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ConAgra Foods Lamb Weston Inc. Pasco, Washington

Hydrogeologic Assessment

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ConAgra Foods Lamb Weston Inc.
Pasco, Washington

Hydrogeologic Assessment

by

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- WRIA - 36 Esquatzel Coulee
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Abstract

ConAgra Foods Lamb Weston Inc. in Pasco, Washington (ConAgra) is a vegetable processor that applies process wastewater year-round to over 3,000 acres of land. This land is used to grow crops as part of a land treatment system.

Washington State requires that all wastewater be treated with AKART (All Known, Available and Reasonable Methods of Prevention, Control and Treatment) prior to being discharged to the environment. AKART for industrial land treatment systems typically includes (1) agronomic application of wastewater during the growing season and (2) winter storage in a lined impoundment. This is the treatment standard unless a facility can present site-specific conditions and a wastewater management strategy that demonstrates an alternative treatment system will be equally protective of the environment.

The objective of this review is to provide an independent evaluation of all relevant reports, data, and literature in order to provide a technically defensible AKART determination regarding ConAgra's year-round land application of wastewater at their site. This evaluation considers compliance with Washington State groundwater quality standards, which is part of the AKART demonstration.

It is determined that ConAgra is land applying excessive wastewater to the soils. This is causing both elevated soil nitrate concentrations and elevated nitrate and total dissolved solids (TDS) concentrations in groundwater. It is determined that year-round application at this site is not protective of groundwater quality.

It is recommended that ConAgra modify their wastewater management to apply process wastewater to land only in amounts and at times when crops can use the nutrients.

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Introduction

ConAgra Foods Lamb Weston Inc. in Pasco, Washington (ConAgra) is a vegetable processor that uses a year-round land treatment facility to manage their process wastewater. ConAgra does not have a winter storage lagoon. As part of their treatment process, this facility spray irrigates approximately 1.5 million gallons per day to 3,120 acres to grow crops.

Typically, the treatment technology in Washington State, AKART (All Known Available and Reasonable Methods of Prevention, Control and Treatment), is the agronomic application of wastewater during the growing season and winter storage. The Washington State Department of Ecology (Ecology) guidance on minimum treatment standards for land treatment of industrial wastewaters states that a lined lagoon is necessary to contain process wastewater generated over the winter when (1) crops are dormant or (2) agronomic application of wastewater is not a viable treatment option. AKART allows Ecology to consider site-specific information to modify the minimum level of treatment if the proposed treatment alternative is at least as protective of groundwater quality and the environment as the Ecology recommended treatment (Ecology, 2004).

ConAgra submitted technical documents to Ecology that substantiate year-round application of process wastewater. The documents describe annual nitrogen and water balances, management of the sprayfields, limited vertical transport of contaminants within the vadose zone, and how nitrogen can be stored in the soils during the colder months. Additionally, ConAgra proposes compliance measures that they advocate should be used in the permit. These technical perspectives are discussed in the section on *ConAgra Proposal of Year-Round Application of Wastewater as AKART.*

The goal of this investigation is to review all relevant ConAgra facility documents, literature, and data to (1) assess the impacts of ConAgra's discharge on the environment, (2) determine if their current treatment process is protective of groundwater quality, and (3) determine if the practice of year-round land application at this site is adequate to be considered AKART.

Background

Currently ConAgra processes french fries, formed potato products, onion, and other appetizer products. This facility processes 800 to 1,600 tons of raw potato products per day. They operate 24 hours a day and 7 days a week. They apply an average of 500 million gallons of process wastewater every year to 3,120 acres of land.

Ecology works with ConAgra to develop a wastewater management system that is compliant with Washington State laws and regulations. Ecology administers the State Waste Discharge Permit ST-5309 for ConAgra (Ecology, 2009a, 2009b, and 2010).

ConAgra began operations in 1965 as a vegetable processor. This facility has always employed land treatment as an integral component of their wastewater management. Prior to land application, the wastewater is screened, then treated through a clarifier and a settling pond. The settling pond is an unlined earthen structure. All of the wash water is recycled, and the solids are trucked off site for cattle feed.

Process Wastewater

ConAgra beneficially reuses their process wastewater by using the nutrient-rich water to support the growth of a variety of crops. Additionally, ConAgra uses the soil horizon as a natural form of treatment and attenuation. Wastewater is generated at the facility from washing, transporting, and grading potatoes. (Pritchett, 2011). Supplemental freshwater from irrigation wells is mixed with the process wastewater at the central pump station or is delivered directly to the fields from designated wells. A lined 19 million gallon surge/storage basin adjacent to the central pump station is used to equalize daily flow variations and to store wastewater during freezing weather conditions. Process wastewater monitoring occurs at the pump station.

The land treatment site is located south of the Esquatzel Diversion Canal and north of the Tri-Cities airport (Figure 1). The site has been leveled over the years but still has a slight topographic gradient dropping from 520 feet above mean sea level in the northeast and southwest, to 430 feet in the center, and 400 feet in the south near the airport (Coffan, 2000). ConAgra can land apply process wastewater using center pivot irrigation, solid set irrigation systems, and wheel lines (Pritchett, 2011).

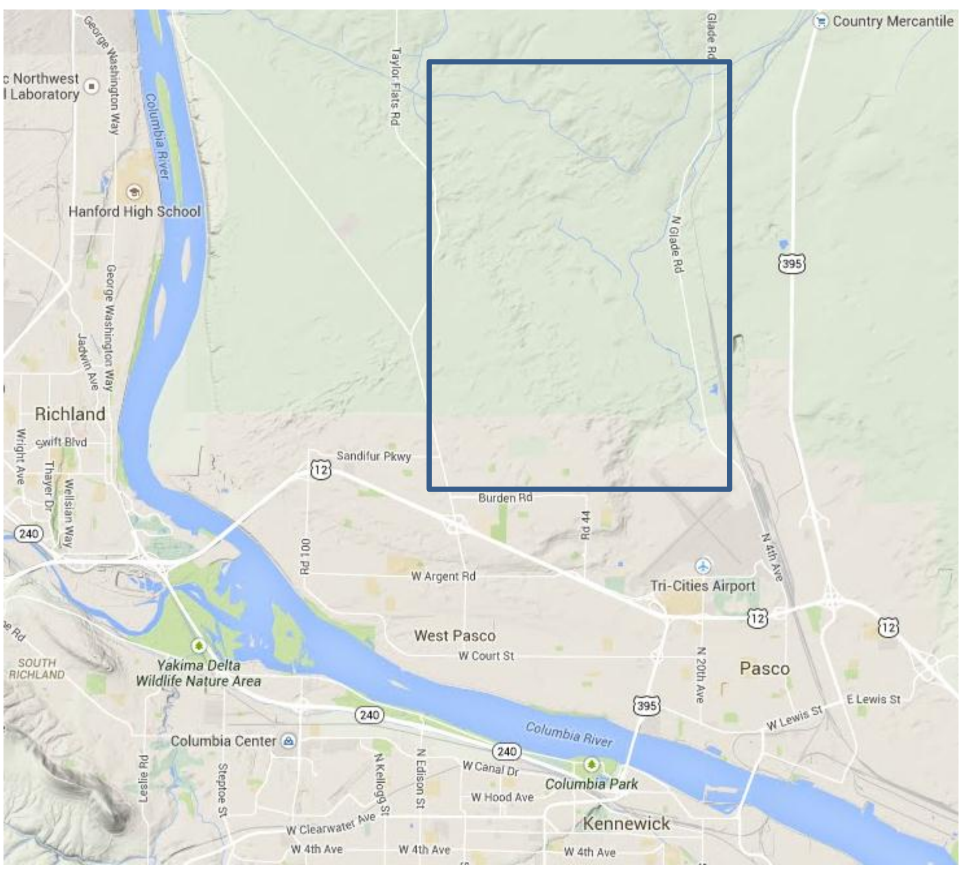

Figure 1. ConAgra Foods (Pasco) Sprayfield Site.

ConAgra generated an average of 610 million gallons (MG) of wastewater per year, with daily flows averaging approximately 1.7 MG/day (Table 1). The treatment facility is designed for 803 million gallons per year and a maximum of 2.2 million gallons per day (Ecology, 2009b; Pritchett, 2011). ConAgra owns or leases 3,120 acres which it employs as sprayfields as part of their land treatment system. Crops typically grown on the sprayfields are alfalfa, corn, winter wheat, potato, grass hay, and sudan grass.

Table 1. Wastewater Flows.

Actual Flows	Units	2009	2010	2011	2012
Yearly Process Wastewater	MG/year	587.1	627.9	616.6	610.8
	Acre/feet/year	1,801	1,926	1,892	1,874
Total Irrigated (wastewater + irrigation)	MG/day	731.8	797.1	782.7	779.1
	Acre/feet/day	2,245	2,446	2,401	2,390
Daily Process Wastewater	MG/year	1.6	1.7	1.7	1.67
	Acre/feet/day	4.9	5.2	5.2	5.1

MG: million gallons

The land application site receives nutrients from the process wastewater but is also supplemented with nutrients from commercial fertilizer and irrigation water (Burgard and Pritchett, 2009). Process wastewater quality is summarized in Table 2.

Table 2. Process Wastewater Quality, June 2009 to July 2013.

Constituent	Mean	Maximum	Minimum
TKN (mg N/L)	122	244	21
Ammonia (mg N/L)	39.2	84	13
TDS (mg/L)	1,913	3,366	510

TKN: Total Kjeldahl nitrogen
TDS: Total dissolved solids

Figure 2 illustrates the variation in the total Kjeldahl nitrogen (TKN) and ammonium concentrations in the wastewater from September 2009 to July 2013. Figure 3 illustrates the total dissolved solids (TDS) concentrations in wastewater for this same time period. Best fit trend lines were used in Figures 2 and 3 to illustrate the general variability in the process wastewater.

Irrigation water contributes nutrient and salt loading to the land treatment system, with a mean nitrate concentration of 18 mg N/L and a mean TDS concentration of 558 mg/L.

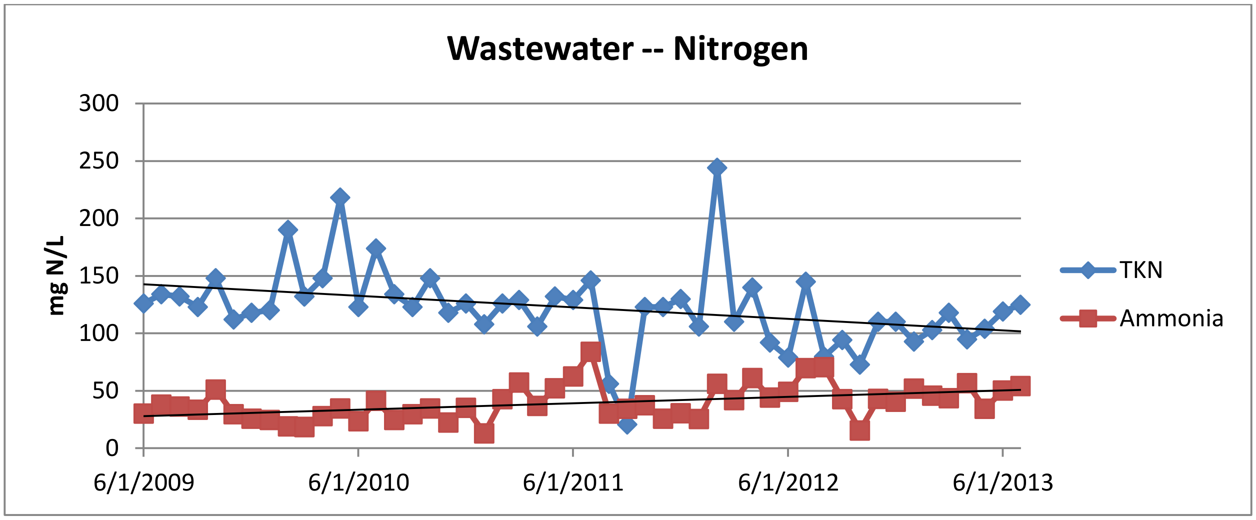

Figure 2. Wastewater Nitrogen Concentrations.

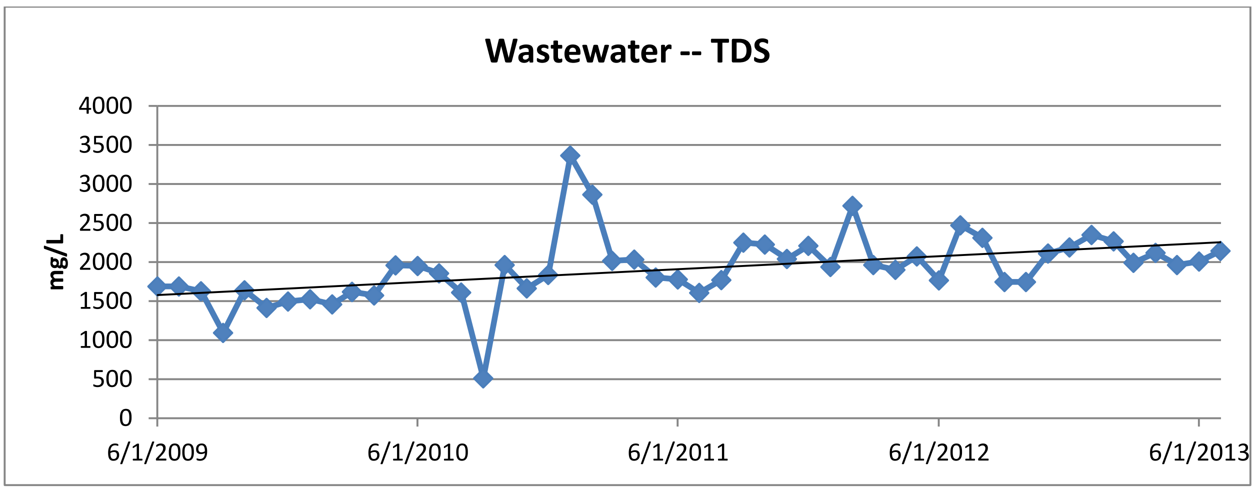

Figure 3. Wastewater TDS Concentrations.

Climate

ConAgra is located in Pasco, Washington (Franklin County), west of the Tri-Cities airport and north of the Columbia River.

Pasco is a semi-arid region with annual precipitation equal to 7.5 inches, snowfall equal to 9.4 inches, and evapotranspiration (pan) equal to 41 inches per year. The average daily annual temperature is 57°F, with an average annual high of 70°F and an average annual low of 44°F (Pritchett, 2011). Typical temperatures over the year range from 26˚F to 93˚F.

The growing season is the period of time when temperature and moisture conditions are suitable for crop growth. The rest of the year comprises the non-growing season. This is when there is intermittent freezing of the surface soils; for the ConAgra fields, this timeframe is characterized as November 16 to March 15 (Pritchett, 2011).

