recent Benton County nitrate data.
- Identify areas in Benton County where anthropogenic practices contributed to groundwater nitrate concentrations.
- Identify areas of high nitrate concentrations.
- Conduct a trend analysis for Benton County's recently collected nitrate data.
- Evaluate possible sources of groundwater nitrates in Benton County.

2 BACKGROUND

2.1 Common Nitrate Sources

Groundwater in predominantly agricultural areas, such as Benton County, Washington often contains nitrate, potassium, chloride, calcium, and magnesium concentrations elevated above normal background conditions (Nolan et al. 1997). Nitrogen from inorganic and organic fertilizers, animal manure, and lime that is not taken up by plants is converted to nitrate via the nitrogen cycle. This nitrate can leach into groundwater where it can accumulate for years, resulting in high nitrate concentrations, especially in areas where nitrogen sources are continually active. All nitrogen applied to the soil becomes nitrate unless it is lost through volatilization (Nolan et al. 1997).

There are multiple potential sources of nitrate found in groundwater. Agricultural fertilizers, both inorganic and organic, are generally the most widespread. Examples of organic fertilizers include plant waste left in the field; land-applied food-processing discharge; land-applied manure solids, liquids, and compost; and seepage from leaking corrals and manure storage lagoons (Center for Watershed Sciences UC, Davis, 2012). Potential non-agricultural groundwater nitrate sources commonly include fertilizers applied to urban parks, residential landscaping, golf courses; and leachate from septic systems (Center for Watershed Sciences UC, Davis, 2012). The nitrate needs of crops varies based on the type of crop, the soil type, and climate and the season, making the optimal amount of fertilizer difficult to determine year to year, even if the same crop is planted annually in the same soil. Any nitrogen/nitrate application above the amount taken up by crops, landscaping, and/or denitrification processes has the potential to lead to increased nitrate in groundwater (Herman et al 2015).

Nitrate present in shallow groundwater has the opportunity to move into deeper groundwater systems via geologic pathways and wells open to multiple geologic units. The movement of nitrate to groundwater from these potential sources, generally, can be reduced with decreased application of water or increased with greater water application to the land surface.

2.2 Nitrogen/Nitrate Cycle

Nitrogen is an essential element for all living organisms. Nitrogen cycles through the atmosphere, hydrosphere, and biosphere. The dominant gas (78%) in the atmosphere is highly stable (inert) N_2 gas. Biological nitrogen fixation transforms N_2 gas into ammonia (NH_3), which is rapidly converted to the forms of nitrogen needed for plant growth. Nitrogen fixation is performed only by specialized soil and aquatic microbes. Other living organisms cannot use inert atmospheric N_2 directly, but rely on accumulated soil organic matter, plants, animals, and microbial communities for nitrogen.

Soil nitrogen is most abundant in the organic form (N_{org}). Mineralization is a suite of processes performed by soil microbes that converts organic nitrogen to inorganic forms of nitrogen. The rates of mineralization depend on the environmental conditions such as temperature, moisture, pH, and oxygen content, as well as the type of organic matter available. The first product of mineralization is ammonium (NH_4^+), but under aerobic conditions, microbes can convert ammonium (NH_4^+) first to nitrite (NO_2^-) and then to nitrate (NO_3^-). Most plants use nitrate or ammonium as their preferred source of nitrogen (Snoeynk et al. 1980). Immobilization is the reverse of mineralization in that soil ammonium and nitrate are taken up by soil organisms and plants and converted into N_{org}. The ultimate fate of "reactive" nitrogen (organic nitrogen, ammonium, nitrate, ammonia, nitrous oxide, etc.) is to return back to the atmosphere as N_2. For nitrate, this denitrification process is mediated by microbes and requires an anoxic (oxygen-free) environment (Snoeynk et al. 1980, Center for Watershed Sciences UC, Davis, 2012). The nitrogen cycle is shown in Figure 2.

All of the major nitrogen-containing species are produced via microbial catalyzed oxidation reactions that rapidly occur in neutral to slightly basic pH levels. Since oxygenated groundwater is usually characterized by a pH from 7 to 8, it is an excellent media for the conversion of nitrogen into nitrate (Snoeynk et al. 1980). Denitrification is a redox reaction and requires highly reducing conditions such as those that occur in plant cells for photosynthesis (Snoeynk et al. 1980).

Groundwater is becoming a growing component of the global nitrogen cycle because of increased anthropogenic (human induced) nitrogen inflows into aerobic groundwater systems and under these conditions the relatively long residence times of nitrate. Nitrate does not significantly adhere to or react with sediments or other geologic materials, and it moves with groundwater flow. Other forms of reactive nitrogen in groundwater are less significant and much less mobile: ammonia occurs under some groundwater conditions, but it is subject to sorption and rapidly converts to nitrate under oxidizing conditions. Dissolved organic nitrogen concentrations are generally much less than those of nitrate, except near wastewater sources, due to the high adsorption of dissolved organic nitrogen to aquifer materials (Center for Watershed Sciences UC, Davis, 2012).

2.3 Nitrate Sources in Benton County

The primary potential sources of nitrogen, and by association nitrate, in Benton County are livestock agriculture, agricultural fertilization activities, urban wastewater, septic systems, and residential landscape fertilization, and urban landscape fertilization practices such as large area commercial landscaping including golf courses and parks. Of these, crop agriculture generally covers the largest area and likely contributes the largest amount of nitrogen. Croplands generally receive nitrogen from multiple inputs, including synthetic fertilizer, compost, solid and liquid animal manure, wastewater treatment plant and food processor effluent, wastewater treatment plant biosolids, atmospheric deposition, and nitrate in irrigation water sources. Animal agricultural facilities and areas of high density residential landscape, irrigation and septic systems may at least locally form elevated nitrogen sources. Natural sources may also contribute a small amount of nitrogen. Figure 3 shows areas in Benton County dominated by these different land uses.

In Benton County, irrigated farming is most common in the Yakima River Valley and adjacent to the Columbia River in the eastern and southern portions of the County (Figure 3). The primary source of water for these irrigated areas is surface water drawn from these two rivers and delivered via pipelines and canals. A small area of irrigated farming also occurs in the northwest part of Benton County where the water source is basalt aquifer pumping. Nitrate concentrations are generally expected to be elevated in these irrigated areas because irrigation seepage water moving out of the root zone to depth will carry nitrate with it. Dryland (non-irrigated) agriculture is most common on the Horse Heaven Hills in the south-central County (Figure 3). These areas receive little or no artificial irrigation. Consequently, movement of water, and nitrate in solution, to depth is slow and groundwater nitrate concentrations are expected to be lower than in irrigated areas.

Given these generalizations, the presence of irrigation canals in irrigated areas have the potential to seasonally affect groundwater nitrate concentrations. Leaking irrigation canals can lower nitrate concentrations via dilution of the effected groundwater. Where this occurs one will commonly see decreased groundwater nitrate concentrations during the irrigation season. After the irrigation season ends, nitrate concentrations will then increase as the diluting effect of canal leakage is removed. In dryland areas, elevated shallow groundwater nitrate is occasionally encountered because of the lack of irrigation dilution. Figure 3 shows the locations of the primary irrigation canals servicing Benton County.

More localized and/or high density land uses that are potential sources of elevated groundwater nitrate include: animal agriculture activities associated with concentrated feeding operations, dairies and their associated manure storage facilities, wastewater percolation at municipal wastewater treatment plants and food processors, septic system drainfields (onsite sewage systems), leaky urban sewer lines, lawns, parks, golf courses, and dry wells or percolation basins that collect and contaminated stormwater runoff. Only five (5) animal agricultural facilities operate in Benton County, their locations are shown on Figure 3. The other generally localized potential nitrate sources are most prevalent in urban growth areas associated with Benton County's towns, cities, and rural residential developments. The locations of these areas also are shown on Figure 3.

Potential natural sources of nitrate in groundwater include geologic minerals and atmospheric sources (nitrate and ammonia suspended in air and nitrate generated during lightning). However, the amount of nitrate in groundwater that may be attributed to natural sources is negligible compared with the anthropogenic sources, especially the amounts applied to crops.

Several land use types have the potential to contribute nitrate to groundwater, including, irrigated and dryland agriculture, areas with dense rural residential development but without sewage services, high density rural residential and urban areas with extensive irrigated landscaping, and confined animal feeding operations and/or dairies. The higher nitrate concentrations are predominantly detected in shallow wells penetrating the suprabasalt or the shallow basalt aquifers, and not generally detected in deeper basalt aquifers in Benton County. This finding suggests that the source of nitrate loading is percolation from the surface. These sources may have a significant localized impact, which would be most prevalent in urban growth areas within Benton County. Incidental leakage of nitrate may also occur directly via poorly constructed wells.

3 HYDROGEOLOGIC SETTING

Benton County is located in the central portion of the Columbia River flood basalt province (Figure 4). The province comprises continental flood basalt flows collectively known as the Columbia River Basalt Group (CRBG), thin interbedded continental sedimentary units known as the Ellensburg Formation, and a thin discontinuous sequence of continental sedimentary units overlying the CRBG alternatively referred to as suprabasalt sediments or alluvial sediments. This section summarizes the basic hydrogeologic setting of Benton County, and includes a discussion of the primary geologic units hosting the aquifer system (from youngest to oldest unit or shallowest to deepest), a brief summary of geologic structures, which potentially influence groundwater occurrence, and a summary of basic aquifer system characteristics including recharge and discharge.

3.1 Geology

The basic geologic framework of the region is described in a number of reports, with Waters (1961), Mackin (1961), Grolier and Bingham (1971, 1978), Tolan et al. (1989, 2009), Smith et al. (1989), GWMA (2009a, 2011d), Burns et al. (2011), Kahle et al. (2011), and Reidel et al. (2013) all offering reviews, summaries, and/or detailed descriptions of many aspects of that framework, including the history and origin, physical composition, and hydrogeologic regimes of the CRBG and associated continental sedimentary units. The following is a summary derived from these and other reports as cited.

3.1.1 Suprabasalt (Alluvial) Sediments

The youngest strata in Benton County consists of a thin sequence of generally discontinuous continental sedimentary units deposited following the emplacement of the underlying CRBG. Based on surface geologic mapping in Benton County, suprabasalt sediment strata (also referred to as alluvial sediments) include recent wind-blown silt and sand, Quaternary alluvium, Pleistocene cataclysmic flood deposits, Pleistocene loess, and the Mio-Pliocene Ringold Formation and associated unnamed caliches. Basic characteristics of these units in Benton County are summarized in the following bullets:

- Recent (<12,000 years old) wind-blown silt and sand constitutes the thin (usually <5 feet thick) surface soils found throughout Benton County. In much of Benton County this horizon is being actively farmed. In the scabland areas adjacent to the Yakima River and Columbia River this horizon is commonly absent.
- Quaternary (˜2,500,000 years old to modern) alluvium consists of thin (<20 feet thick), discontinuous occurrences of silt, sand, and gravel derived from eroded basalt and

reworked outburst flood deposits. Where present, Quaternary alluvium overlies outburst flood deposits, the Ringold Formation, and/or the CRBG.

- Pleistocene (~2,500,000 to 12,000 years old) cataclysmic flood deposits, consisting predominantly of sand, cobbles and boulders are present along the Columbia River and interbedded silt and sand (also referred to as Touchet Beds) are found in the Yakima River Valley. These strata are mapped and identified as outburst deposits of glacial Lake Missoula. Where present in Benton County, flood deposits are found in relatively thin (<30 feet), narrow, elongated tracts to the north, south, and southeast, and as a thin veneer overlying older units.
- Pleistocene loess consists of regionally widespread eolian (wind-blown) deposits of silt to very fine sand. These deposits are found at the surface commonly in upland areas, with the most notable of those being the Horse Heaven Hills. In dryland farming areas it is the primary surficial unit. Its thickness is generally 50 feet or less, although locally it can be over 100 feet thick. Loess is generally absent in scabland coulees and stream drainages.
- The Ringold Formation is a Miocene- to Pliocene-aged alluvial-lacustrine unit between approximately 8,500,000 and 3,000,000 years old that in Benton County consists predominantly of weakly cemented siltstone and claystone (GWMA 2007, 2009a, 2011d). It is found overlying basalt in portions of the lower Yakima River valley and underlying many of the benches in south Kennewick. Typically, it is capped by a thin (less than 20 feet) layer of caliche (calcium carbonate-rich strata) near the ground surface.

Figure 5, a geologic map of Benton County, shows the surface occurrences of the sedimentary strata introduced above and the basalt units introduced below.

3.1.2 Columbia River Basalt Group (CRBG)

The CRBG is laterally extensive, covering an area of more than 59,000 square miles (Tolan et al. 1989) and spanning parts of Washington, Oregon, and Idaho. Individual basalt flows that make up the CRBG occur as laterally widespread sheets that cover up to several thousand square miles each. The number of flows and overall CRBG thickness is greatest near the central portion of the Columbia Basin and least near its margins. In the Pasco Basin and Benton County, the CRBG exceeds 10,000 feet thick and is subdivided into three primary units, or formations, designated (from youngest to oldest) the Saddle Mountains Basalt, the Wanapum Basalt, and the Grande Ronde Basalt (GWMA, 2009a, 2011d; Swanson et al. 1979a, 1979b). These formations are further subdivided into several dozen members and several hundred flows. For this project, the hydrogeologic framework is described within the context of the formations which are summarized in the following paragraphs.

The Saddle Mountains Basalt is exposed at the surface across much of Benton County. Unit thicknesses range between 180 and 800 feet. The upper portions of the Saddle Mountains Basalt generally have limited lateral continuity and extent because it is commonly locally incised into by the Yakima River and the Columbia River. Given this river incision, the Saddle Mountain Basalt can generally be divided into an upper sequence corresponding to strata above the Umatilla Member and a lower sequence corresponding to deeper strata. The upper Saddle Mountains comprises the uppermost CRBG strata across most of Benton County, and it is exposed in river valleys and on uplifted highland areas, where younger sediments do not cover it. The deeper, more laterally continuous lower Saddle Mountains Basalt is only found at the surface in the deepest canyons (such as Wallula Gap) and major uplifts of the Rattlesnake Hills, Columbia Hills, and Horse Heaven Hills.

The Wanapum Basalt underlies all of Benton County and can be over 800 feet thick. It is exposed in many of the deeper canyons and on the higher ridges in Benton County. The even deeper Grande Ronde Basalt also underlies the entire county. Grande Ronde Basalt outcrops are only found at the Wallula Gap area. Depths to the top of the Grande Ronde are greater than 1,600 feet in the deepest basins, including the Pasco Basin (GWMA 2009a, 2011d). The uppermost Grande Ronde unit underlying Benton County is the Sentinel Bluffs Member (GWMA 2009a, 2011d). The thickness of the Grande Ronde Basalt beneath Benton County is not well known because few, if any, wells with public records fully penetrate it (Burns et al. 2011; GWMA 2009a, 2011d; Kahle et al. 2011).

Sedimentary interbeds found between the various CRBG formations, members, and flow units beneath Benton County belong to the Ellensburg Formation. These sedimentary interbeds vary in nature and composition, typically ranging between 1 and 100 feet thick, and while widespread, they can be locally absent (GWMA 2009a, 2011d). Within the Saddle Mountains Basalt there may be multiple Ellensburg Formation interbeds. Below the Saddle Mountains Basalt three primary Ellensburg Formation members are identified: the Quincy Member (predominantly claystone separating the Priest Rapids and Roza Members of the Wanapum Basalt), the Squaw Creek Member (predominantly claystone separating the Roza and Frenchman Springs Members), and the Vantage Member (predominantly claystone separating the Wanapum and Grande Ronde Basalts).

3.1.3 Geologic Structure

Benton County lies within the central portion of the Columbia Basin, a structural basin formed by regional subsidence and tectonic warping. Compressional and extensional tectonic stresses have led to the formation of regional fault and fold structures (e.g., anticlinal ridges and synclinal valleys) and four distinct structural subprovinces: Yakima Fold Belt, Blue Mountains, Palouse Slope, and the Clearwater Embayment (Myers and Price, 1979; Reidel et al. 1994). Of these, Benton County is located entirely within the Yakima Fold Belt.

The Yakima Fold Belt subprovince is characterized by a series of east-west-trending, anticlinal ridges, associated faults, and synclinal valleys. The major east-west oriented ridges cutting across Benton County, the Rattlesnake Hills, Horse Heaven Hills, and Columbia Hills, are such features (Figure 5). These ridges mark the locations of uplifts in which strata have been warped upwards hundreds to several thousand feet. Generally, the same units found at the tops of these ridges lie in the subsurface beneath adjacent valleys. Major fault systems have been mapped on the north sides of the Rattlesnake Hills and Horse Heaven Hills, and south side of the Columbia Hills. These faults abruptly truncate the rocks they cross cut, lifting them on one side and dropping them on the other.