Application of process wastewater when the soils are frozen is not conducive to agronomic uptake by plants. Freezing conditions typically occur at this location, causing plants to be dormant. This is the period when land application should not occur.

History

Over the last 50 years ConAgra has made numerous improvements to its wastewater treatment system and monitoring capabilities (Table 3).

Table 3. Historical Improvements.

Coffan, 2000; Burgard and Pritchett, 2009

Year	Location	Explanation
1965	LW-9	Original land application field
1970	LW-10 and LW-11	250 acres added
1990	A-1, A-2, A-3, and A-5	372 acres added
1990	LW-6, LW-7, and LW-8	400 acres leased (and later purchased) from Roundy Farms
1991	MW-1 to MW-8	First set of monitoring wells installed
1994	J fields	382 acres added
1994	G fields	475 acres added
1994	MW-9 to MW-17	Monitor wells installed
1995	MW-18 to MW-23	Monitor wells installed
1998	J-11, J-12, J-13, J-14, and J-15	540 acres added
2000	R fields	791 acres added
2000	MW-24 to MW-27	Monitor wells installed
2009	Roundy Farms	243 acres added

New fields were added to reduce loadings and impacts to groundwater quality. The goal was to increase the hydraulic and nutrient capacity of the land treatment system and to minimize losses to the environment. (Burgard and Pritchett, 2009). ConAgra designated the fields by letters and numbers that correspond to ownership (Table 4). The contracted sprayfield acreage (2,553 acres) accounts for approximately 82% of the total available land treatment acreage.

Table 4. Field Size and Designations.

Field	Land Owner	Acres
LW	Lamb Weston	567
G	Tomlinson Farms	475
J	LC Farms	916
R	Roundy Farms	791
A	Port of Pasco	371

Until 1994, year-round land application occurred only on the LW fields. Once the underground piping and monitoring wells were installed, year-round application to the other fields began. (Coffan, 2000). Until 1997, J and G fields were irrigated primarily with irrigation water.

Other Area Activities

Irrigated agriculture has been occurring in the vicinity of ConAgra's sprayfield site for more than 45 years (Coffan, 2000). The sprayfields are located within the southern area of the federal Columbia Basin Irrigation Project. Columbia River water is withdrawn from behind Grand Coulee Dam and distributed to approximately 500,000 acres for production agriculture in Washington State's central basin. Low-density residential development has also become predominant to the west and south of the sprayfield site (Burgard and Pritchett, 2009). Leakage from the irrigation canal causes groundwater mounding along the northern portion of the sprayfield site. (Coffan, 2000)

Geology

The sprayfield (land treatment) site is located in the Columbia Plateau. This area is underlain by a series of basalt flows which comprise the Columbia River Basalt Group. Over 300 flows occurred during various eruptions during the Miocene age, 17 to 6 million years ago. (Burns et al., 2012). The Columbia River Basalt Group is divided into four formations, with the Saddle Mountain Basalt being the youngest forming the uppermost bedrock beneath the site, then the Wanapum Basalt, then the Grand Ronde Basalt, and then the Imnaha Basalt. (Coffan, 2000) Interflow zones between the basalt groups consist of weathered basalt sediments. These interflow zones can be hydraulically conductive. (Wanta, 1995)

The aquifer system at this site is predominantly contained in the sediments which were deposited on top of the basalt group. Sediments from the cataclysmic floods were deposited during the Pleistocene age. Eolian deposits of sand and silt were deposited with terrace fluvial gravels during the Miocene to Holocene age. (Burns et al., 2012; Newcomb, 1958).

Soils

Soils at the land treatment site are characterized as Quincy loamy fine sand with 0 to 15% slopes and 15 to 30% slopes (Burgard and Pritchett, 2009). Pritchett (2011) defines four soil types at the land treatment site.

- Fine sandy loam with loamy fine sand; deep, well-drained soil and somewhat excessively drained.
- Loamy fine sand with sand to coarse sand; excessively drained soil.
- Loamy fine sand; well-drained soil.
- Loamy fine sand; excessively drained.

These soils have a low-to-moderate available water holding capacity (7.22 to 11.12 inches) and drain at a moderate-to-moderately-rapid rate (1.1 to 6.3 inches/hour). The average bulk density of the soil is 1.51 g/cm^3 for the land treatment site. (Pritchett, 2011)

Hydrogeology

Groundwater beneath the sprayfield site occurs in two primary aquifers: the uppermost unconfined aquifer located in the alluvial aquifer overlying the basalt, and the lower confined aquifer located within the basalt interflow zones (Wanta, 1995; Coffan, 2000). Within the uppermost aquifer, finer grained cemented sediments cause localized perched shallow groundwater. These distinct aquifers have been delineated in Table 5.

Groundwater in the vicinity of the sprayfield site flows south-southwest towards the Columbia River. Coffan (2000) notes that there are two distinct gradients underneath the sprayfield site. The northern part of the sprayfield has a relatively steep gradient of 0.023 near the Esquatzel Diversion Canal. Then the gradient flattens towards the southwestern portion of the site to 0.006.

All ConAgra monitoring wells are completed in the shallow alluvial aquifer. Coffan (2000) observed that depth-to-groundwater ranges from 5 feet below land surface (bls) in the northern part of the sprayfield, to 165 feet bls in the southern sections, with seasonal fluctuations of 2 to 6 feet across the site. Saturated thickness varies from 60 to 110 feet.

Groundwater

The ConAgra land treatment site is located within the larger Columbia Basin Groundwater Management Area. There have been numerous efforts and research projects focusing on groundwater issues in this area.

Columbia Basin Groundwater Management Area

In 1998, a groundwater management area (GWMA) was established for the Columbia Basin at the request of Adams, Franklin, Grant, and Lincoln Counties. The GWMA is governed by local citizens, stakeholders, industries, and leaders as a non-regulatory, proactive means to protect groundwater and address issues relating to the aquifer for the Columbia Basin. Figure 4 illustrates the extent of the GWMA which covers over 7.5 million acres.

The GWMA was originally established to assess the extent and magnitude of nitrate contamination in groundwater and to identify the population at risk. An interagency study found that approximately 20% (127 wells) of the wells sampled (631 wells) exceeded (did not meet) the Washington State drinking water standard of 10 mg N/L. Localized areas of nitrate contamination were identified, but the health effects were not quantified (Columbia Basin Groundwater Management Area, 2008).

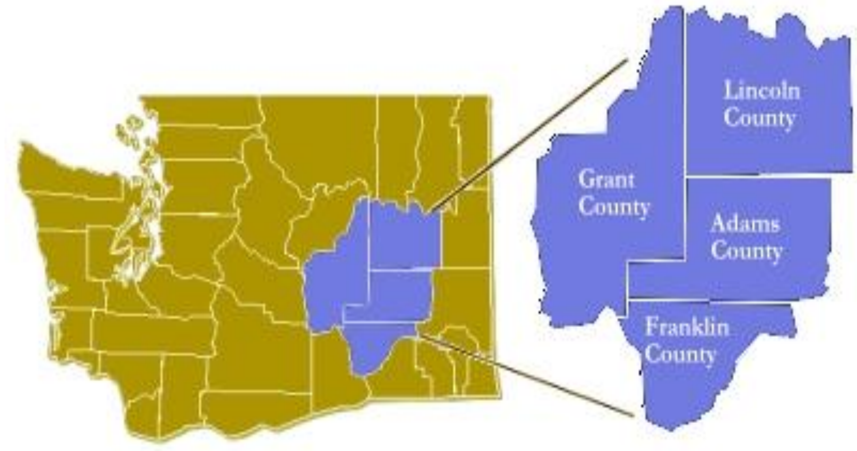

Figure 4. Columbia Basin Groundwater Management Area (GWMA) Location.

Columbia Basin GWMA, 2015

While the extent and nature of this GWMA effort is more expansive than the ConAgra land treatment site, the GWMA information is useful in understanding the larger impacts to groundwater in this region.

Groundwater Quality

The U.S. Geological Survey (USGS) evaluated anthropogenic and natural influences to assess the sources of elevated nitrate concentrations in the Columbia Basin GWMA. Over 80% of the drinking water in the Columbia Basin comes from groundwater. This study evaluated well construction and location information, recharge rates, proximity to canals, fertilizer application rates, soils, surficial geology, and land use. (Frans, 2000)

Frans found that the strongest correlations with nitrate concentrations above 3 mg N/L (indicates anthropogenic impacts) were fertilizer applications and well depth. The strongest correlations with nitrate concentrations above 10 mg N/L (drinking water standard) were fertilizer application, well depth, and soil infiltration rate. These observations were used to develop a model that predicts the probability of groundwater exceeding the concentration thresholds of 3 mg N/L and 10 mg N/L. Maps were developed to illustrate the predicted nitrate concentrations at different depths below land surface. Frans found that the irrigated agricultural areas were at the highest risk of having elevated groundwater nitrate concentrations. (Frans, 2000)

The USGS evaluated groundwater nitrate concentrations from approximately 500 wells in the GWMA. Based on an aggregate evaluation of data from these wells, USGS determined that there were no statistically significant trends in nitrate concentrations from 1998 to 2002. However, when only nitrate data exceeding the drinking water standard were evaluated for the entire GWMA, a statistically significant declining trend of -0.4 mg N/L per year was observed during this timeframe. In Franklin County, the wells with nitrate levels higher than the drinking water standard had a declining nitrate trend of -0.46 mg N/L for this timeframe. (Frans and Helsel, 2005)

When evaluating nitrate trends in Franklin County from a smaller data set of 51 wells over a longer time period, Frans and Helsel (2005) found a statistically significant increase in nitrate concentrations of 0.1 mg N/L per year between 1986 and 1991, but they observed no statistically significant trends between 1998 and 2003. This seems to suggest that, while nitrate concentrations in the Columbia Basin are locally elevated, they are stable and in some places declining.

In 2008, additional research was conducted analyzing nitrate groundwater data within the Columbia Basin GWMA. Table 5 describes the mean nitrate concentration for the various geologic units in the Columbia Basin GWMA. Figure 5 illustrates the widespread elevated nitrate concentrations present in groundwater in the vicinity of Pasco, Washington. (Columbia Basin GWMA, 2008)

Table 5. Geologic Units.
Columbia Basin GWMA, 2008

Unit Abbreviation	Geologic Unit	Description	Mean Nitrate Concentration (mg N/L)
Qf	Pleistocene cataclysmic flood deposits	Coarse sand and gravel deposits	15.2
Trf	Ringold Formation fine unit	Predominantly silt and clay with minor sand	9.5
Trwie	Ringold Formation Wooded Island member unit E	Predominantly sandy gravel	9.5
Trwilm	Ringold Formation Wooded Island member lower mud unit	Predominantly silt and clay	28.1
Trwia	Ringold Formation Wooded Island member unit A	Predominantly sandy gravel	5.9

Within the Pasco basin of the Columbia Basin GWMA, 70 wells were analyzed by GWMA researchers, within the uppermost aquifer system. The mean nitrate concentration was 12.3 mg N/L, with concentrations ranging from non-detect (0.01 mg N/L) to 70.4 mg N/L. These researchers noted that elevated average nitrate concentrations (higher than the drinking water standard) tend to be located in areas where the groundwater gradient is relatively flat. The greatest density of high nitrate wells is in the southeastern area (Figure 5). This phenomenon is the result of slower groundwater flow rates, less dilution, mixing, and flushing of nitrate loading to the land surface. Additionally, a positive correlation was observed between nitrate concentration and well depth. These researchers noted that the highest concentrations are located within the uppermost 40 feet of the aquifer system. A statistical analysis of the data indicates a decreasing nitrate trend with increasing depth in the aquifer. (Columbia Basin GWMA, 2008)

Additionally it was noted that a dilution effect occurs when wells were located within one-half mile of an unlined irrigation canal. Leaking canals provide added groundwater recharge during the irrigation season of approximately April through September. The researchers concluded that the majority of wells with nitrate concentrations less than 10 mg N/L are located within one-half mile of a canal. These results are summarized in Table 6. These researchers also noted that manmade subsurface drains, used for collecting irrigation return flows, typically leak and could also contribute additional recharge and dilution; however, this source was not evaluated. (Columbia Basin GWMA, 2008)

Table 6. Groundwater Nitrate Concentration Based on Proximity to Canals.
Columbia Basin GWMA, 2008

Well Location	Nitrate Concentration (mg N/L)	
	Median	Maximum
Within half-mile radius to a canal	8.36	47.9
Farther than half-mile radius to a canal	13.3	70.4

These researchers also noted that there are no consistent seasonal variations across the Pasco basin, but within individual wells, seasonal variations of nitrate levels are related to variations in the elevation of the water table. This dilution effect is characterized by decreasing nitrate concentrations as the water table rises. However, a decreasing nitrate concentration with a lowering of the water table was noted with the wells that are in close proximity to canals. This phenomenon is related to the dilution effects of the canals. (Columbia Basin GWMA, 2008)