3.2 Hydrogeology

The primary groundwater systems underlying Benton County are found within the alluvial sediments overlying the CRBG and within the CRBG. The CRBG aquifer system also is commonly subdivided into systems hosted primarily by the Saddle Mountains Basalt, the

Wanapum Basalt and the Grande Ronde Basalt (Ely et al. 2014). Further subdivisions of these basalt aquifer systems have also been suggested, such as the upper (Priest Rapids and Roza) and lower (Frenchman Springs) Wanapum (GWMA 2011e). In the Benton County region Ecology Central Region Office also subdivides the Saddle Mountains Basalt into an upper and lower aquifer unit for the purpose of water rights management. Hydrologic characteristics of the CRBG and alluvial aquifer systems are summarized further in the following sections.

3.2.1 Alluvial Aquifer System

The alluvial aquifer (or suprabasalt sediment aquifer) system comprises all saturated sediments that overlie the CRBG and is sometimes termed the overburden aquifer (Hansen at al. 1994). In Benton County, the alluvial aquifer is hosted primarily by fine grained Ringold Formation strata and coarser grained cataclysmic flood deposits. Loess, which also is a widespread alluvial unit (Figure 5), is not a significant water bearing unit in Benton County, and where it does host groundwater, it is not productive because of its fine-grained texture.

The lateral extent and continuity of the Ringold Formation, the cataclysmic flood deposits and the aquifer system they host, are effected by anticlinal ridges in the Yakima Fold Belt region and basalt bedrock scabland areas. Consequently, groundwater in this system tends to be localized, has limited lateral extent, and does not serve as a major, widespread county water supply. This aquifer system can produce usable quantities of groundwater in the larger basins, such as portions of the Yakima Basin and the Pasco Basin near the Columbia River. Groundwater occurring within the alluvial aquifer system is predominantly unconfined given that, surface recharge, where present, can easily reach this aquifer system.

3.2.2 Columbia River Basalt Aquifer System

The CRBG groundwater system in Benton County is regional in scale. The physical characteristics and properties of individual CRBG flows affect their intrinsic hydraulic properties and influence potential distribution of groundwater within the CRBG. Based on both surface and subsurface data and mapping, CRBG flows are most commonly classified as sheet flows (Beeson and Tolan 1990, 1996; Beeson et al. 1985, 1989; Reidel 1998; Reidel et al. 1994; USDOE 1988). As these and other reports show, CRBG sheet flows exhibited a basic three-part internal arrangement of internal intraflow structures that originated during the emplacement and cooling of the lava flows. These three features are referred to as the flow top, flow interior, and flow bottom. Flow tops and flow bottoms are variously vesicular to rubbly. With increasing vesicles and rubble porosity and permeability will generally increase. Flow interiors tend to consist of massive jointed rock which generally has very low permeability and porosity, even in the presence of joints. The combination of a flow top of one flow and the flow bottom of the overlying flow (with or without interbedded sediment) is commonly referred to as an interflow zone. Laterally continuous interflow zones host and transmit a large majority of the groundwater found in the CRBG aquifer system.

Groundwater within the CRBG aquifer system is typically confined. Where basalt flows are thick and laterally extensive, there is little vertical hydraulic connectivity between interflow zones. Conversely, where basalt flows thin, pinch out, or are disrupted, the degree of hydraulic continuity between interflow zones commonly increases. Unconfined conditions may exist in permeable, uppermost portions of the basalt where exposed at the surface. The hydrogeology of the CRBG is discussed further in a number of reports, including Ely et al. 2014; GWMA 2009c, 2011b, 2011e; Kahle et al. 2011.

Where not fractured by faults and folding, the basalts typically exhibit high horizontal and vertical hydraulic conductivities in the vesicular/rubbly permeable interflow zones, and low horizontal and vertical hydraulic conductivities in the dense flow interiors. Basalt flow interiors exhibit much lower hydraulic conductivities compared to the interflow zones, generally 6 to 9 orders of magnitude less than those displayed by interflow zones (Reidel et al. 2002; USDOE 1988).

3.2.3 Groundwater Movement

Groundwater flow direction within basalt units exposed at the surface generally follows the land surface, flowing from topographic and structural uplands down-dip to low-lying areas. At depth, groundwater flow is less controlled by surface topography and is more generally down-dip to the south toward the Columbia River (GWMA 2009c, 2011e; Hansen et al. 1994). Sediments interbedded within the basalt can either enhance or inhibit groundwater flow.

Groundwater flow directions in saturated portions of the alluvial aquifer system generally follow the land surface and discharge to surface drainage features or underlying basalt units. Alluvial aquifers tend to be localized by the numerous basalt outcrops that truncate these strata. Downward movement would be largely controlled by alluvial aquifer heterogeneities (e.g., cemented zones, caliche, and fine-grained overbank flood deposits) and the distribution of open joints and fractures in the underlying upper portions of the basalt aquifer system.

Fault/fold structures may present either barriers to groundwater movement or zones of enhanced groundwater flow (GWMA 2009c, 2011b, 2011e). The major structural features found in Benton County are the Rattlesnake Hills, the Horse Heaven Hills, and the Columbia Hills (Figure 5). Folding and faulting in these structures may cause reduced porosity and permeability through compression and destruction of basalt interflow zones, forming partial or complete barriers to groundwater movement. In the Benton County area, the general assumption was that these fold and fault structures form barriers to groundwater flow much as suggested by Hansen et al. (1994).

3.2.4 Recharge and Discharge

Recharge to the basalt and alluvial aquifer systems is primarily from infiltration of precipitation, loosing stream reaches, and seepage from canals and irrigation. The basalt aquifer system is recharged via more permeable sections of the basalt flows including vesicles, vertical joints, fractures and permeable interflow pathways. According to Hansen et al. (1994), groundwater recharge in the central Columbia Basin can range from as low as zero inches where annual precipitation is less than 8 inches up to several inches per year in heavily irrigated areas.

Given the location of Benton County in the central Columbia Basin, natural groundwater recharge is interpreted to be relatively small, to absent. Conversely, anthropogenic groundwater recharge in Benton County is interpreted to be common because of the wide extent of irrigated agriculture and landscaping. Groundwater geochemical data though indicates that many existing deep basalt aquifer wells in the region receive essentially none of this type of anthropogenic recharge (GWMA 2009b, 2009d, 2011a, 2011c, 2012, 2013). This work showed that deep aquifer groundwater in the region is characterized by increasing (Sodium[NA] + Potassium[K])/(Sodium[Na] + Potassium[K] + Calcium[Ca] + Magnesium[Mg]) ratios and decreasing percent modern carbon, suggesting slow recharge and long residence times for groundwater in the deeper portions of the CRBG aquifer system. Figure 6 illustrates some of the basic ways basalt aquifer groundwater recharge may occur in Benton County.

Discharge from the basalt and alluvial aquifer systems is generally toward topographic and structural lows, such as down dip in syncline axes and towards streams and lakes (Ely et al. 2014; Kahle et al. 2011). Shallow basalts commonly discharge to coulees and surface water systems while deeper units predominantly discharge into the major structural lows. The alluvial system can also discharge to and be a recharge source for the underlying basalts, primarily in areas where the suprabasalt deposits overlying the basalt are highly permeable and where the nature of the underlying basalt favors vertical flow.

Irrigation has influenced the surface hydrology of the area contributing to base flows in streams and irrigation waste ways. Intensive application of irrigation water in the region causes peak surface water flows (and groundwater recharge) to occur mostly during the summer and early fall with base flows from groundwater discharge taking place mostly during the fall and early winter (Williamson et al. 1998). The hydraulic connection between surface water and groundwater would likely be greater in drainages situated in the alluvial or outburst flood deposits compared to those incised in the less permeable loess or Ringold Formation deposits. Shallow groundwater pumping could induce recharge from surface water to groundwater in these areas or in permeable alluvial/outburst deposits adjacent to perennial streams. Low-permeability conditions underlying or within the suprabasalt deposits or within the basalt flow interiors would separate and confine deeper groundwater aquifers from surface water bodies.

3.2.5 Groundwater Quality

Basalt groundwater is generally reducing, having very low levels of dissolved oxygen and negative oxidation-reduction potential. Geochemical sampling has shown that shallower portions of the CRBG aquifer system have lower (Na+K)/(Na+K+Ca+Mg) ratios than deeper portions of the system (GWMA 2009c, 2011a, 2011b, 2011c, 2012). This work also showed that deep aquifer groundwater in the region is characterized by decreasing percent modern carbon, suggesting slow recharge and long residence times for groundwater in these portions of the CRBG aquifer system. Common water quality constituents in basalt groundwater that often exceed primary state standards include fluoride, iron, and manganese. Isotope chemistry data coupled with carbon-14 age dating suggest that deep aquifer basalt groundwater in the Columbia Basin generally has an average age of 30,000 years, or more (GWMA 2009b, 2009c, 2009d, 2011a, 2011c, 2013; Reidel et al. 2002).

Given the widespread occurrence of farming in the region, fertilizer application and irrigation can cause high nitrate in the aquifer systems. Shallow domestic wells generally have higher concentrations of nitrate (some exceeding 10 mg/L) than deeper wells (Williamson et al. 1998). Such groundwater quality conditions generally limit utilization of shallow groundwater sources, and most drinking water comes from deeper wells.

3.3 Benton County Wells

For the purposes of this Project the hydrostratigraphy of Benton County is simplified into major groundwater producing zones, including alluvial, shallow basalt, intermediate basalt, and deep basalt. Sampled wells are assigned to the zone(s) from which they are producing water. This is done to facilitate the analysis of historical and recently collected water quality data. By assigning sampled wells to a specific water producing zone comparisons can be made of nitrate conditions in similar portions of the aquifer system and avoid comparing nitrate conditions from different portions of the aquifer system. The scope of this study coupled with inherit variations in subsurface geology throughout Benton County precluded a detailed evaluation of the open intervals of each sampled well.

Definition of the water producing zone(s) each sampled well is open to, is based on the depth of the open interval in it and the open interval position above or below the top of basalt. Based on these criteria, the water producing zone(s) for sampled wells are assigned as follows:

- A well is classified as alluvial if it is reported to have an open interval (screen or open hole/not cased) between the ground surface and top of basalt.
- Basalt wells are classified on the basis of the reported depth of the open interval below the top of basalt, as follows:
    - A shallow basalt well has a reported open interval between the top of basalt and 350 feet below the top of basalt.
    - An intermediate basalt well has a reported open interval between 350 and 1,000 below the top of basalt.
    - A deep basalt well has a reported interval more than 1,000 feet below the top of basalt.
- Although depth intervals were not assigned to specific hydrogeologic units, the shallow, intermediate, and deep basalt water producing zones generally correspond to the upper Saddle Mountains, lower Saddle Mountains, and Wanapum-Grande Ronde, respectively.

Many of the sampled wells were found to be open to more than one water producing interval. For example, many wells reported to be open to the: (1) alluvial and shallow basalt water producing zones, (2) the shallow and intermediate basalt water producing zones, and (3) the intermediate and deep basalt water producing zones. These wells are addressed later in the Report.

4 GROUNDWATER NITRATE CHARACTERIZATION STUDY

The Benton County Groundwater Characterization study included a review of both the historic and recent nitrate groundwater data, identifying areas of increased nitrate contamination in groundwater from the four water production zones; alluvium, shallow basalt, intermediate basalt, and deep basalt. The locations of the historic sampling locations including their water production zone are provided on Figure 7 and the locations of the recent sampling locations are provided on Figure 8.

To facilitate evaluation, Benton County is divided into six distinct areas based on topography, land use (Figure 3), and potential nitrate sources, which may or may not be influenced by the topography. These six areas are shown on Figure 1, Figure 7, and Figure 8 and include the following:

- Prosser, consisting of mixed small urban, dense rural residential, and irrigated farming areas (Figure 7.1 and Figure 8.1).
- Benton City-Kiona, which includes mixed small urban, dense rural residential, and irrigated farming areas (Figure 7.2 and Figure 8.2).
- Richland Wye, which corresponds to the dense urban area of central/west Kennewick and Richland, and the irrigated farming area northwest of Richland (Figure 7.3 and Figure 8.3).
- Finley, including the relatively dense urban area of east Kennewick transitioning into the dense rural residential and collocated irrigated farming areas of Finley (Figure 7.4 and 8.4).
- Badger Coulee, which consists primarily relatively dense rural residential interspersed with irrigated farming (Figure 7.3 and Figure 8.3).
- Horse Heaven Hills, which consists of dryland farming in its northern area and mixed dryland and irrigated farming to the south and closer to the Columbia River (Figure 7 and Figure 8).

In each area nitrate contamination is evaluated based on the water production zones, alluvium, shallow basalt, intermediate basalt, and deep basalt, the sampled wells are interpreted to be open to.

There is a seventh area of historically and recently sampled wells that are present in the northwestern corner of Benton County. These wells are separated from the rest of Benton County by the Hanford Site. Both historical and recent sampling of this area shows low to no nitrate. Because they are isolated from the rest of the project area they are not discussed further in this report.

4.1 Historic Data

Historic nitrate data used in this report was collected from 142 alluvial, alluvial and shallow basalt, and shallow basalt wells from 1971 to 2011. This data, organized by water producing zone is presented in Table 1. The highest and lowest concentrations for each historic well in each water producing zone are plotted on maps (Figures 9, 10, and 11) so that areas of anthropogenic impact, elevated nitrate, and high nitrate can be evaluated spatially in Benton County.

Historic groundwater nitrate concentrations are categorized into four levels:

- *Background:* nitrate concentrations are less than 1.0 mg/L,
- *Anthropogenic Effect*: nitrate concentrations are greater than 1.0 mg/L and less than 10 mg/L,
- *Elevated:* nitrate concentrations are equal to or greater than 10 mg/L and less than 20 mg/L, and
- *High:* nitrate concentrations are equal to or greater than 20 mg/L.

The designation of High Nitrate concentration at equal to or greater than 20 mg/L was established because it is twice the regulatory limit of 10 mg/L.

Levels of effect are determined by the water producing zone for each of the six areas. Data density plays a role in this evaluation. In general, higher data density is available for the shallower units in urban areas. In addition, urban areas contain fewer intermediate and deep basalt wells, while rural areas have more of these wells. The urban areas contain more wells and more data spatially than the rural areas, but the rural areas contain longer temporal data records.

4.1.1 Alluvial Wells

The greatest densities of historically sampled alluvial wells are in the urban areas: Richland Wye (Figure 9.1) and Finley (Figure 9.2), followed by Badger Coulee and Benton City-Kiona (Figure 9.1). Historic alluvial nitrate data is sparse in Prosser and Horse Heaven Hills (Figure 9). Many of the gaps in alluvial well occurrence are because the alluvial aquifer is not a continuous unit across Benton County, being absent on the ridges and the Horse Heaven Hills. Generally, it is localized by basalt highs, and as a result only occurs in low areas along the Yakima and Columbia Rivers and in Badger Coulee (Figure 9.1).

Historical nitrate concentrations measured in alluvial wells range from 0.10 mg/L to 24.00 mg/L. The majority of the wells sampled have nitrate levels indicating Anthropogenic effects. There are some pockets of Elevated nitrate in the Finley and Badger Coulee areas and High nitrate in the northern end of the Badger Coulee area and in the north-central part of the Richland Wye area (Figure 9, Figure 9.1, and Figure 9.2).

4.1.2 Shallow Basalt (Including Mixed Alluvial/Shallow Basalt) Wells

The greatest density of historically sampled shallow basalt wells are in the Prosser (Figure 10.1), Benton City-Kiona (Figure 10.2), Richland Wye (Figure 10.3), and Finley (Figure 10.4) areas. Historically sampled shallow basalt wells are sparse in Badger Coulee and Horse Heaven Hills (Figure 10).

Historical nitrate concentrations measured in shallow basalt wells (including mixed alluvial and shallow basalt wells) range from 0.05 mg/ L to 54.00 mg/. Most of the wells in the urban areas and mixed dense rural/agricultural areas (Benton City-Kiona, Richland Wye, Finley, and Badger Coulee areas) have nitrate levels indicating Anthropogenic effects (Figures 10, 10.2, 10.3, and 10.4). All the shallow basalt wells in the Prosser area are affected by nitrate with large areas of Elevated nitrate, and two pockets of High nitrate (Figure 10.1) present north and east of the City of Prosser. Areas of High nitrate also are found in the Richland Wye area north of I-182. Many of the wells sampled in Horse Heaven Hills also contained High nitrate (Figure 10); however, the horizontal extent of the Elevated and High nitrate concentrations is not defined, and cannot be estimated due to very sparse data.

4.1.3 Intermediate Basalt (Including Shallow/Intermediate Basalt) Wells

Fewer historically sampled intermediate basalt wells as compared to shallower wells were sampled in all areas with the exception of the Horse Heaven Hills area (Figure 11). Historical nitrate concentrations in the intermediate basalt wells (including the mixed shallow and intermediate basalt wells) range from below laboratory detection limits to 35.70 mg/L.