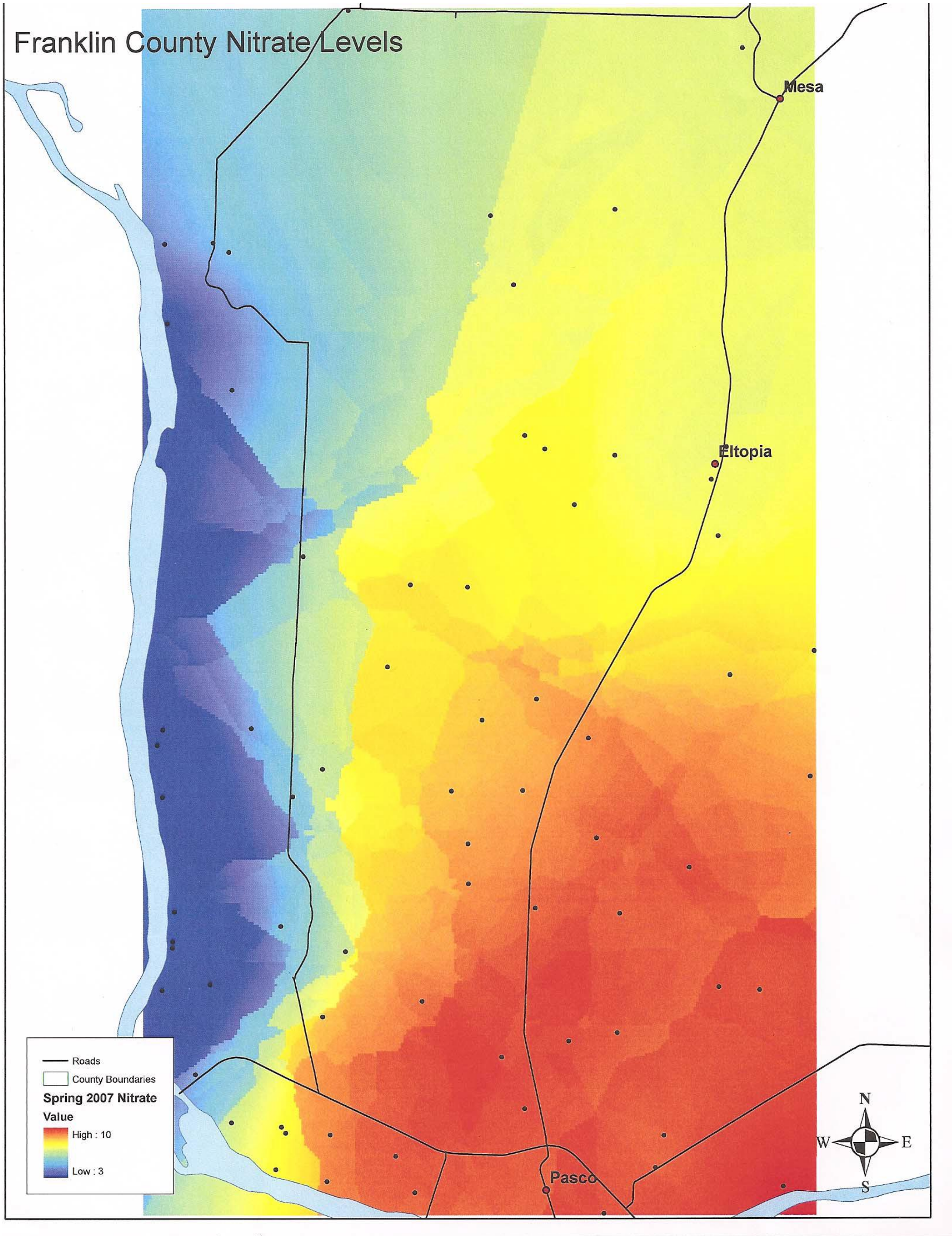

Figure 5. Groundwater Nitrate Concentrations in the Columbia Basin near Pasco, Spring 2007. *Columbia Basin GWMA (2008)*

Groundwater Quality Standards

The goal of Washington State groundwater quality standards (Chapter 173-200 WAC) is to maintain a high quality of groundwater and to protect existing and future beneficial uses through the reduction or elimination of contaminants discharged to the subsurface. This goal is achieved through three mechanisms: AKART, the antidegradation policy, and the numeric and narrative criteria. These standards affect all activities which have a potential to impact groundwater quality (Kimsey, 1996). A discharge cannot cause groundwater degradation, even if the discharge mobilizes or exacerbates existing contaminants.

Antidegradation Policy

The antidegradation policy is designed to ensure the protection of the state's groundwaters and the natural environment. The antidegradation policy and AKART form the primary mechanisms for protecting groundwater quality. Antidegradation protects background water quality and prevents degradation of the state's waters beyond the criteria. Criteria are the numeric values and narrative standards that represent contaminant concentrations that are not to be exceeded in groundwater. Regardless of the quality of the receiving water, AKART must be applied to all wastes. Degradation of water quality that would either harm a beneficial use or violate the groundwater quality standards is allowed only in extreme circumstances. AKART must always be applied to the wastewater, and the goal is to maintain existing high quality water and improve degraded groundwater whenever possible.

Antidegradation applies when background water quality contaminant concentrations are less than criteria defined in the groundwater quality standards. If discharges will result in exceedance of the criteria, facilities must apply additional treatment before Ecology can permit the discharge. In order to meet the antidegradation policy, the facility must prepare an AKART engineering analysis (which is reviewed and approved by Ecology) that demonstrates that discharges to groundwater will not result in increasing background contaminant concentrations. (Kimsey, 1996)

Point of Compliance

The point of compliance is the location where the facility must be in compliance with the groundwater quality standards. The point of compliance should be located in groundwater as near and directly downgradient from the pollutant source as technically, hydrogeologically, and geographically feasible. The groundwater quality standards protect all water in the saturated zone; therefore, the facility must be in compliance with established limits everywhere under the property and in water originating from all wells located on site. (Kimsey, 1996)

Enforcement Limits

Enforcement limits are the site-specific permit limits which are established to achieve compliance with the groundwater quality standards. They are defined on a case-by-case basis, and compliance with these limits is met at the point of compliance. Enforcement limits are established sufficiently below the criteria to provide an adequate margin of safety to ensure pollution does not extend beyond the property boundary.

The *Implementation Guidance for the Groundwater Quality Standards* (section 3.3.3) discusses enforcement limits. Background water quality is a statistical calculation of contaminant concentrations without the impacts of the proposed activity. Ecology defines *background water quality* for most contaminants as the 95% upper tolerance limit. This means that Ecology is 95% confident that 95% of future measurements will be less than the upper tolerance limit. (Kimsey, 1996)

Definition of Agronomic Rate

Agronomic rate for land treatment systems is defined as the rate at which a viable crop can be maintained and there is minimal leaching of chemicals downwards below the root zone. Crops should be managed for maximum nutrient uptake when the land is used for wastewater treatment. (Kimsey, 1996)

AKART

AKART (All Known Available and Reasonable Methods of Prevention, Control and Treatment) is the treatment standard required in RCW 90.48 and Chapter 173-200 WAC. All wastes must be provided with AKART prior to entry into the state's waters, regardless of the quality of the water.

AKART should reduce the contaminant load sufficiently to assure that the criteria will not be exceeded. If AKART does not reduce the contaminant load sufficiently to prevent degradation of a beneficial use or cause an exceedance of a criterion, then additional treatment may be required. The discharge cannot cause an impairment of a beneficial use. (Kimsey, 1996)

AKART encompasses the design, operation, and maintenance for land treatment systems that includes (1) the application of wastewater and its nutrients at rates, times, and durations that do not exceed the crop's agronomic rates, and (2) the storage of wastewater in properly lined lagoons when the wastewater is produced in excess of the crop's requirement or outside of the growing season (Ecology, 2004). An AKART analysis includes a pollution prevention component.

Ecology Guidance on Land Treatment Systems

Ecology has extensive experience with land treatment systems and their effects on groundwater quality. Ecology concludes that the current AKART definition addresses the many uncertainties and potential negative consequences to groundwater quality associated with excessive nitrogen land applied during the non-growing season. Ecology will consider site-specific demonstrations of innovative treatment approaches to achieving compliance, when the treatment is determined to be equivalent in effectiveness for protecting groundwater quality as the current AKART approach. (Ecology, 2004)

The primary goal of land treatment systems is to maximize contaminant uptake by the crop and minimize contaminant leaching below the root zone to protect the beneficial uses of the groundwater. Maximizing crop yield is not equivalent to maximizing crop uptake and is not the goal of a land treatment system. Land treatment systems that have been approved and permitted by Ecology (AKART) require that water and nutrients must not be applied in excess of the agronomic rate of the site's cover crop. (Ecology, 2004)

For facilities that operate year-round, a critical element in meeting AKART is the management of their wastewater that is produced during the winter non-growing season. Continued application of wastewater will most likely exceed the agronomic rate and AKART will not be achieved when (1) a crop is not actively growing or the growth rate is very slow, (2) air and soil temperatures are low, or (3) crops are not able to use nutrients supplied in the wastewater. A management strategy that has been approved by Ecology (AKART) and implemented by most year-round dischargers that use land treatment is the storage of wastewater in lined impoundments during the non-growing season.

Ecology's guidance concluded the following for AKART for land treatment systems:

- Nitrogen applied to land in the form of ammonia or organic nitrogen can (1) convert to nitrate during the non-growing season and (2) leach out of the soils and migrate to the groundwater.
- Applying wastewater to the land during the non-growing season does not reliably protect the groundwater and, therefore, does not meet the AKART requirement.
- Site-specific demonstrations of innovative plans to manage wastewater during the non-growing season will be considered by Ecology. Approval of these plans will depend on their achieving nitrogen treatment which is equivalent in effectiveness for protecting the groundwater as the current approved AKART. (Ecology, 2004)

Previously, Ecology has also considered other options for managing excess wastewater (Ecology, 2004). These include:

- Storage in a properly constructed lined lagoon.
- Discharge to a surface water body in accordance with Chapter 173-201A WAC and Chapter 173-220 WAC.
- Discharge to a publically owned treatment works (POTW) in accordance with Chapter 173-216 WAC.

Soil Mechanics

The soil horizon and vadose zone are the locations where nitrogen treatment and transformations occur. Land treatment systems rely on the subsurface for attenuation, crop uptake, removal, volatilization, mineralization, denitrification, and degradation of nutrients and other constituents. Whatever residual nitrate is not treated has the potential to leach to groundwater. These processes are influenced by a variety of site-specific factors, and they also affect the fate and transport of chemicals in the environment. Residual nitrate that is not treated within the soil horizon and vadose zone has the potential to leach to groundwater.

Mineralization is the process that converts organic nitrogen into ammonium, while *nitrification* is the process that converts ammonium into nitrate. Volatilization and denitrification losses are minimal and occur under specific conditions (van der Schans et al., 2009; Sullivan et al., 2000; Dzurella et al., 2012; Hermanson et al. 2000). Nitrate and ammonium are the plant available forms of nitrogen which are available for crop uptake in the root zone during the growing season. Once nitrate migrates below the root zone, it is no longer available to the crop and will eventually migrate to groundwater. (Hermanson et al., 2000)

Green et al. (2008a) investigated the nitrogen transport processes that occur in the vadose zone at several sites across the United States including Washington State. Their goal was to verify previous findings that suggest a positive correlation exists between higher nitrate concentrations in groundwater and thicker unsaturated zones. These findings are inconsistent with the vulnerability assessment methodology which assumes longer transport times in the vadose zone result in lower nitrate concentrations in groundwater due to denitrification. These researchers concluded that advective transport is the predominant process that influences nitrogen below the root zone. They found nitrogen fluxes to the water table ranged from 7 to 99 kg/ha/year. Values at the high end of the nitrogen range were measured at course grained sites with high nitrogen application rates. They concluded that nitrogen application rates, water application, and evapotranspiration were the dominant factors that accounted for the differences between nitrogen concentrations at sites, not denitrification.

University of California (2005) committee of experts recommends that a total nitrogen mass balance can be used to predict atmospheric losses prior to land application, but that it requires extensive data management and record keeping, and it is associated with significant estimation errors. These researchers advocate that losses should be measured or estimated based on site-specific conditions, and they caution against using one percentage for all situations.

Denitrification

Denitrification requires low oxygen environments and the presence of electron donors, such as organic matter or reduced minerals. Green et al. (2008b) investigated natural attenuation of agricultural nitrate contamination in four areas within the United States, including the Yakima watershed in Washington State. This research used methods to analyze all nitrogen species simultaneously to determine nitrogen transformations. In Yakima they found that the zones of denitrification were not uniform across the watershed and were not consistent. They determined that this variability resulted from differences in land use and the intensive application of manure in some areas.

Sullivan et al. (2000) determined that denitrification rates in agricultural soils typically range from 5 to 15%, with the highest rate of 16% noted in October and November after the soil was saturated following a dry summer. These researchers also noted that the remaining soil nitrate (85% to 95%) is lost to groundwater.

Dzurella et al. (2012) estimate that 10% of the nitrogen in the applied manure in the California Central Valley is lost to denitrification.

Hermanson et al. (2000) noted that denitrification may reduce nitrate loading to groundwater under some conditions, though it is of little importance in well-drained soils.

Green et al. (2008b) investigated denitrification in agricultural soils at four sites across the United States. These researchers state that some degree of denitrification occurs at all sites, but that the high denitrification rates reported in the literature are not representative of shallow sandy aquifers. These researchers concluded that many of the denitrification values in the literature were far higher than what they observed. They caution that assuming high denitrification rates based on reported literature values may be skewed due to method limitations and biased site selection, since in some denitrification studies the sites are often chosen for promoting higher denitrification rates. These researchers concluded that the electron donor concentrations from recharge were insufficient to promote high denitrification rates. They estimate that it would require decades or longer for denitrification to reduce the existing groundwater contamination to background conditions.

Collectively, the literature concludes that denitrification may reduce nitrate loading to groundwater by 5% to 16% under some conditions, though it was determined that it is of little importance in well-drained soils. It was observed that some degree of denitrification occurs at all sites, but high denitrification rates reported in some literature are not representative of shallow sandy aquifers.

Volatilization

Van der Schans et al. (2009) estimate that 5% or less of the land-applied nitrogen is lost to volatilization. Additionally these researchers concluded that volatilization and denitrification losses in the vadose zone are not significant.

University of California (2005) committee of experts estimate atmospheric losses from liquid manure range between 20 to 40%, and they note that this does not include losses which occur during land application.

Mineralization

Mineralization of organic nitrogen to nitrate occurs year-round, even during the winter months, although the rate varies seasonally. Studies have shown that mineralization and nitrification can occur at significant rates in frozen soils, especially in the presence of organic matter.

Nitrogen mineralization generally increases during warmer weather and slows during cooler weather, but the fraction of nitrogen that mineralizes and becomes available for crop uptake or leaching to groundwater is difficult to accurately estimate. Watts et al. (2007) state that nitrogen mineralization is most influenced by temperature and notes that the greatest mineralization occurs at 77°F (25° C). However, recent studies show that significant mineralization occurs during the winter months, creating an additional soil nitrate load that is susceptible to leaching.

Zhao et al. (2006) evaluated the ConAgra Pasco sprayfield site and determined that a mineralization rate of 50 lbs N/acre/year is a reasonable estimated rate.

Lamb (2012) observed that the conversion of organic nitrogen to nitrate nitrogen typically occurs when the soil temperatures are greater than 50°F (10°C), but that this transformation continues at a decreased rate at lower temperatures until soil temperatures reach 43°F (6°C). Kowalenko et al. (2007) concluded that mineralization of soil nitrogen does not cease in the fall after the crop has been harvested but continues during the winter months in British Columbia.

Clark et al. (2009) investigated the fate of fall nitrogen application of pig slurry to loamy and clay soils. These researchers observed that nitrification and mineralization continued during the winter in frozen soils; but that mineralization and nitrification were higher in clay soils and immobilization was higher in loamy soils. They also noted that at temperatures between -2°C and 2°C a significant portion of the ammonium in the slurry was nitrified, but little immobilization occurred even with soil amendments of organic matter. They found that nitrogen immobilization ceases at a higher temperature than nitrification, potentially resulting in an excess of nitrate. These researchers concluded that microbial activity occurs in frozen soils, with mineralization and nitrification occurring at significant rates, especially in the presence of organic matter. They concluded that fall-applied nitrogen could pose a risk of leaching to groundwater, particularly in fine-textured soils.

Cookson et al. (2002) noted significant mineralization in temperate soils (2 -15°C) amended with clover residues at temperatures as low as 2°C. These researchers concluded that nitrogen amendments applied in the winter pose a risk to groundwater leaching, and they recommend that nitrogen applications be limited until the spring.

Winter groundwater nitrate levels at the downgradient edge of a raspberry field at the top of the Abbotsford-Sumas aquifer in southern British Columbia indicated a continued source of newly mineralized nitrate throughout the winter (Kuipers et al., 2014).

Moberg et al. (2013) evaluated mineralization rates in agricultural soils during different seasons. Based on samples collected from October to February, the mean soil nitrate concentration was 24.4 mg/kg (ppm). These researchers reported an annual precipitation rate of 118 cm/yr (3.9 feet/yr). If this mineralized soil nitrogen were mixed with recharge, it would result in approximately 8 mg N/L of nitrate available to leach to groundwater.

Chantigny et al. (2014) state that the residual soil nitrate measured at harvest represents the risk of nitrate loss to groundwater during the non-growing season. These researchers used ^{15}N isotopes as a tracer of nitrogen from applications of pig slurry. Their data indicate that 30% to 60% of nitrogen applied in the spring was still present in the soils at the fall harvest. Further, these researchers found that in clay soils 16% of the nitrate was lost to groundwater, and 45% was lost to groundwater in sandy soils. This work provides evidence that soil organic nitrogen and immobilized nitrogen contributed one-third to one-half of the nitrogen lost during the non-growing season in Canada. Similar research by Jayasundara et al. (2010) discovered nitrogen losses of 16 to 29% from the fall application of pig slurry during the non-growing season. These researchers caution that measuring the fall soil nitrate concentration is inadequate to completely assess the risk of nitrate leaching to groundwater.

Uncertainty in the timing and rate of mineralization and nitrification makes it challenging to accurately estimate the amount of plant-available nitrate in the soil. These rates are dependent upon the amount of organic matter, climate, temperature, and biological activity. Dessureault-Rompré et al. (2010) assessed the variables which predict nitrogen mineralization rates in agricultural soils. These researchers found that soil bacteria in colder climates (mean annual temperature <2°C) adapt more readily to declining temperatures compared to bacteria in warmer climates (mean annual temperature >6°C). This research verifies that mineralization occurs in the winter, and that rates can be greater in colder climates. These researchers also noted a greater mineralization response to temperature in agricultural soils than in forested soils.

Generally, the reviewed studies concluded that mineralization is a significant source of nitrogen in agricultural fields. Additionally, it was concluded that, due to the continued mineralization during cold and freezing temperatures, fall applied nitrogen poses a risk of leaching to groundwater particularly in fine-textured soils.

Summary of Nitrogen Literature Review

Washington State University (WSU; Hermanson et al., 2000) conducted a literature search titled *Nitrogen Use by Crops and the Fate of Nitrogen in the Soil and Vadose Zone*. The primary goal of this review is to provide Ecology with information on the fate and transport of nitrogen in the subsurface for land treatment systems. This WSU report focuses on nitrogen use by crops and the interactions between soil, water, and nitrogen. The following are some of the general principles and recommendations drawn from their comprehensive review:

- The estimation of agronomic rate for a crop must factor in all sources of nitrogen available during the growing season. This includes mineralization, residual inorganic nitrogen, and contribution from irrigation water. Agronomic rate is defined as the recommended rate of nitrogen addition to the soil that is needed to produce an expected yield, while minimizing adverse environmental effects.
- In waste management scenarios, agronomic rate and the application rate may be different. When the application rate exceeds the agronomic rate, close attention must be given to the environmental consequences of this practice.
- All nitrogen applied to the soil, that is not volatilized, will eventually convert to nitrate. The total transformation to nitrate may take a few weeks to a few years, depending on the nature of the organic waste.
- Nitrate moves readily with water in the soil profile and can reach groundwater if not taken up by the crops, denitrified, or volatilized. Other forms of nitrogen are less mobile.
- Soil nitrogen that moves below the root zone will eventually leach to groundwater as nitrate. Steps should be taken to minimize movement of nitrogen below the root zone during the growing and non-growing seasons.
- Denitrification may reduce nitrate loading to groundwater under some conditions, though it is of little importance in well-drained soils.
- Nitrogen applied at the time and in the amounts needed by the crop will minimize the buildup of soil nitrogen.

- Wastes applied substantially before or after maximum crop demand may result in the buildup of inorganic soil nitrogen that will subsequently be susceptible to nitrate leaching.
- Use of winter cover crops can minimize movement of nitrogen deeper into the soil profile by utilizing the nitrogen in the root zone, storing it in the plant tissue, and ultimately returning it to the soil surface after death of the cover crop. Cover crops temporarily store nitrogen removed from the root zone.
- Winter cover crops are not a reason to over apply nitrogen. If excess nitrogen is applied in one growing season, it must be offset by decreased nitrogen application the following season to avoid residual nitrogen buildup and subsequent nitrogen leaching.
- Poor irrigation management will prevent efficient nitrogen management and recovery.
- The nitrogen composition of the manure should be determined before application because it will affect the timing of nitrogen availability and the susceptibility to nitrate leaching.
- Maximizing nitrogen removal by crops will generally increase the risk of nitrate accumulation in the soil.
- Organic wastes applied during the non-growing season will partially or totally convert to nitrate before the next growing season. The fraction mineralized will depend on the composition of the process wastewater, the soil temperature, and moisture conditions. The depth that nitrates will travel in the soil before the next growing season will depend on the soil hydraulic properties and the volume of recharge (precipitation and irrigation).
- Nitrate leached beyond the root depth of the crops to be grown during the following season will be susceptible for transport to groundwater.
- Steps should be taken to minimize movement of nitrogen below the root zone during the growing and non-growing season.
- Applying organic wastes during the non-growing season has an inherent risk in terms of leaching nitrogen to groundwater.
- The use of storage facilities to minimize waste applications during the non-growing season is a safe alternative.

These WSU researchers do not completely rule out the application of wastewater outside of the growing season. However, this WSU literature review emphasizes the uncertainties associated with nitrogen dynamics in the subsurface and concludes that applying wastewater to crops and soil systems during the non-growing season is not reliably protective of groundwater. These researchers conclude that applying organic wastes during the non-growing season has an inherent environmental risk and requires close soil monitoring to establish the success of the operation in terms of avoiding nitrate leaching (Hermanson et al., 2000).

It is apparent that there are enough uncertainties associated with nitrogen dynamics in the subsurface that applying wastewater to crops and soil systems during the non-growing season is not reliably protective of groundwater (Ecology, 2004).

ConAgra Proposal for Year-Round Application of Wastewater as AKART

ConAgra has made improvements to their wastewater treatment system over the last 50 years by increasing the total acreage available for land treatment. As part of their State Waste Discharge Permit requirements, they submit an annual Irrigation and Crop Management Plan (ICMP) which summarizes the previous year's operations and their plans for the upcoming year. This ICMP summary includes the quality and quantity of process wastewater land applied, hydraulic and nutrient loadings, crop production, water and nutrient balances, and soil and groundwater monitoring results.

Ecology has not yet approved the engineering report (Burgard and Pritchett, 2009) submitted by ConAgra. Approval is contingent on the findings of this assessment. Until the engineering report is approved, the document is considered a proposal.

ConAgra states that their land application farming system has sufficient size and cropping to adequately manage the process water (Pritchett, 2011).

ConAgra also states that the potential to contaminate groundwater is driven by a combination of water balance, nutrient balance, and the timing of nutrient application. These components are important to prevent soil nitrate from leaching in the winter with irrigation or rainfall. ConAgra states that winter crops utilize residual nitrate during the non-growing season. (Coffan, 2000)

Nitrogen Balance

- ConAgra states that the nitrogen capacity of their land treatment system has not been the design-limiting parameter for this site (2005-2009) (Burgard and Pritchett, 2009).
- ConAgra's ICMPs estimate that process wastewater is responsible for contributing between 34 to 54% of the nitrogen load applied to the land treatment site (Pritchett, 2010; Kronschnabel, 2011; Kronschnabel, 2012; Burgard, 2013).
- ConAgra notes that some years, and for some sprayfields, the application of process wastewater is limited (5 – 44%) but that commercial fertilizer or irrigation water are used instead, contributing between 56 – 95% of the total nitrogen applied to the sprayfield site (Blair, 2011; Burgard and Pritchett, 2009).
- ConAgra assumes a 25% total Kjeldahl nitrogen (TKN) loss factor to account for denitrification and volatilization, and a 50% loss factor to account for volatilization of ammonium (NH_4) (Burgard and Pritchett, 2009).
- ConAgra states that increases in soil nitrate between fall and spring are not high enough to be of concern. They feel that a compliance metric for soil nitrate should not be assigned for this facility. (Burgard and Pritchett, 2009)

Water Balance

- ConAgra estimates that the amount of process wastewater that is spray irrigated is well below the crop requirement. Wastewater accounts for 18% of the total water applied to the site. (Burgard and Pritchett, 2009)
- In order to meet the crop requirement, supplemental freshwater is needed to maintain crop production and maintain the soil salt balance (Burgard and Pritchett, 2009).
- ConAgra states that the average leaching fraction (the amount of excess water applied) for the sprayfield was less than the leaching requirement (Ecology, 2009b).

Site Management

- ConAgra leases much of their land treatment site and does not have full control over sprayfield management (Burgard and Pritchett, 2009).
- ConAgra state that the owners of the leased land control the cropping and irrigation schedules on their lands according to their judgment of agronomic needs. These schedules are controlled under contracts and periodically discussed between the land owner and ConAgra.
- Proper design and good management of process water irrigation and nutrients encompasses the requirements of AKART for land application (Burgard and Pritchett, 2009).

Seasonal Storage of Nitrogen in the Soils

Pritchett (2011) advocates that, by controlling the residual nitrate in the soils, the predominance of organic nitrogen and ammonium in the process wastewater allows application outside of the growing season by allowing seasonal storage of nitrogen in the soil horizon.

Nitrogen Transport

Coffan (2000) used a numerical hydrologic model to estimate the vertical migration time of nitrate movement beneath the land treatment site from the bottom of the root zone to the top of the water table. The estimated travel time through the vadose zone is summarized in Table 7.

Model assumptions (Coffan, 2000):

- The upper soil horizon, 0 to 10 ft below land surface (bls), is a sandy loam soil.
- The lower soil horizon, 10 to 120 ft bls, is a fine sand.
- Silt is not predominant in the soil horizon.
- Field J-10 was used to model site conditions.
- An estimate of 0.3 inches of water is lost as percolate through the soil horizon to groundwater per winter months, for a total of 1.7 in December, January, February, March.
- Depth to water (dtw) for this site is 100 ft.

Table 7. Modeled Vertical Transport Time.

Vertical Transport Depth (feet)	Transport Time (days)	Transport Time (years)
15	790	2.17
25	1,050	3.15
50	2,420	6.63

Groundwater velocity was calculated at the sprayfield, recognizing that the hydraulic gradient at this site varies dramatically from northeast to southwest. In the northern part of the sprayfield, depth-to-groundwater is greater, and the flows are influenced by the canal. As groundwater flows southwest, it levels out as it approaches the Columbia River. Based on this complexity, Coffan (2000) calculated groundwater velocities to address these differences:

- Hydraulic conductivity is 2.1 meters/day.
- Hydraulic gradient in the northeast portion of the site is 0.023.
- Hydraulic gradient in the southwest portion of the site is 0.006.
- Groundwater velocity ranges from 60 ft/yr in the northeast to 15 ft/yr in the southwest part of the sprayfield.

ConAgra-Proposed Compliance Measures

ConAgra proposes the following measures to demonstrate that their discharge is in compliance with Washington State groundwater quality standards (Coffan, 2000):

- Percolate losses (i.e., leaching fraction) equal to, or less than, the leaching requirement.
- Stable or declining end of cropping year, soil profile nitrate concentration trends over three years.

Evaluation

This section evaluates AKART for this site to determine whether ConAgra's current management practices (i.e., year-round land application) are sufficient to protect groundwater quality. This includes (1) evaluating ConAgra's proposal for determining the effectiveness of their treatment process and (2) analyzing soil nitrate and groundwater quality data.

Mass Balance

Nutrient and hydraulic mass balances are an important component of wastewater management with a land treatment facility. A mass balance is the difference between inputs and outputs, and this difference provides an estimate of the relative environmental risk. The goal is to apply the right amount of nutrients and water at times when crops can use them and to minimize residual nitrate that could be leached to groundwater with excess water.

Nitrogen Losses

Mass balance calculations rely on assumptions of losses for nutrients and hydraulic loading. These assumptions are estimates. If these estimates are inaccurate, management practices will be inaccurate as well. ConAgra's annual Irrigation and Crop Management Plan (ICMP) reports the difference between total *gross* nitrogen application and total *net* nitrogen application, which is attributed to nitrogen losses by denitrification and volatilization. These losses are assumed after the process wastewater is land applied. These ICMPs assume a loss factor of 25% of the TKN to account for denitrification and a loss factor of 50% to account for ammonium lost from volatilization.

General literature on nitrogen losses for land treatment systems advocates that when site-specific information is not available, that a 5% volatilization loss and a 10% denitrification loss should be used.

Zhao et al. (2006) reviewed the ConAgra land treatment facility. These researchers state that the nitrogen loss estimates for the ConAgra facility are considerably overestimated, and they recommend that these losses be reevaluated to prevent over application of nitrogen. They determined that use of these extreme loss values were the biggest concern regarding the land treatment system. Their independent assessment of denitrification at this site concluded that an annual denitrification rate of 4% to 5% was appropriate for this site, based on the high sand content of the soils, the high infiltration rate, and the low soil water content.

Zhao et al. (2006) also determined that the ammonia volatilization rates used in ConAgra's ICMPs are also overestimated for four reasons: (1) the pH of the process wastewater is too low to support a high level of volatilization, (2) the predominance of sandy soils (90%), (3) the high infiltration rate, and (4) the low cation exchange capacity of the soils. They recommend a volatilization loss rate for this site between 15% and 20%.

Table 8 describes the combined average estimated nitrogen losses and the estimated nitrogen load for each year listed in the ICMPs. Table 8 also compares the nitrogen loss rates recommended in the general literature and the nitrogen loss rates recommended by Zhao et al. (2006). Based on these losses, there is an annual average of greater than 200,000 lbs N/year that is unaccounted in the mass balance.