The majority of sampled wells in the intermediate basalt contained only Background levels of nitrate with the exception of Horse Heaven Hills (Figure 11). In the Horse Heaven Hills area many of the wells in the intermediate basalt displayed Elevated and High nitrate concentrations (Figure 11). As with the shallow basalt, the extent of the Elevated and High nitrate concentrations in Horse Heaven Hills is not well defined and cannot be estimated due to the sparsity of available historical data. These basalt wells are the primary source of water across much of the Horse Heaven Hills area where surface water and shallow high yield groundwater aquifers are not available. Wells showing Anthropogenic Effect are present in the Richland Wye and Badger Coulee areas (Figure 11.1).

One well in the Prosser area and one well in the Finley area had Elevated nitrate concentrations (Figure 11).

4.1.4 Deep Basalt (Including Intermediate and Deep Basalt) Wells

In the historical data sets there are very few sampled wells open to the deep basalt. There is one in the Prosser area, one on the border of the Benton City-Kiona and Badger Coulee areas (Figures 11 and 11.1), and one in the Badger Coulee area (Figure 11.1). Nitrate concentrations in the deep basalt did not exceed Background levels, ranging from 0.050 mg/L to 0.500 mg/L.

4.1.5 Historical Data Summary

Although the historic data has a large temporal spread some general behaviors of nitrate in groundwater were observed. The shallower water producing units, the alluvium and the shallow basalt, had the highest measured nitrate effects. Deeper water producing intervals had nitrate concentrations that generally decreased.

Nitrate groundwater concentrations were highest in areas with irrigation, both agricultural and urban landscaping, especially in areas where irrigation is known to have been occurring for a long period of time. Higher nitrate concentrations in the shallower water producing zones are expected because the nitrate sources in Benton County are associated with surface activities. The presence of nitrate in some of the wells open to deeper units suggests localized migration may occur through natural pathways such as open fractures and faults and artificial pathways such as unsealed wells and/or wells screened through multiple units.

4.2 Recent Data

Building on the historical data, BCD began a new sampling program in the Fall of 2015. Many of the wells sampled in the Fall of 2015 were re-sampled in the Spring and Fall of 2016, along with additional wells that were not available during the Fall 2015 sampling event. In all cases, the sampled wells consisted of existing irrigation wells, stock wells, and potable water supply wells. Where access to historically sampled wells could be acquired, many of those were re-sampled in the recent sampling efforts. For the recent sampling (2015-2016), 229 wells were sampled, this total includes one well to the northwest of the Hanford Site. Nitrate data for each of these wells, and its associated hydrostratigraphic unit, are listed in Table 2. The recent well locations are shown on Figure 8. Nitrate occurrence and trends are explored below.

4.2.1 Nitrate Occurrence

As with the historic nitrate data, the recent data were evaluated based on geographic area and water producing zone. For each area and water producing zone these data are recompiled in

Tables 3 through 8. The same nitrate effect categories used in the historical data evaluation are used in the recent data evaluation, namely Background, Anthropogenic, Elevated, and High (Figure 12). A total of 188 wells are included in this portion of the report. Wells for which the water producing zone could not be determined as a result of missing well logs are discussed separately from data collected from wells where water producing zones are identified.

Alluvial Wells

Most of the alluvial wells sampled in 2015 to 2016 are located in the Badger Coulee and Finley areas (Figures 12, 12.1, and 12.2). Nitrate concentrations in the sampled alluvial wells ranged from 0.05 mg/L to 32.30 mg/L. Elevated nitrate is detected in the Richland Wye and Finley areas (Figure 12, 12.1, and 12.2). In the Badger Coulee area Elevated and High nitrate effects are observed (Figure 12.1).

Shallow Basalt (including Alluvial and Shallow Basalt) Wells

In general, the shallow basalt wells are relatively evenly distributed in the Prosser, Benton City-Kiona, Richland Wye, Finley, and Badger-Coulee areas, with a sparser distribution in the southern portion of Horse Heaven Hills (Figures 13 and 13.1).

Nitrate concentrations in the sampled shallow basalt wells ranged from 0.11mg/L to 85.10 mg/L. Measured nitrate effects in the Shallow Basalt is similar to measured effects in the alluvial wells in the Benton City-Kiona, Richland Wye, Badger Coulee, and Finley areas (Figure 13). In the Prosser area, while there are only few sampled alluvial wells, there are nearly twenty sampled shallow basalt wells. Most of these wells display nitrate concentrations indicating Anthropogenic effects. In addition, there are two sampled wells in the Prosser area with Elevated nitrate. Many of the sampled shallow basalt wells in Horse Heaven Hills area have Elevated or High nitrate (Figure 13).

Intermediate and Deep Basalt Wells

A few intermediate wells were sampled from each area, except for the Richland Wye where no intermediate basalt wells were sampled (Figure 14). Nitrate concentrations in the intermediate basalt ranged from 0.11 mg/L to 47.00 mg/L. The intermediate basalt wells sampled in Prosser and Benton City- Kiona areas have nitrate concentrations indicating Anthropogenic effects. One of the two wells sampled in the Finley area has Elevated nitrate. Five of nine intermediate wells sampled in Badger Coulee and Horse Heaven Hills areas contained Elevated and High nitrate concentrations (Figure 14). The 4 wells that did not display these effects, plus one isolated well east of the Horse Heaven Hills Area are notable in that they yielded samples from which nitrate was not detected.

Unknown Production Zone Wells

Hydrostratigraphic interpretations are not made for 100 of 229 recently sampled wells because well logs were not available. These unknown wells are located in all the areas as shown on Figures 15, 15.1, 15.2, and 15.3. Nitrate concentrations in the unknown completion wells range from 0.04 mg/L to 73.20 mg/L.

Measured nitrate concentrations in these unknown completion wells are generally similar to those seen in the alluvial and shallow basalt wells in all areas. Like those sampled wells assigned to a water producing zone, most of the unknown sampled wells display Anthropogenic effects with some areas of Elevated and High nitrate (Figures 15 and 15.1). The lateral extent of Elevated and High nitrate in Horse Heaven Hills could not be determined or estimated due to the sparsity of data. Finley had the highest number of unknown completion wells with 36 unknown completion wells (Figure 15.3).

4.2.2 Summary of Recently Collected Nitrate Data

Most of the recently sampled wells show Anthropogenic effects. The second largest group of sampled wells shows Background nitrate concentrations. The third largest group of recently sampled wells display Elevated nitrate and the smallest group of wells display High nitrate concentrations. With respect to specific areas in Benton County:

- **Prosser**: Of the 41 sampled wells in the Prosser area, 24% of them display Background levels of nitrate (less than mg/L), 59 % of them display nitrate concentrations indicative of Anthropogenic effects (nitrate ranging from 1 to less than 10 mg/L), 15% of them display Elevated effects, and 2% of them contain High nitrate (Appendix A, Figure A.1).
- **Benton City-Kiona**: There are 26 sampled wells in the Benton City-Kiona area. Of these, 19% are at Background levels, 73% display concentrations indicative of Anthropogenic effects, 4% are Elevated, and 4% are at High nitrate levels (Appendix A, Figure A.2).
- **Richland Wye**: There are 30 sampled wells in the Richland Wye area. Of these, 47% are at Background, 37% were at Anthropogenic levels, 13% of them are Elevated, and 3% are High (Appendix A, Figure A.3).
- **Finley**: There are 81 sampled wells in the Finley area. Of those, 20% are at Background levels, 65% are at Anthropogenic levels, 12% are Elevated, and 3% contained High nitrate levels (Appendix A, Figure A.4).
- **Badger Coulee area**: There are 25 sampled wells in the Badger Coulee area. Of these 12% are at Background, 52% are at Anthropogenic levels, 20% are Elevated, and 16% contain High nitrate (Appendix A, Figure A.5).
- **Horse Heaven Hills**: There are 25 sampled wells in the Horse Heaven Hills area. Of these 36% are at Background, 20% are at Anthropogenic levels, 16% are Elevated, and 28% are High nitrate (Appendix A, Figure A.6)

4.2.3 Trend Analysis

Nitrate concentration trends for each area (Prosser, Benton City-Kiona, Richland Wye, Finley, and Badger Coulee) are evaluated by hydrostratigraphic unit and compiled in Appendix B. Basic trends displayed by these data are summarized in the following paragraphs. Wells from which only one sample was collected are not represented on the trend plots.

<u>Prosser</u>

Thirty-eight sampled wells in the Prosser area have two or more samples for each well (Appendix B.1, Table 3). Some fluctuation is seen in the Alluvial and Shallow Wells and the unknown wells. This fluctuation appears to be seasonal in character, which is common in areas where irrigated agriculture and landscaping occurs. These wells display lower nitrate concentrations in the fall following the irrigation season, resulting in the dilution of nitrate concentrations in the groundwater. There was a slight increase in nitrate concentrations between irrigation periods when irrigation water is not available to dilute nitrate concentrations.

Nitrate concentrations in sampled alluvial wells remained at Background levels for the 2015 and 2016 sampling events. The majority of the sampled alluvial and shallow basalt wells show Anthropogenic effects (Appendix B.1, Table 3). Two of the wells have Elevated Nitrate concentrations. All sample wells completed in the shallow and intermediate basalt have nitrate levels indicating Anthropogenic effects (Appendix B.1). The trends for unknown completion wells in Prosser appear to behave similarly to those screened in the alluvium and shallow basalt with most of them falling in the Anthropogenic effect range, with a few wells containing Elevated nitrate concentrations. Again, a few of the wells show some seasonal/irrigation influence. One well sampled had High nitrate concentrations, and it appeared to be influenced by seasonal irrigation practices (Appendix B.1).

Benton City-Kiona

Twenty-two of the sampled wells in the Benton City-Kiona area have two or more samples per well. Most of these samples show little variation with the following exceptions: two alluvial, one alluvial and one shallow basalt well, and one intermediate well show varying nitrate concentrations in excess of 1 mg/L. One of the alluvial wells showed fluctuating concentrations suggestive of seasonal irrigation influences and another alluvial well showed a large increase, from Anthropogenic to High concentrations (Appendix B.2, Table 4). Sampled alluvial, shallow, and intermediate basalt well nitrate effects also are fairly constant with one increasing and two decreasing. The unknown completion depth wells follow the wells screened in the alluvium and shallow basalt with most of the wells remaining constant in the Anthropogenic effect range, which is below the MCL of 10 mg/L (Appendix B.2). Further sampling of the varying wells will be needed to determine if the high nitrate concentrations will remain or return to the Fall 2015 levels

Richland Wye

In the Richland Wye area, twenty-three of the sampled wells had two or more samples per well. Two alluvial and shallow basalt wells and two unknown wells show fluctuations greater than 1 mg/L. Of the former grouping one High effect well is rising while one Anthropogenic well is decreasing. The two unknown wells with large fluctuations both show Anthropogenic effects and the fluctuation appears to be at least partially seasonal in nature.

Alluvial wells in the Richland Wye area remained constant over the 2015 to 2016 sampling period, although only two of these types of wells were sampled. Well BC142834 WW displayed elevated nitrate concentrations and well BC141785 WW remained around 2.00 mg/L. Sample well BC089 WW had a decrease in nitrate from Spring 2015 to Fall 2016; however, the well was not sampled in Fall 2015 so the cause of the decrease cannot be confidently attributed to seasonality (Appendix B.3, Table 5). Wells screened in the alluvium and shallow basalt had a wide range of nitrate concentrations (Appendix B.3), and as noted above two of the nine sampled wells in this water producing zone fluctuated by more than 1 mg/L. Most of the sampled wells contained nitrate concentrations in the Anthropogenic and Background range. One well, BC124 WW, had constantly High nitrate (Appendix B.3). One well in the Richland Wye area is completed in the shallow basalt production zone and remained at background levels for the 2015 to 2016 sampling events (Appendix B.3).

The unknown completion wells in the Richland Wye area follow a similar patter to those completed in the alluvium and shallow basalt production zones. Most of the wells remained stable in the Anthropogenic or Background level ranges (Appendix B.3). Two wells, BC008 WW and BC013 WW, showed a similar decrease to well BC089 WW, however, none of these wells are located near each other. Further sampling at these wells is will help determine possible causes of well behavior.

Finley

Sixty-four sampled wells with two or more samples were collected in the Finley area. Six alluvial wells show fluctuations greater than 1 mg/L, with three of them generally decreasing and three of them generally increasing (Appendix B.4, Table 6). The wells with decreasing concentrations have Anthropogenic and Elevated concentrations. Two of the wells with increasing concentrations show Anthropogenic effects while one of them is High. Five alluvial and shallow basalt wells show nitrate fluctuations greater than 1 mg/L, with all of them increasing between the spring and autumn samples (Appendix B.4).

Given the fluctuations noted above, most sampled alluvial wells in the Finley area remained relatively constant over the 2015 to 2016 sampling events. With the exception of wells BC137860 WW and BC115 WW most of these stable wells show Anthropogenic effects while six wells show Elevated nitrate, and one well BC115 WW, show High nitrate. Well BC137860 WW contained Elevated nitrate in the Fall 2015 sampling event and decreased concentrations in the Spring and Fall 2016 sampling events (Appendix B.4, Table 6).

Most of the wells screened in the alluvium and shallow basalt production zone display Anthropogenic and Background effects. Generally these nitrate concentrations remained relatively constant with a few minor fluctuations in wells BC045, BC146313 WW and BC493528 WW (Appendix B.4). Well BC114 WW contained Elevated nitrate with a slight increase from Spring to Fall 2016. Well BC087 WW contained High nitrate concentrations that increased slightly from the Spring to Fall 2016 events. Both wells BC114 and BC087 were only sampled over the two events, so the changes in nitrate cannot be positively related to seasonal influences. Additional sampling at these wells is will help determine possible causes of well behavior.

In the two sampled shallow and intermediate basalt wells, well BC404762 WW remained constant at Background levels and well BC042 WW displayed Elevated nitrate (Appendix B.4). Nitrate concentrations in the unknown completion wells are all constant in the Background and Anthropogenic effect ranges with the exception of BC043 WW and BC003 WW. Continued sampling at these wells is will help determine possible causes of well behavior (Appendix B.4).

Badger Coulee

In the Badger Coulee area, twenty-one of the sampled wells had two or more samples collected per well. Alluvial wells in the Badger Coulee area were mostly constant in the Anthropogenic and Background ranges, except well BC022 WW, which appears to display seasonal behavior (Appendix B.5, Table 7).

Wells completed in the alluvium and shallow basalt production zones had a wide spread of nitrate concentrations and behaviors. Well BC004 WW had nitrate concentrations in the Anthropogenic range and is likely influenced by seasonal irrigation (Appendix B.5). High nitrate concentrations were observed in wells BC117 WW and BC588903 WW. Well BC588903 had the highest concentration in Fall 2015 and decreased over the following two events, but remained above 20 mg/L. Well BC117 WW was constantly around 27 mg/L (Appendix B.5).

The three sampled wells in the shallow and intermediate basalt production zone ranged from Background to High nitrate levels. Nitrate concentrations in all three wells remained constant from Fall 2015 to Fall 2016 (Appendix B.5).

The unknown completion wells display a range of effects, from Background to Elevated, with the majority of the wells in the Anthropogenic Impact range (Appendix B.5). Nitrate concentrations remained constant in most of the wells with one well, BC036 WW, showing seasonal variations (Appendix B.5).

<u>Horse Heaven Hills</u>

In the Horse Heaven Hills area, twenty-four of the sampled wells had two or more samples per well. Only one alluvial well was sampled in Horse Heaven Hills, BC145628 WW. Nitrate concentrations in the well were constant and in the Anthropogenic Effect range (Appendix B.6, Table 8).

The wells screened in the alluvium and shallow basalt had a wide range of nitrate concentrations ranging from Background to High nitrate concentrations (Appendix B.6). Nitrate concentrations in the alluvial and shallow basalt production zones remained relatively constant over the three sampling events, except for wells BC148771 WW and BC322098 WW, which appeared to fluctuate greatly. Further sampling will help determine possible sources of variability at these wells.

The Horse Heaven Hills wells screened in the intermediate and shallow basalt fell into two categories. The wells in the central and southern areas had High nitrates and remained relatively stable, except well BC145482 WW where nitrate concentrations decreased in the Spring 2016 (Appendix B.6). Nitrate concentrations in the northern portion of Horse Heaven Hills were at Background levels for all the sampling events.

One sample well in Horse Heaven Hills was screened in the intermediate and deep basalt, BC023 WW. Nitrate concentrations in this well were at Background levels (Appendix B.6).