If ConAgra used the recommended literature values for volatilization and denitrification, the difference would be significant (24% to 35%), resulting in a nitrogen budget that underestimates a nitrogen loading of 202,453 lbs N/year. If ConAgra used the nitrogen loss rates recommended by Zhao et al. (2006) for this site, the difference is also significant (27% to 37%), resulting in a nitrogen budget that underestimates a nitrogen loading of 217,038 lbs N/year. If these loss values are overestimated, the result is an underestimation of nitrogen loading and a greater risk to groundwater.

Table 8. Nitrogen Loading Comparing ConAgra Loss Estimates with General Literature Recommended Loss Rates and Site-Specific Rates for ConAgra.

Pritchett, 2010; Kronschnabel, 2011; Kronschnabel, 2012; Burgard, 2013; Zhao et al., 2006

Year	Organic N	Ammonium	Ammonium with 5% Volatilization	Total N	Total N with 10% Denitrification	Gross N (estimated in ICMP)	Net N (estimated in ICMP)	Difference in Estimated N Loads	Loss Estimated in ICMP	Loss Estimated by Using Literature Recommended Values
	Lbs N/Year								% Loss	
General Literature Recommended Loss Rates										
2009	602,170	209,930	199,434	801,604	721,443	812,100	504,130	217,313	38%	11%
2010	635,700	157,200	149,340	785,040	706,536	792,900	516,090	190,446	35%	11%
2011	495,110	195,830	186,039	681,149	613,034	690,940	420,300	192,734	39%	11%
2012	335,590	262,830	249,689	585,279	526,751	589,420	317,430	209,321	47%	12%
							Mean Additional Nitrogen Load:	202,453		

Year	Organic N	Ammonium	Ammonium with 17.5% Volatilization	Total N	Total N with 4.5% Denitrification	Gross N (estimated in ICMP)	Net N (estimated in ICMP)	Difference in Estimated N Loads	Loss Estimated in ICMP	Loss Estimated by Using Literature Recommended Values
	Lbs N/Year								% Loss	
Zhao et al. (2006) Recommended Loss Rates Specific to ConAgra Pasco										
2009	602,170	209,930	173,192	775,362	740,471	812,100	504,130	236,341	38%	9%
2010	635,700	157,200	129,690	765,390	730,947	792,900	516,090	214,857	35%	8%
2011	495,110	195,830	161,560	656,670	627,120	690,940	420,300	206,820	39%	9%
2012	335,590	262,830	216,835	552,425	527,566	589,420	317,430	210,136	47%	10%
							Mean Additional Nitrogen Load:	217,038		

Crop Uptake

Data from ConAgra's nitrogen uptake for various crops were compared to the net nitrogen load. It was noted that this ratio averaged 81.2%, with a high range of 140%. Typical ratios are presented in Table 9. Crop uptake rates are greater than the "extremely high" range at this land treatment site. This is indicative that nitrogen loss assumptions are overestimated. (Zaho et al., 2006)

Table 9. Ratio of Nitrogen Uptake to the Net Nitrogen Load.
Zaho et al., 2006

Nitrogen Crop Uptake Rate	Typical
30- 40%	Normal
40 – 50%	High
60 – 70%	Extremely High

This imbalance is also reflected in the year-end nitrogen balances summarized in Table 10.

Table 10. Nitrogen Balance for Each Year.
Pritchett, 2010; Kronschnabel, 2011; Kronschnabel, 2012; Burgard, 2013

Year	Nitrogen Budget
2009	- 82 lbs/N/yr
2010	- 103 lbs/N/yr
2011	- 28 lbs/N/yr
2012	- 206 lbs/N/yr

The ICMPs consistently show a negative balance for nitrogen for the four consecutive years that were evaluated. The ICMPs also state that crop yields were good, residual soil nitrate was low, and there is minimal leaching to groundwater. "*Nitrogen balances indicate that plant uptake consumed more nitrogen than the combination of what was available in the soil at the beginning of the growing season and what was applied."* (ICMP, 2011). This statement may be misleading if:

- There is an overestimation of nitrogen losses due to denitrification and volatilization, or
- All nitrogen sources are not included in the net nitrogen load (i.e., fertilizer applied by land owners, residual soil nitrate, mineralization of organic nitrogen).

A useful mass balance for managing the sprayfield site should include all sources of nitrogen and water being applied to, and removed from, the fields. Any assumed losses should be measured on site or based on reasonable estimates found in published literature.

Groundwater Recharge

Groundwater is the subsurface water that fully saturates pore space. Groundwater is replenished by precipitation and other additions to the land surface. Some of the rain and snow that reaches the land surface will evaporate, some is transpired by plants, some flows overland and collects in streams, and some infiltrates into the pores or cracks of the soil and rocks. After the water requirements for plant and soil are satisfied, any excess water will infiltrate to the water table where saturated conditions exist. Natural refilling of aquifers is a slow process because groundwater moves slowly through the unsaturated zone and the aquifer. The rate of recharge is also an important consideration. In arid areas, the rate of replenishment is slow, while in more temperate areas where precipitation is high, the rate of replenishment is greater. Groundwater can be recharged locally, or further upland, and transported via underflow. (USGS, 1999)

Hydrographs were developed for all monitoring wells over the evaluation timeframe. These are included in Appendix I. The following observations were noted from these hydrographs:

- There appears to be a seasonal fluctuation in static water level for most wells (93%).
- The groundwater flow field has not changed dramatically over time, and there does not appear to be a seasonal shift in flow patterns. Knowing that the flow field is stable makes the designation of upgradient and downgradient conditions consistent. (Zhao et al., 2006)
- This fluctuation averages approximately 6 feet per year, with a range of 2.5 to 12.3 feet.
- Groundwater levels do not appear to be declining over time in any wells.
- Groundwater recharge primarily occurs from precipitation, irrigation, land application of process wastewater, and groundwater underflow.
- The ICMPs indicate that there is minimal leaching through the soils and minimal groundwater recharge from the sprayfield site.
- The hydrographs illustrate seasonal changes that are either from seasonal recharge or changes in regional groundwater levels from lateral groundwater movement. (Zhao et al., 2006)
- If recharge from ConAgra is small, the inputs into groundwater will not be evident. (Zhao et al., 2006)
- The increasing concentrations of nitrate and total dissolved solids (TDS) indicate that recharge is occurring in an area where these constituents are discharged.
- There is not enough information to conclude the source of the annual recharge.

If minimal leaching were occurring at this site as the ICMPs state, then it would be expected that the following conditions would exist:

- Groundwater levels would be declining beneath the sprayfield site from lack of recharge.
  - The sprayfield site is over 3,000 acres.
  - The subsurface is comprised of predominantly sandy soils with a porosity of 40% (Coffan, 2000). Groundwater flow is estimated to be between 15 - 60 ft/year
  - This means that if recharge were not occurring over this site, we would expect to see declines in groundwater levels.

- Coarse soils (with a porosity of 40%) do not promote water retention. Controlling vertical water migration at this site is challenging under these conditions.
- Despite the uppermost regional aquifer being transmissive, groundwater flow is not fast enough to migrate from the northeast (upgradient) part of the sprayfield to the southwest (downgradient) part in the course of a year. Therefore, recharge from lateral groundwater movement cannot account for all of the recharge.

- Downgradient water quality would be similar to upgradient water quality.
- There would not be a correlation of static water level with nitrate and TDS concentrations. Correlations appear to exist in 40% of the wells (12/30) (Appendix I).

The conceptual model proposed by ConAgra is not supported by the hydrographs, the water quality data, and the physical hydrogeologic characteristics at this sprayfield site.

Percolate Losses Equal to, or Less than, the Leaching Requirement

The leaching requirement is the amount of water that is necessary to leach salts from the soils to maintain the health of the soils and promote crop production. This practice is a management tool for the long-term maintenance and operation of the land treatment system. It is an ancillary management activity that should not result in groundwater degradation. Salt leaching is not part of the wastewater treatment process. Salt leaching must be conducted in a manner that protects groundwater quality.

To balance the risks associated with this practice, soil salinity should be managed by using freshwater or precipitation rather than process wastewater. Using water low in TDS for leaching will reduce the soil salinity content and reduce the soil leaching requirement. The mean nitrate concentration from these sources is 18 mg N/L, and the mean TDS concentration is 558 mg/L. The freshwater quality is elevated for both constituents but is below the wastewater mean nitrate concentration of 122 mg N/L and below the wastewater mean TDS concentration of 1,912 mg/L (Table 11). Water quality from ConAgra's available freshwater sources is summarized in Table 12.

Table 11. Comparison of Freshwater to Process Wastewater.

Concentration of Constituent	Mean Freshwater Concentration	Mean Process Wastewater Concentration
Nitrogen	18 mg N/L	122 mg N/L
TDIS	558 mg/L	1,912 mg/L

TDIS: Total dissolved inorganic solids

ConAgra proposed using the following as a compliance metric:

Percolate losses equal to, or less than, the leaching requirement

Since the leaching requirement is not directly related to the treatment of process wastewater and it does indicate impacts to the environment, it is not typically considered for use as a compliance metric for determining compliance with the groundwater quality standards.

Table 12. Supplemental Fresh Irrigation Water Quality, 2010.

Freshwater Source	Nitrate mg N/L	TDS mg/L
UIW-2	18.9	650
UIW-1	19.5	602
UIW-9	22.2	622
UIW-9	22.2	622
UIW-1	19.5	602
G-1 pond	6.1	401
G-2 pond	5.7	365
G-2 pond	5.7	365
G-2 pond	5.7	365
G-3, 4 pond	5	138
G-3, 4 pond	5	138
G-3, 4 pond	5	138
J-8	18	613
J-9	19.8	566
J-10	33.9	847
J-11	18	559
J-12/13	20.5	515
J-12/13	20.5	515
J-14/15	15.7	468
J-14/15	15.7	468
UIW-6	16.6	511
UIW-6	16.6	511
UIW-7	24.1	744
PW-6	19.4	550
PW-6	19.4	550
PW-6	19.4	550
UIW-7	24.1	744
RR-1	41.4	880
R-26	10.5	496
R-3	18.2	556
R-27	0.5	354
R-70	29.7	656
Range:	**0.5 - 41.4**	**138 - 880**
Mean:	**18.1**	**558**

Control of Field Management

A significant portion of the nitrogen load to the sprayfield site originates from sources other than process wastewater (Table 13). In some instances ConAgra states that their process wastewater is responsible for contributing 5% to 44% of the total nitrogen load to the land treatment site with supplemental fresh irrigation water and fertilizer responsible for contributing 56% to 95% of the total nitrogen load. (Burgard and Pritchett, 2009; Blair, 2011)

Table 13. Nitrogen Load Based on Source.

Pritchett, 2010; Kronschnabel, 2011; Kronschnabel, 2012; Burgard, 2013

Year	Process Wastewater	Fertilizer	Irrigation Water
2009	34%	33.1%	32.9%
2010	42.1%	30.7%	27.2%
2011	53%	19.3%	27.7%
2012	53.8%	15.8%	30.4%

Effective management of wastewater using land treatment involves closely controlling all water and nutrients that are land applied to the treatment site. Control of the land treatment site is also an important component when measuring and assuring compliance with all water quality laws and regulations. If ConAgra does not have full control over management of their sprayfields, it may be difficult to determine responsibility if compliance is not achieved.

Vertical Transport

Depth-to-groundwater at this site ranges from 5 to 165 feet below land surface (bls). Assuming the calculations computed by Coffan (2000) are correct, this modeling illustrates that soil nitrate will migrate through the vadose zone at a rate of 1 foot every 52.6 days. Where the depth-to-groundwater is 5 feet bls, soil nitrate will reach groundwater in approximately 263 days. Where depth-to-groundwater is 165 feet bls, soil nitrate will reach groundwater in 8,679 days or 23.7 years.

It is important to note that Washington State groundwater quality standards protect all groundwater in the saturated zone (Kimsey, 1996). The standards do not distinguish groundwater quality between near-surface unconfined aquifers and deeper confined aquifers. The groundwater standards do not allow a mixing zone.

Soil Nitrate

There are numerous studies which document the variability of soil nitrate with depth and with time: Lamb, 2012; Carey and Harrison, 2014; Staben et al., 2003; Gehl et al., 2006; Camberato et al., 2013; Sanchez-Perez et al., 2003. This indicates that soil nitrate values reflect the conditions of the soil at the time and location that the samples were taken. There are limitations in using soil nitrate to extrapolate soil conditions in other locations, depths, or times. Soil nitrate can indicate when excessive nitrate is present in the soils and poses a risk to leach to groundwater, but soil nitrate cannot provide assurance that groundwater has been protected.

Soil Nitrate Concentrations

The current State Waste Discharge Permit requires ConAgra to collect soil nitrate samples in the spring and fall, every foot down to the 5-foot depth from 33 fields, for a total of 330 soil samples per year. This information is to be reported annually in the ICMP. This extensive dataset provides an excellent tool to assess the changing conditions of the soil nitrate profile within the root zone. These data are compiled in Appendix H.

It is challenging to evaluate the soil nitrate data given the limitations of trying to consolidate data over space and time. The average soil nitrate value from 2009 to 2012 is 6.27 mg/kg with a range of 1 to 81.2 mg/kg. When considering what fraction of soil nitrate is susceptible to leaching to groundwater and unavailable to crops during the growing season, the fall soil nitrate values were compiled for the upper one foot and the total soil profile (Table 14).

Table 14. ConAgra: Average Fall Soil Nitrate Values.

Pritchett, 2010; Kronschnabel, 2011; Kronschnabel, 2012; Burgard, 2013

Year	Upper Foot	Soil Profile (sum of 1 - 5 foot measurements)
	Nitrate as N (mg/kg)	
2009	6.92	23.03
2010	17.12	38.14
2011	11.04	37.54
2012	15.07	37.15

Recommended targets for fall soil nitrate are found in the literature and range from 5 to 24 mg/kg depending on the site-specific conditions (Sullivan and Cogger, 2003; Sullivan and Cogger, 2002; Bary et al., 2000; Ecology, 2000; Kratochvil and Stenhilber, 2013; Kowalenko et al., 2007; Drury et al., 2005).

Soil Nitrate Trends

ConAgra proposed a compliance metric where soil nitrate values would show a declining or stable trend for all fields (Coffan, 2000). Ecology's fact sheet for ConAgra reported that in 2009, 8 of the 27 fields (30%) achieved this proposed compliance metric by having stable or declining soil nitrate trends (Ecology, 2009b).