5 Discussion

Benton County has a number of potential urban and rural sources of groundwater nitrate. These sources include: agricultural irrigation practices, livestock agriculture, agricultural fertilization activities, urban wastewater, septic systems, residential landscape fertilization and irrigation, and urban landscaping and fertilization practices including commercial landscaping for golf courses and parks. Many of these anthropogenic practices have been taking pace in Benton County for decades. In addition to these potential sources, there are also relatively (lower nitrate) clean water sources in Benton County, which may contribute to decreased groundwater nitrate concentrations through dilution. These sources include the Columbia River, Yakima River, deep basalt groundwater, and irrigation water derived from the aforementioned sources.

The documented record of nitrate in groundwater, compiled in a series of historic reports, shows groundwater nitrate contamination since at least the early 1970's. This groundwater characterization study encompassed available county-wide nitrate data in the form of two records, the historic nitrate data ranging from 1971 to 2011, and a series of fall and spring sampling events from 2015-2016. It is evident in the historic reports and available historic nitrate data that nitrates in the Benton County groundwater system have been introduced by anthropogenic sources. Recent data shows that Benton County groundwater is still impacted by nitrate.

5.1 Historic vs. Recent Groundwater Nitrate Data

In general, areas with sampled wells displaying High nitrate, Elevated nitrate, and Anthropogenic effects are very similar when comparing the historic and recent groundwater nitrate data. The historic data mapped on Figures 9 through 11 closely resemble the recent data mapped on Figures 12 through 15. The recent sampling event does not pinpoint any new sources in Benton County, but suggests that the anthropogenic practices influencing nitrate are still in effect, as distribution has not changed significantly over time.

Both the historic and recent groundwater nitrate data are interpreted to indicate that irrigation and fertilization practices introduce some of the highest nitrate concentrations into groundwater. The urban areas, Benton City-Kiona, Richland Wye, and Finley had local spots of nitrate contamination, while mixed urban and rural areas and rural areas, Prosser, Badger Coulee, and Horse Heaven Hills exhibited potentially larger areas of high nitrate. In both records, the available data in Horse Heaven Hills is sparse, and nitrate effected areas may not be well represented (Figures 9 through 15). The distinct behaviors of groundwater nitrate due to land use practices are further discussed in Section 5.2.

Maximum detected nitrate concentrations and average concentrations appear to have increased slightly in most water production zones:

- In the sampled Alluvial wells the highest nitrate concentrations increased from 24.00 mg/L in the historic record to 32.30 mg/L in the recent record, and the average increased from 4.57 mg/L to 6.51 mg/L.
- The highest concentrations in sampled Shallow Basalt wells increased from 54.00 mg/L in the historic record to 85.1 mg/L in the recent record, and average concentrations increased from 4.44 mg/L to 7.01 mg/L.
- The highest concentrations in the Intermediate Basalt wells increased from 35.70 mg/L in the historic record to 47.2 mg/L in the recent record, and average concentrations increased from 5.51 mg/L to 12.35 mg/L.
- Deep Basalt remained at background levels for nitrate.

While it is possible that increased maximum nitrate concentration and average nitrate concentration simply reflects the locations of recently sampled versus historically sampled wells, it is also possible that these increases reflect increasing groundwater nitrate concentrations in portions of Benton County. Because the basic distribution of Background, Anthropogenic, Elevated, and High effect areas does not change significantly between the two data sets, while the highest concentrations and average concentrations have increased, it seems likely that groundwater nitrate concentrations have increased in areas where anthropogenic activities introduce nitrate, in both urban and rural areas.

5.2 Source Characterization, Land Use, and Water Producing Zones

In Benton County, groundwater nitrate is generally: (1) above Background levels where there is anthropogenic development, including urban or rural residential or agricultural development, (2) highest in shallower water producing zones and lowest in deep zones, and (3) lower in alluvial and shallow basalt water producing zones near major surface water sources. Nitrate concentrations in most wells sampled in 2015 and 2016 showed relatively minor fluctuations. However, some sampled wells do display seasonal nitrate concentration variations interpreted to reflect irrigation season dilution of groundwater nitrate.

In the urbanized Richland Wye area and mixed residential and farming Finley area, Elevated and/or High groundwater nitrate was observed in individual wells, which are separated by clusters of wells displaying Background and Anthropogenic effects. Nitrate also generally occurs at lower concentrations in sampled alluvial, shallow basalt and intermediate basalt wells than is observed from the same water production zones in the mixed rural residential and irrigated agriculture areas of Prosser, Badger Coulee, and the Horse Heaven Hills (Figures 12 through 15). The primary difference between the urbanized and residential areas of Richland and Finley and the rural/irrigated areas of Prosser, Badger Coulee, and Horse Heaven Hills is interpreted to result from low nitrate water seeping from the Columbia River and associated irrigation systems into shallow groundwater systems, diluting groundwater nitrate. Given this difference, locally higher nitrate may reflect urban landscaping and legacy nitrate sources. Much of the residential development in these areas is on ground converted from irrigated farming, and there is the potential that historical (i.e., no longer active sources) could have contributed to observed nitrate effects. In general, the wells in the urban areas had nitrate trends that were constant over the year, and did not display seasonal fluctuations or increased concentrations during the 2015 to 2016 sampling events.

In the Benton City-Kiona area, land use consists of a mix of small urban, rural residential, and irrigated farming. Active sources of nitrate in this setting consist of a mix of urban landscaping, irrigated farming, and variable density on-site waste water systems. In this area sampled alluvial, shallow basalt and intermediate basalt wells generally display lower nitrate concentrations than observed from the same water production zones in the mixed rural residential and irrigated agriculture areas of Prosser, Badger Coulee, and Horse Heaven Hills (Figures 12 through 15). There are also several wells in the Benton City-Kiona area located near the Yakima River displaying Background nitrate conditions. These wells, like Background wells in the Richland Wye and Finley areas, are interpreted to be receiving a significant amount of low nitrate recharge water from nearby surface water, which in the Benton-City-Kiona area is the Yakima River and associated canals.

Groundwater nitrate effects in sampled Prosser and Badger Coulee area wells from all water producing zones range from Background to High nitrate concentrations (Figures 12-15). In Badger Coulee, sampled wells exhibiting very different nitrate concentrations are located near each other. The land use map supports this mixed behavior, where there is both urban development and moderate to high efficiency irrigation processes in Prosser and Badger Coulee

(Figure 3). Much of the residential development in these areas is on ground converted from irrigated farming; therefore, there is the potential that historical, no longer active sources, could have contributed to observed nitrate effects. The large range of observed groundwater nitrate effects in these two areas likely reflects this mix of very different and changing land uses. In addition, where there are Background effects seen, wells are either near low nitrate surface water recharge sources or deep in the aquifer system.

In the Horse Heaven Hills area, which is dominated by dryland farming in the north and irrigated farming in the south, Elevated and High groundwater nitrate effects are spread out geographically (Figures 12 through 15). However, the available data in Horse Heaven Hills is sparse and lateral continuity of the High and Elevated nitrate effects are difficult to determine. Nitrate concentrations are also higher and affect the intermediate basalt production zone to a greater degree. This finding may be due to wells completed in both the alluvial and shallow basalt water producing zones and other wells completed in both shallow basalt and intermediate basalt acting as preferential flow pathways for nitrates to move between the geologic units in addition to the naturally occurring pathways in the geology. Some wells exhibit seasonal influences, and some wells have unexplained large increases or decreases in nitrate concentrations over the 2015 to 2016 sampling events. Horse Heaven Hills also has the highest percentage of wells sampled containing Elevated and High Nitrates.

Wells in the alluvial water producing zone in all six areas display nitrate effects from Background and Anthropogenic conditions near surface water bodies to Elevated and High. Given the mix of current land uses and historical transition from farming to mixed farming and high density rural residential and urban development, the cause(s) of Elevated and High nitrate in the alluvial water producing zone is not well understood. The occurrence(s) of groundwater nitrate in the alluvial water producing zone could reflect both active and historical land uses, but the information collected does not yet lead to a definitive conclusion.

In the shallow basalt water producing zone, which includes mixed alluvial and shallow basalt wells, groundwater nitrate concentrations observed in sampled wells are similar to what is seen in the alluvial wells. Sampled wells near surface water bodies commonly display Background to Anthropogenic effects. However, Elevated and High effect wells are present as individual points separated by lower concentration wells and as a cluster of wells in Badger Coulee area. These areas could be due to singular or point sources near the sampled well, or the source may no longer exist due to urban development. Given the mix of current land uses and historical transition from farming to mixed farming and high density rural residential and urban development the cause(s) of Elevated and High nitrate in the shallow basalt water producing zone is not well understood. The occurrence(s) of nitrate in the shallow basalt water producing zone could reflect active and historical land uses, in addition to well construction where wells lack adequate seals. The information collected, however, does not yet lead to a definitive conclusion.

The wells sampled in the intermediate and deep basalt water producing zones display a large range in observed nitrate concentrations. There were 17 of these wells sampled. Of the intermediate and dep basalt sample wells, 6 of them display Background effects. Of the remaining 11 wells, High to Elevated nitrate is measured in 6 wells, half in the Horse Heaven Hills area and half in the Badger Coulee and Finely areas. The cause(s) of these observed conditions are not known, but might include compromised/inadequate well seals, and in the

Badger Coulee area proximity to other wells which have similar seal issues. The five deep to intermediate wells showing Anthropogenic effects are located in the Prosser and Benton City-Kiona areas where well density is relatively high.

Groundwater flow direction in the alluvial water producing zone is expected to generally follow the land surface and discharge to surface waters and underlying basalt units via natural and artificial pathways (usually wells). Generally this flow will be down the Yakima River (to the east) and down the Columbia River (to the south and west). Groundwater flow direction within basalt units exposed at the surface generally follows the land surface, flowing from topographic highs to low-lying areas. In the deeper basalt units groundwater flow is expected to be toward the Columbia River. Fault/fold structures may present either barriers to groundwater movement or zones of enhanced groundwater flow (Figure 5). Given the scope of the study area, the data density for the study area, and numerous significant pumping stresses likely active in the area, the lateral migration of nitrate was not evaluated.

Nitrates introduced on the surface infiltrate through the alluvium and into the alluvial aquifer, where they may infiltrate into the deeper basalt units. There are naturally occurring preferential flow pathways such as joints fractures and more permeable sediments that allow for faster movement of nitrate into deeper groundwater systems. In addition to these natural preferential flow paths, wells with open intervals across multiple groundwater systems can also act as preferential flow paths. The well records in this study demonstrated many of wells are completed across multiple intervals, which are most likely acting as preferential pathways since the areas of High Nitrate and Elevated Nitrate are mirrored to a lesser extent in deeper units.

5.3 Possible Trends

At present there is not enough data to establish increasing or decreasing nitrate trends for the individual recently sampled wells; however, some seasonal and irrigation influence is seen in wells located in irrigated areas. Some wells exhibited large decreases or spikes that may be outliers or attributed to the natural behavior of the well. Sources of outliers in the area can be nitrate sources temporarily stored next to a sampling well, outside water source being poured down the well, and field or lab error can causing either a dip or spike in the data. Further regular sampling is needed to establish definitive trends.

Generally, seasonal irrigation trends are seen in areas of moderate and low efficiency agricultural irrigation. Irrigation introduces new water sources that dilute the groundwater nitrate concentrations, which then rebound when irrigation water is no longer being added to the system. These seasonal trends were observed in some of the Prosser and Badger Coulee sample wells (Appendices B.1 and B.5). Seasonal irrigation trends were less prevalent in Horse Heaven Hills because of the high efficiency irrigation. Large amounts of irrigation water are not available to infiltrate into groundwater and dilute nitrate concentrations. This lack of dilution in the Horse Heaven Hills area may be a contributing factor to the elevated groundwater nitrate concentrations (Appendix B.6).

There are five livestock feedlots in Benton County. The available data do not indicate that the feedlots are a significant source of nitrate when compared to the contributions of the surrounding land use. In the event of the Feedlot in west/central portion of Horse Heaven Hills, historical data indicates nitrate concentrations in the area were high before the feedlot came into operation, and the available recent data near the other feedlots do not currently show significant increasing annual trends.

Although irrigation and fertilization occur in urban areas as residential landscaping, parks, and golf courses; they do not appear to produce short-term seasonal trends like irrigated agriculture. Further sampling will be needed to determine if any trend exists as a result of urban fertilization.

6 CONCLUSIONS

Groundwater characterization included evaluation of both historic and current groundwater nitrate data, determination of nitrate producing activities, and the delineation of contamination and location of high nitrate in groundwater. Based on the characterization study the following conclusions are presented.

It is recommended that groundwater sampling is continued in order to identify trends and monitor groundwater nitrate levels. Bi-annual sampling is recommended at this time. However, the monitoring schedule should be updated to accommodate field conditions and trends when they become more established, such as quarterly monitoring of High Nitrate areas near sensitive populations like children, elderly, and women of child bearing age. Conversely, sampling schedules may be decreased to annual sampling in areas of low nitrate and lack of known sources, for instance, as in the dry land area in northern Horse Heaven Hills. It is also recommended to increase sample density as able, especially in Horse Heaven Hills, so the extent of High Nitrate and Elevated Nitrate areas can be better understood and addressed accordingly. Additionally, it is recommended to update and monitor groundwater trends with every sampling event in order to discern and possibly mitigate problem areas as soon as possible. An optimum groundwater monitoring plan is dependent, however, upon available funding.

Mitigating nitrate in and protecting shallow groundwater systems starts at the surface with nitrate application and irrigation. The anthropogenic processes that introduce nitrogen at the surface and result in groundwater nitrate are important to the local economy and the livelihood of Benton County residents. Therefore, a community effort is needed to make these processes more efficient while still being cost effective. This community effort should include education and incentives to educate the public on what they can do to protect their groundwater without significant impacts to their bottom line. These recommendations are organized by land use or suspected source, since this study indicated that may be one of the controlling factors.

The evolution of land use is generally driven by economic forces and public need. Trying to mandate land use is not feasible. Instead, consider working with changes in land use. For example, as urban sprawl continues to spread offer incentives for xeriscaping or low-water use landscaping for home owners and businesses. Educate the public on how xeriscaping can also be aesthetically pleasing and save money on the water bill. Consider working with developers and local builders to encourage low-water use landscaping and setting limits on lawn size. In addition to encouraging low-water use landscaping, educate the public on efficient lawn care, such as the best times to water and fertilize your lawn, so that there is less water and nitrate waste.

Urban landscaping such as parks and gold courses often have designated individuals in charge of landscaping and grass care. Consider holding discussions with those in charge of large urban landscaping about water schedules, sprinkler direction to limit run-off, and the ability to use low-efficiency landscaping. Examples for reference of these types of landscaping are available in communities like New Mexico and Arizona.

For agricultural irrigation practices educate the public on proper storage of nitrate sources like fertilizers and crop waste in order to decrease pathways of nitrate into the groundwater. For instance, fertilizer and crop waste should not be stored near wells. Also, determine if there are more efficient methods for fertilizing and irrigating crops, crop rotations, or cover crops, which can be large, nitrate sinks. Educate the public on the new methods, and offer incentives for the use of these methods.

For livestock feedlots, educate and provide incentives for surface run-off management and lagoons in order to decrease infiltration into the groundwater. Consider installing monitoring wells down gradient of lagoons and feedlots to monitor liner and surface water run off management effectiveness.

Educate the public on the maintenance of septic systems and repercussions of a leaky system. Encourage and offer incentives for the replacement of older septic systems. Remove and or properly abandon "in-place" septic systems that are no longer in use.

Deep water protection comes in two parts: 1) Decreasing nitrate in the shallower units that may mobilized into deeper groundwater, and 2) Educating well users on how well construction may lead to groundwater nitrate exposure, and the importance of maintaining WAC 173-160 compliant well construction practices. Educate the public and enforce regulation for not completing wells with open intervals across multiple sections, particularly in shallower contaminated water and deeper cleaner water. Completing wells through multiple units creates a man-made preferential flow pathway.

Finally, protect the public from current nitrate conditions. Inform the public of what they can do if their well contains elevated or high nitrates, such as filtration systems capable of removing nitrate from water and where they can get a filtration system. Identify and address any High and Elevated Nitrate areas that are near sensitive populations such as children, elderly, and women of childbearing age.

Nitrate can stay in groundwater for decades, as conditions for denitrification must be anoxic or very low in oxygen. Nitrate concentrations in groundwater are expected to increase as long as anthropogenic practices at the surface do not change.

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TABLES

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WELL PERCENTAGE CHARTS

APPENDIX B
RESULT PLOTS

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PROSSER RESULT PLOTS

APPENDIX B.2
BENTON CITY-KIONA RESULT PLOTS

APPENDIX B.3
RIHCLAND WYE TREND PLOTS

APPENDIX B.4
FINLEY TREND PLOTS

APPENDIX B.5
BADGER COULEE TREND PLOTS

APPENDIX B.6
HORSE HEAVEN HILLS TREND PLOTS