Soil nitrate totals are summarized by field and by season from 2009 to 2012 in Table 15 in the column labeled *Soil Nitrate Trends – Fall.* This evaluation considers only the fall soil nitrate from 2009 to 2012 and evaluates trends, as the compliance metric proposed by ConAgra. Graphs of the soil nitrate profiles, as well as residual nitrate trends, are compiled in Appendix H. Soil nitrate data were graphed by field, and a best-fit line was used to visually determine trends. This information provides a progressive look at the soil nitrate, how it moves through the soil horizon over time, if there is excessive residual soil nitrate, and if nitrate is accumulating in any particular depth. The fall soil nitrate data indicate that compliance using stable or declining trends is being achieved for 35% of the fields. This compilation of the annual soil data from recent years indicates that there is an increasing fall soil nitrate trend for 20 of the 33 fields (65%), with 5 fields (16%) having a decreasing soil nitrate trend, and 19% having no trend.

In Table 15, the column labeled *Soil Nitrate Trends – Fall to Spring* evaluates what occurs in the soils during the non-growing season to determine if nitrate concentrations are increasing or decreasing between the fall and spring soil sampling. This evaluation is significant because it indicates whether additional nitrogen applications are necessary during the non-growing season. Based on this evaluation, soil nitrate increased over the winter months (fall to spring) in 21 fields (68%). This indicates that residual fall soil nitrate is not being utilized completely by the winter cover crops and that excess nitrogen is being added to the soils. It is not clear whether this nitrogen is from mineralization of organic soil nitrogen, from addition of commercial fertilizer, or if it is from additional nitrogen loads applied from process wastewater.

Zhao et al. (2006) found that soil nitrate in 10 of the 25 soil samples (20%) at the ConAgra sprayfield site showed an increasing nitrate trend. These deep soil samples were collected down to the 10-foot level as part of the deep soil sampling study in 2000. These researchers state that once nitrate migrates to that depth, there is virtually no mechanism that can remove it and that eventually it will reach groundwater. They concluded that historic residual nitrate from past activities should have already reached groundwater and that these increases in soil nitrate are most likely related to the application of process wastewater.

Table 15. Soil Nitrate Total and Soil Nitrate Trends.

Field	Total (lbs/acre)								Trends	
	2009		2010		2011		2012		2009 - 2012	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Fall	Fall to Spring
A-1	116	52	128	82	130	117	169	247	↑	↑
A-2	124	102	187	111	104	184	128	217	↑	↑
A-3	187	152	80	114	195	132	132	162	–	–
A-4	60	36	54	78	34	30	40	88	↑	↑
A-5	112	69	77	109	91	117	108	212	↑	↑
G-1	44	81	70	77	33	46	70	99	–	↑
G-2	61	80	77	87	109	104	81	52	↓	–
G-2A	66	61	76	74	70	182	174	63	↑	↑
G-2B	45	39	48	62	54	109	87	54	↑	↑
G-3	112	65	66	153	119	212	68	84	↑	↑
G-3A	64	38	60	84	72	152	138	50	↑	↑
G-4	113	76	117	172	129	120	83	66	↓	↓
J-8	78	53	32	107	121	234	162	57	↑	↑
J-9	35	68	86	277	104	98	83	46	↓	–
J-10	90	59	86	141	114	321	936	110	↑	↑
J-11	120	40	36	104	122	338	296	38	↑	↑
J-12	80	112	92	50	28	34	115	192	↑	↑
J-13	60	34	29	98	99	115	72	192	↑	↑
J-14	100	194	90	233	73	30	46	43	↓	↓
J-15	86	251	132	169	64	32	34	47	↓	↓
LW-6	110	91	108	178	60	103	109	89	–	–
LW-7	146	83	78	237	86	114	140	130	–	–
LW-8	175	69	90	172	114	88	140	104	–	–
LW-9	71	102	122	146	94	102	149	170	↑	↑
LW-10	129	141	125	242	124	130	170	150	–	–
LW-11	94	92	89	162	204	158	179	304	↑	↑
RR-1	206	166	157	373	388	199	222	357	↑	↑
R-3	106	214	223	90	140	273	183	511	↑	↑
R-26	165	114	104	350	92	311	202	234	↑	↑
R-27	66	58	106	151	131	168	182	154	↑	↑
R-70	213	64	101	246	103	299	205	286	↑	↑
R-103							83	246	N/A	N/A
R-104							68	246	N/A	N/A
	increasing trend						Total	↑	20	21
	decreasing trend						Total	↓	5	3

Figures 6, 7, and 8 illustrate the change in soil nitrate concentrations from the fall to the following spring. There does not appear to be a clear pattern over these three winters. In some cases the soil nitrate is higher in the fall and in some cases the soil nitrate is higher in the spring. The increased concentrations in spring could be the result of mineralization of residual organic nitrogen in the soils, continued land application of process wastewater, or the addition of commercial fertilizer. Decreases in soil nitrate could be the result of winter cover crop uptake or residual soil nitrate leaching to groundwater.

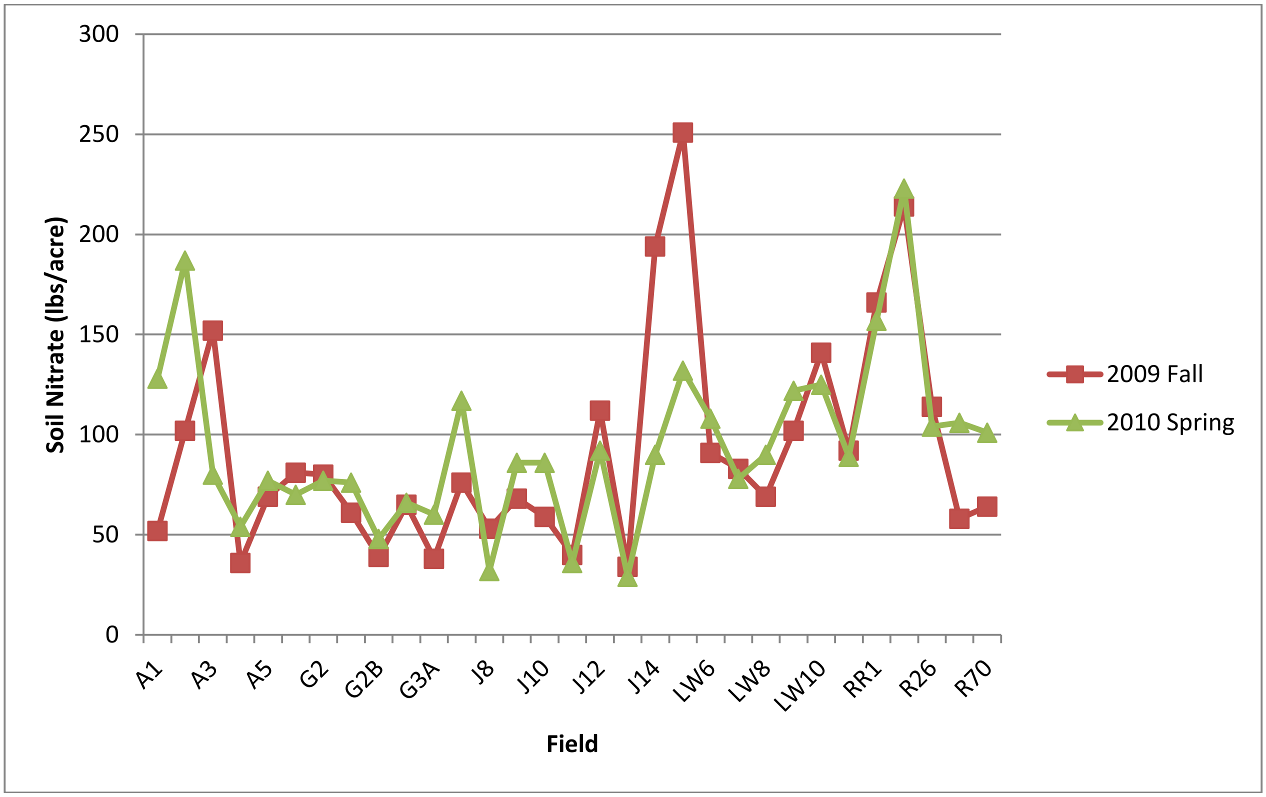

Figure 6. ConAgra Foods: Soil Nitrate Comparison, Fall 2009 to Spring 2010.

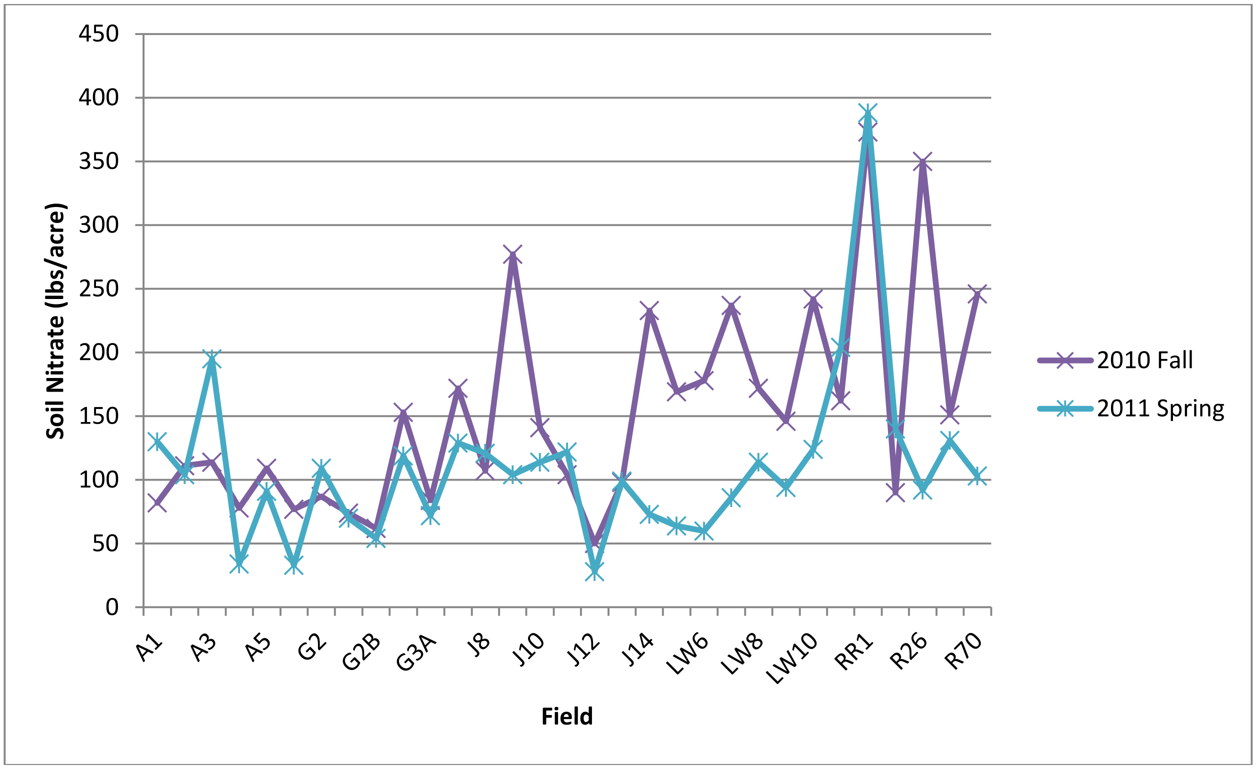

Figure 7. ConAgra Foods: Soil Nitrate Comparison, Fall 2010 to Spring 2011.

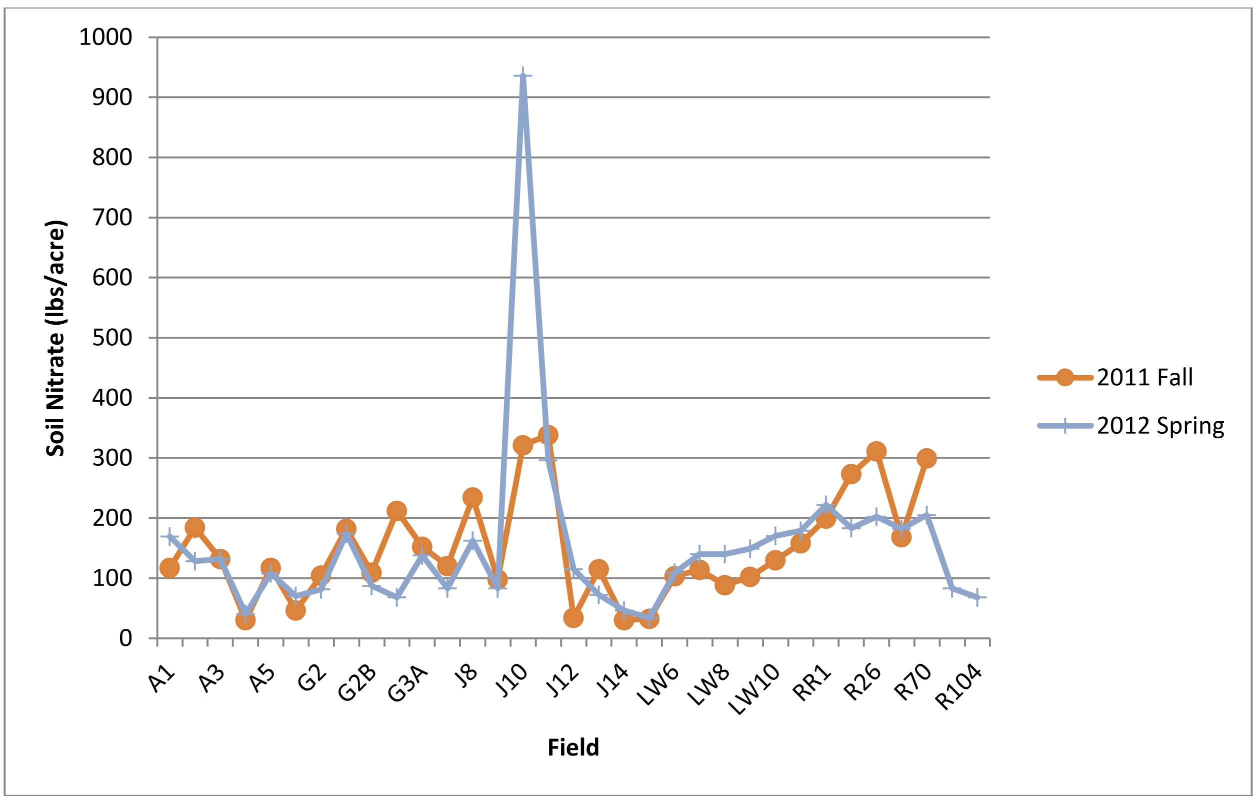

Figure 8. ConAgra Foods: Soil Nitrate Comparison, Fall 2011 to Spring 2012.

Soil Storage of Nitrate

ConAgra proposes to use the soil horizon to store nitrogen during the non-growing season. This proposition relies on many assumptions.

Organic nitrogen and ammonium are typically attenuated in the vadose zone since they are positively charged ions. However, this retention relies on two factors:

- Adequate cation exchange capacity of the soils to retain the nitrogen.
- Control of mineralization and nitrification in the subsurface.

This attenuation is dependent on soil temperature and recharge. As the temperatures increase in the spring, nitrification will occur allowing the conversion of ammonium to nitrate. When this conversion occurs, if the nitrate is within the root zone at a time when the crops can use it and at an amount that the crops can use, nitrate will not leach to groundwater. However, if this conversion occurs prior to when the crops can utilize the nitrate or if it migrates below the root zone, nitrate will leach to groundwater.

Application of organic nitrogen (i.e., potato starch and carbohydrates) and ammonium rich wastewater will generally be retained in the soils until mineralization and nitrification occurs. Mineralization increases as temperatures increase, converting the organic nitrogen to ammonium and then to nitrate. (Moberg et al., 2013) Mineralization has been documented to continue through the winter and in freezing conditions. Since nitrification is temperature-dependent, the conversion of ammonium to nitrate will increase as air and soil temperatures begin to rise in the spring. Nitrification occurs rapidly, and when it happens in the spring, crop growth is low and the ability to uptake nitrogen is also low. This creates a situation where there is an abundance of soluble and mobile nitrate and an abundance of precipitation at a time when the crop uptake is low. This creates a high risk that nitrate will leach to groundwater. Qui et al. (2005) concluded that year-round application of process wastewater is probably fine for the winter, but cannot be controlled in the springtime.

Pritchett (2011) states *"as long as residual nitrate-nitrogen in the soil is controlled, the predominance of organic and ammonium nitrogen in the process water enables process water to be applied outside of the growing season, allowing seasonal storage of nitrogen in the soil, while minimizing nitrate leaching losses and protecting groundwater quality."* It is not evident that the residual soil nitrate is controlled during the winter months at the ConAgra sprayfield site.

The end of winter and early spring when temperatures rise are also typically times of high precipitation and when crop uptake is low. If nitrogen is converted to nitrate and is not utilized by a crop, recharge can cause nitrate to migrate below the root zone and leach into groundwater. Since temperature, microbial activity, and precipitation and recharge cannot be controlled at a field scale, and the amount of nitrogen cannot be precisely gauged to the crop's limited needs at this time, researchers have stated that the application of nitrogen outside of the growing season is a risk to groundwater. (Hermanson et al., 2000; Qui et al., 2005)

Hermanson et al. (2000) conclude that it is not protective of groundwater quality to store nitrogen in the soils during the winter months when crops are dormant, and they assume the nitrogen will remain available in the root zone when crops will utilize it.

Soil storage of nitrogen during the winter months when crops are dormant is not protective of groundwater quality. It is presumptuous to assume the nitrogen will remain available in the root zone until spring when crops can utilize it.

Compliance Measures

ConAgra proposes the following measures to demonstrate that their discharge is in compliance with the groundwater quality standards. (Coffan, 2000):

- Percolate losses equal to or less than the leaching requirement.
- Stable or declining end-of-cropping-year, soil-profile nitrate concentration trends over three years.

ConAgra states:

"Proper design and good management of process water irrigation and nutrients encompasses the requirements of AKART for land application." (Burgard and Pritchett, 2009)

While this statement covers one part of AKART, it neglects to address the water quality component. The treatment process must achieve Washington State water quality standards.

Every permitted discharge facility must demonstrate compliance with water quality laws and regulations. ConAgra's proposal for determining the effectiveness of their treatment process relies on metrics which do not readily assess impacts to groundwater.

Groundwater monitoring is the best means of delineating impacts to groundwater quality. Unless there is a significant obstacle to using the existing 30 monitoring wells located across their 3,120-acre sprayfield site, groundwater monitoring is the best way to measure impacts to groundwater quality. The surficial unconfined aquifer at this site is well delineated and accessible, making groundwater monitoring a good option for measuring compliance with the groundwater quality standards.

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Groundwater Impacts

Ecology downloaded groundwater quality data from the PARIS database for September 2009 to July 2013 for the ConAgra Pasco facility. These data are presented in tabular format in Appendix G. Ecology created time series graphs for nitrate, total dissolved solids (TDS), and the major ions. These graphs are presented in Appendices A, B, and C respectively. Ecology's statistical analysis of nitrate and TDS data were completed using the Mann-Kendall test for trends. Sanitas Statistical Software (version 9.2) was used to generate the nitrate trend figures in Appendix D and the TDS trend figures in Appendix E. Tables 25 and 26 present the summary statistics for each monitoring well and indicate where statistically significant trends in the data were identified.

Groundwater Impacts: Upgradient/Downgradient

The ConAgra land treatment (sprayfield) site near Pasco is comprised of 3,120 acres. Thirty monitoring wells are located across the site, including 11 upgradient wells and 19 downgradient wells (Figure 9). Groundwater flow is generally towards the south-southwest (Figure 9) with some localized anomalies (Figure 21).

In addition to the analysis described above, this report compares upgradient and downgradient wells for the entire site and for each of the seven sub-areas designated in Figure 12 by ConAgra (Burgard et al., 2003; Coffan, 2000; Ecology, 2009b). The upgradient and downgradient wells in each of the sub-areas were proposed by ConAgra (Burgard et al., 2003; Coffan, 2000) and confirmed by Ecology (Ecology, 2009b). The seven sub-areas were delineated based on their spatial location and the timing of the addition of the fields.

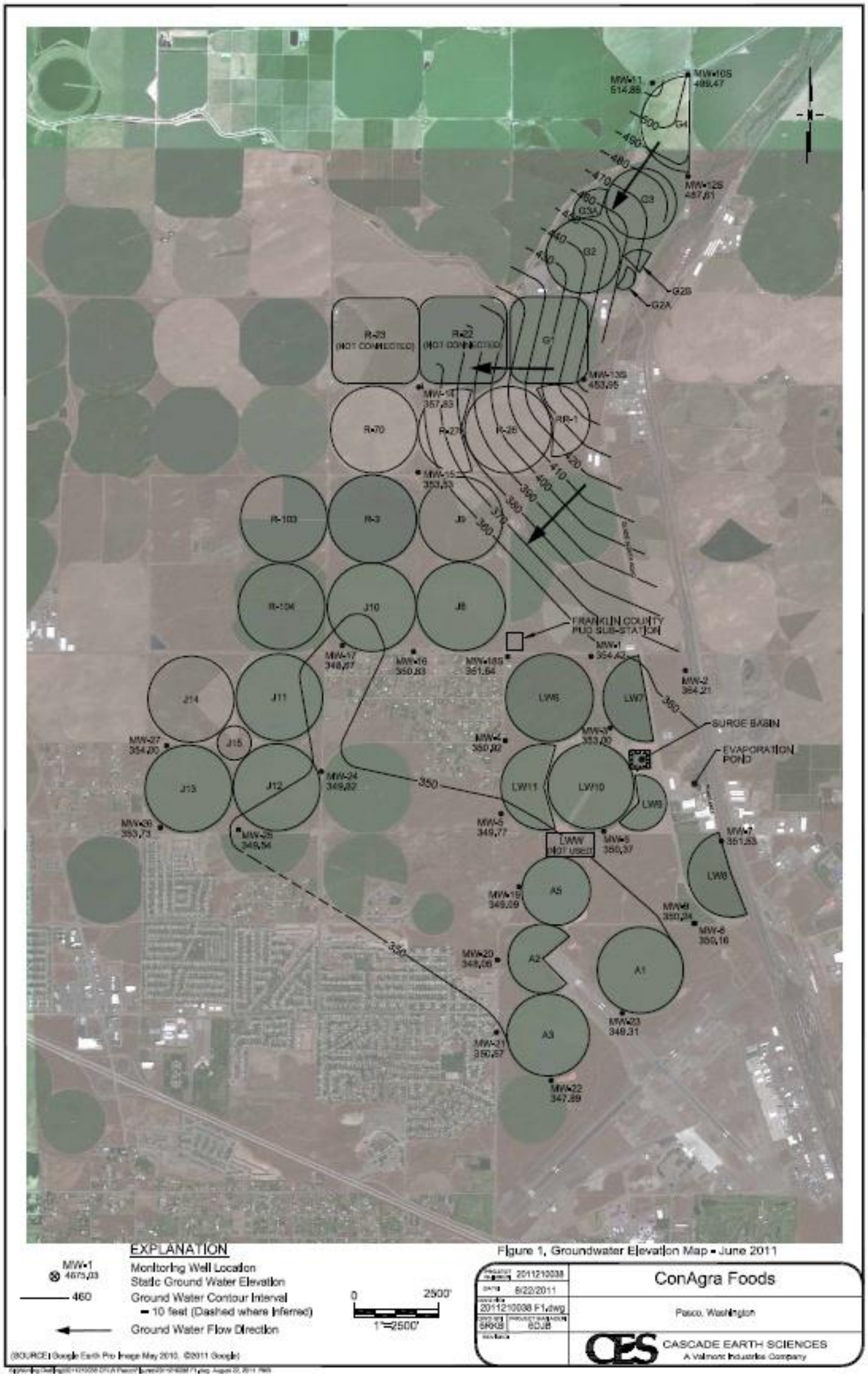

Figure 9. Groundwater Flow Direction.

Entire Site

Upgradient Wells: MW-10S, MW-10D, MW-11, MW-12S.

Downgradient Wells: MW-25, MW-22.

Conclusion: Because downgradient monitoring wells exhibit higher nitrate and TDS concentrations than upgradient wells, it is concluded that the current sprayfield treatment is degrading groundwater quality.

Table 16. Entire Site: Mean Nitrate and TDS Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-10S	upgradient	12.98	478
MW-10D	upgradient	8.30	373
MW-11	upgradient	4.30	357
MW-12S	upgradient	9.81	418
MW-25	downgradient	32.65	731
MW-22	downgradient	23.89	695

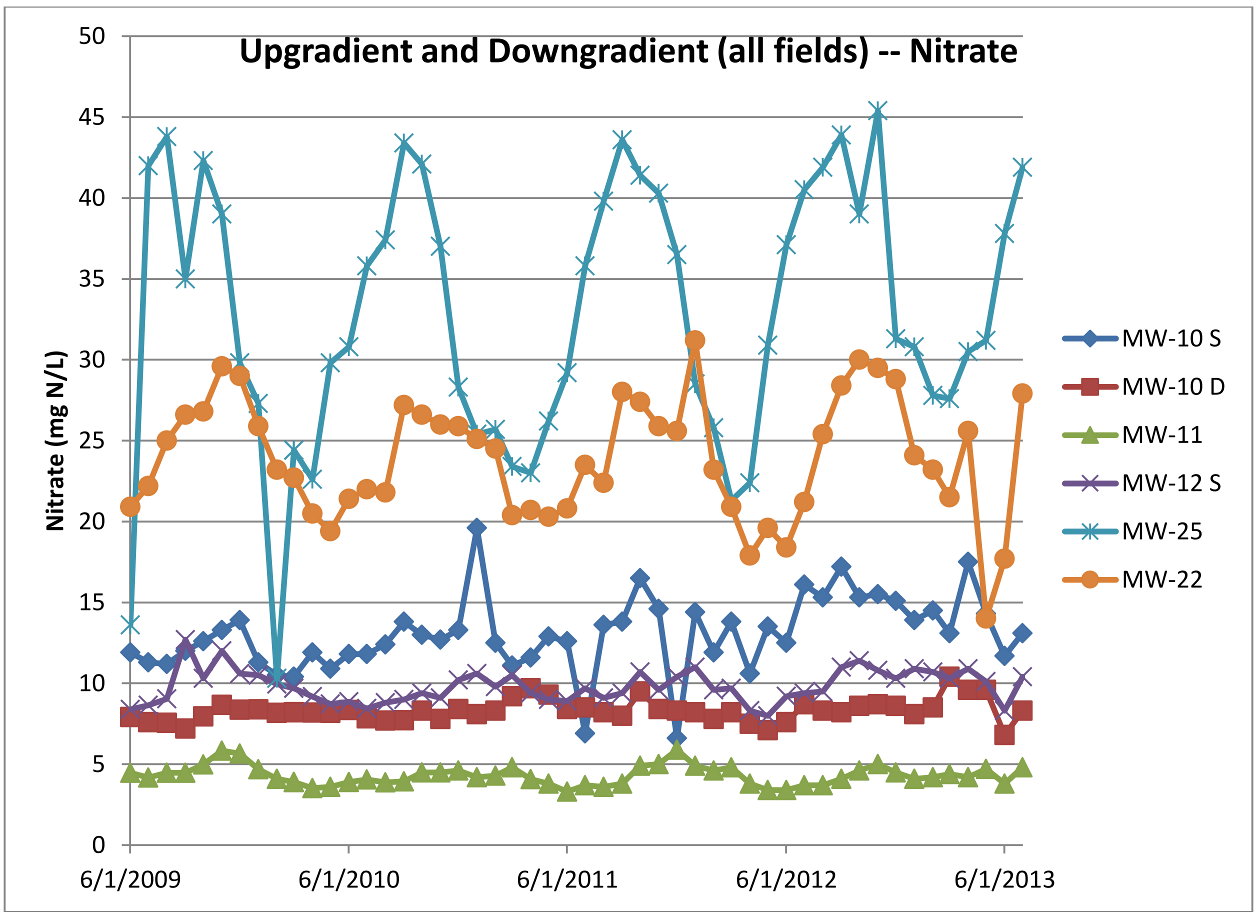

Figure 10. Entire Site: Upgradient and Downgradient Nitrate Concentrations.

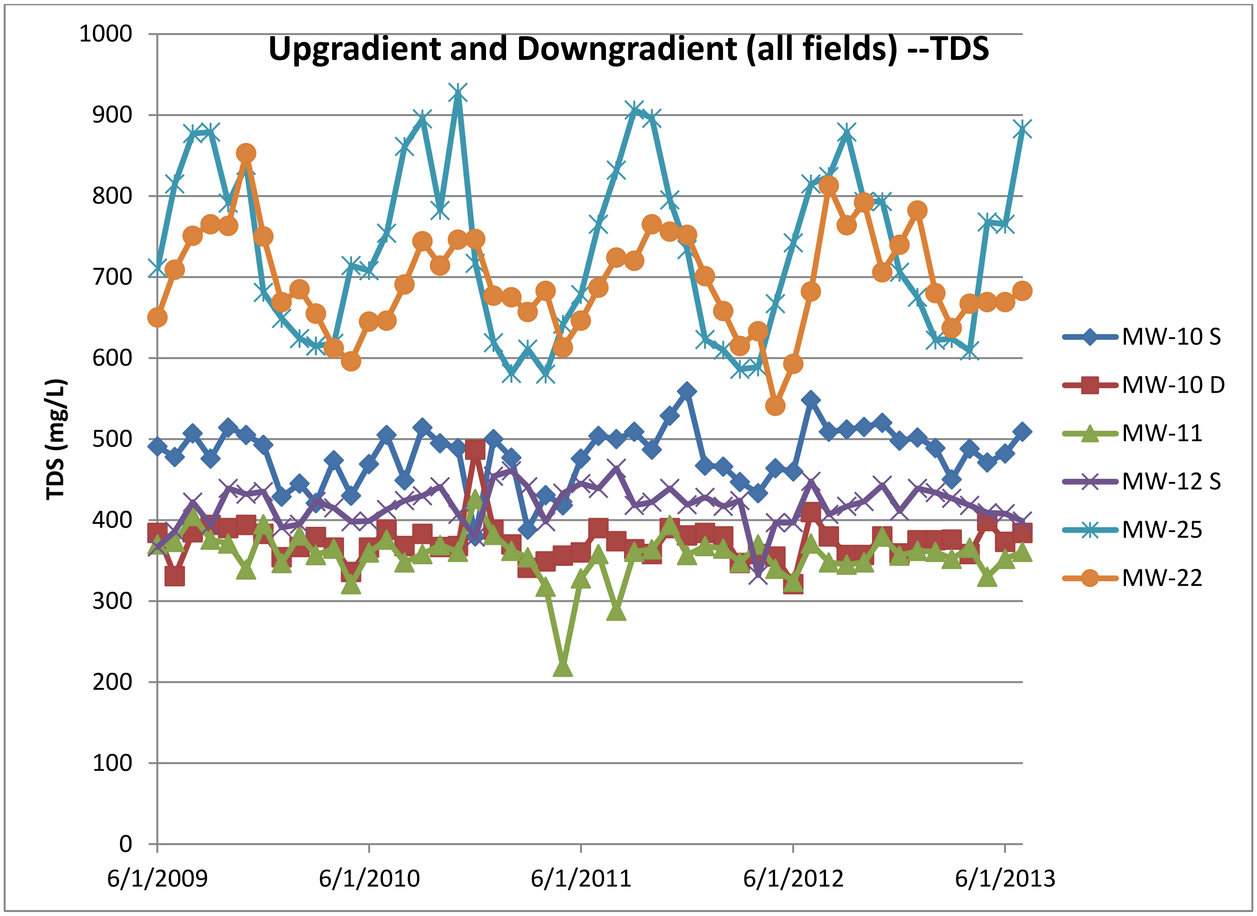

Figure 11. Entire Site: Upgradient and Downgradient TDS Concentrations.

Seven Sub-Areas

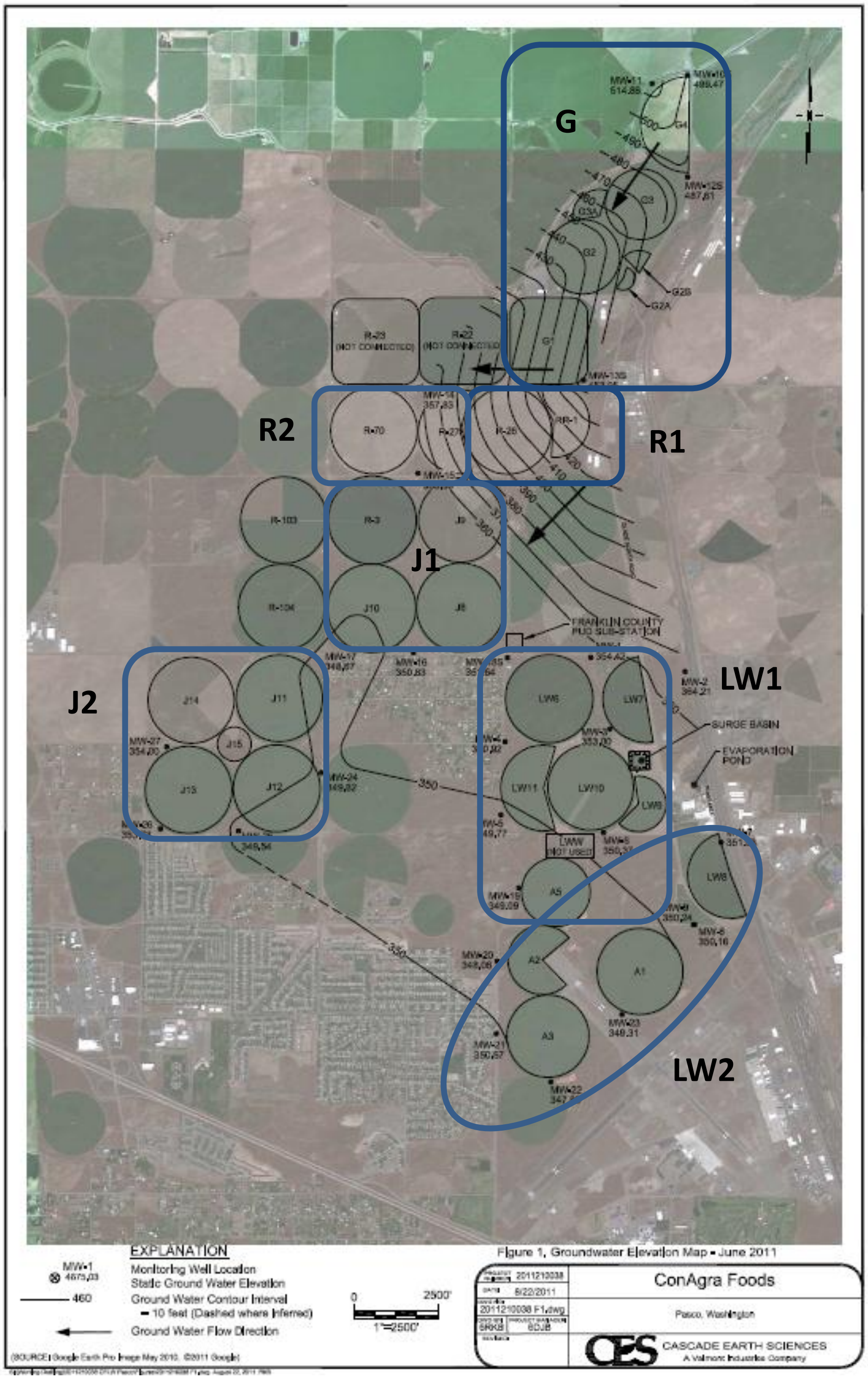

Figure 12. Field Sub-Areas.

G Fields

Upgradient Wells: MW-10S, MW-11, MW-12S.

Downgradient Wells: MW-14, MW-15.

Conclusion: Because downgradient monitoring wells exhibit higher nitrate and TDS concentrations than the upgradient wells, the current sprayfield treatment is degrading groundwater quality.

Table 17. G Fields: Mean Nitrate and TDS Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-10S	upgradient	12.98	478
MW-11	upgradient	4.30	357
MW-12S	upgradient	9.81	418
MW-14	downgradient	22.32	510
MW-15	downgradient	26.92	605

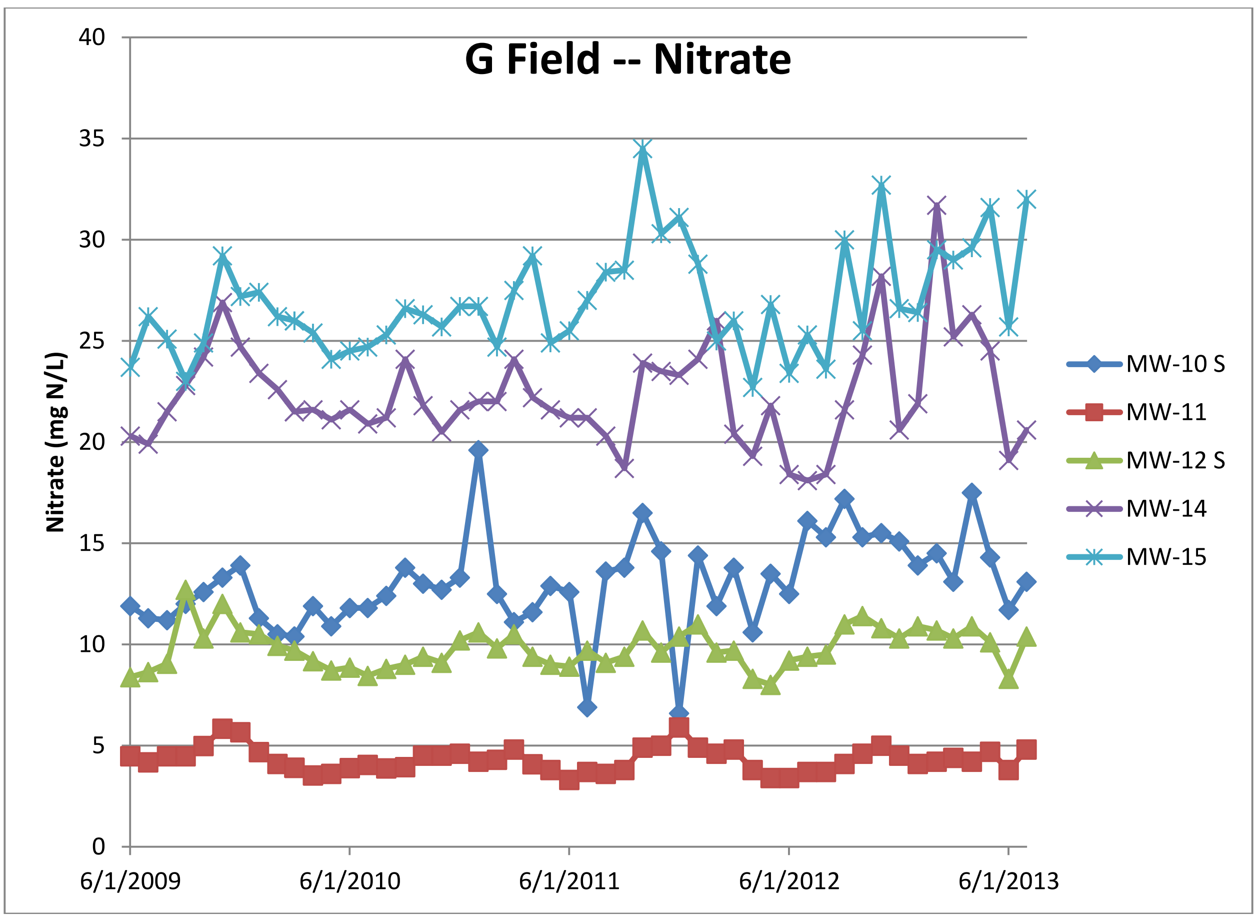

Figure 13. G Fields: Upgradient and Downgradient Nitrate Concentrations.

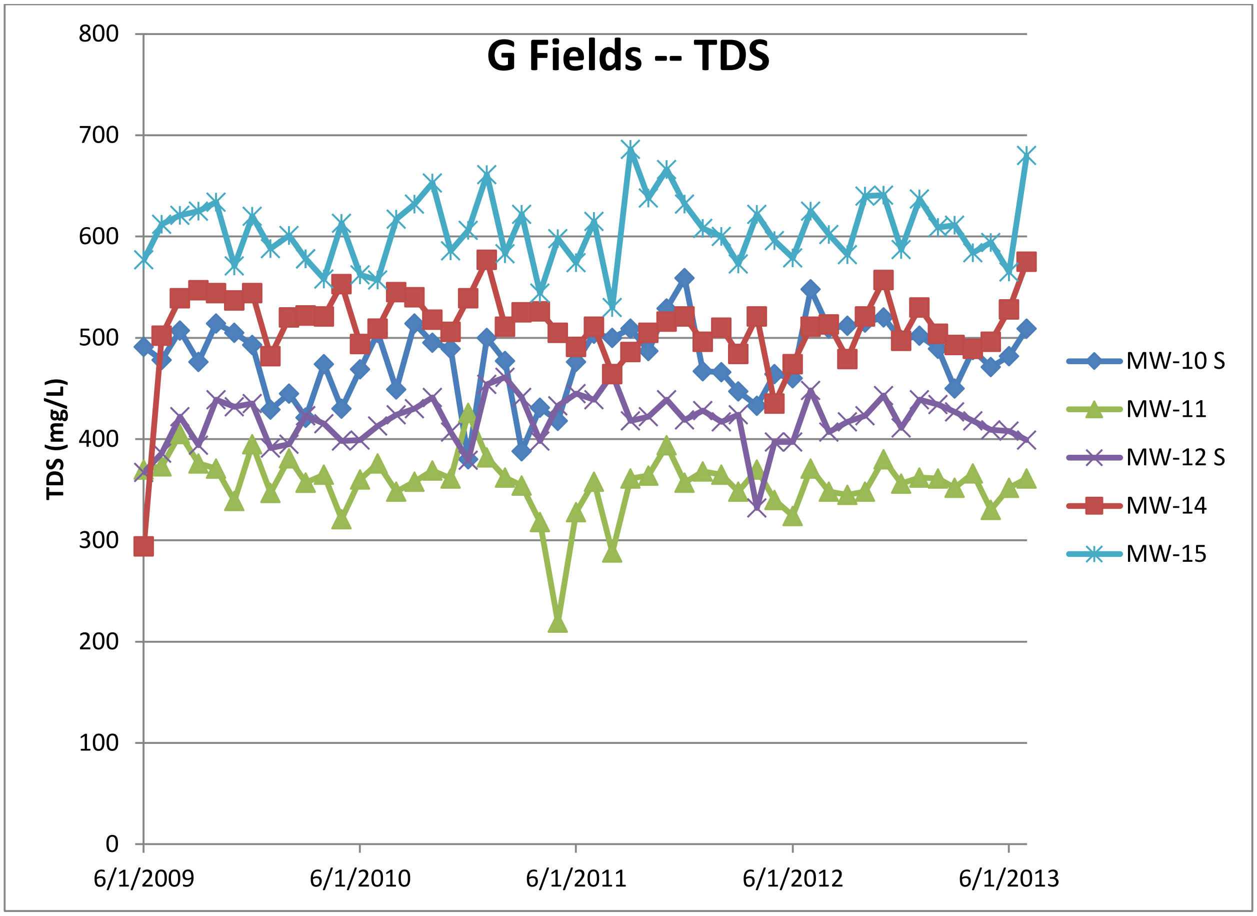

Figure 14. G Fields: Upgradient and Downgradient TDS Concentrations.

R-1 Fields

Upgradient Wells: MW-13S.

Downgradient Wells: MW-14, MW-15.

Conclusion: Because downgradient monitoring wells exhibit higher nitrate concentrations than the upgradient wells, the current sprayfield treatment is degrading groundwater quality. TDS concentrations are approximately the same upgradient and downgradient.

Table 18. R-1 Fields: Mean Nitrate and TDS Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-13S	upgradient	4.11	546
MW-14	downgradient	22.32	510
MW-15	downgradient	26.92	605

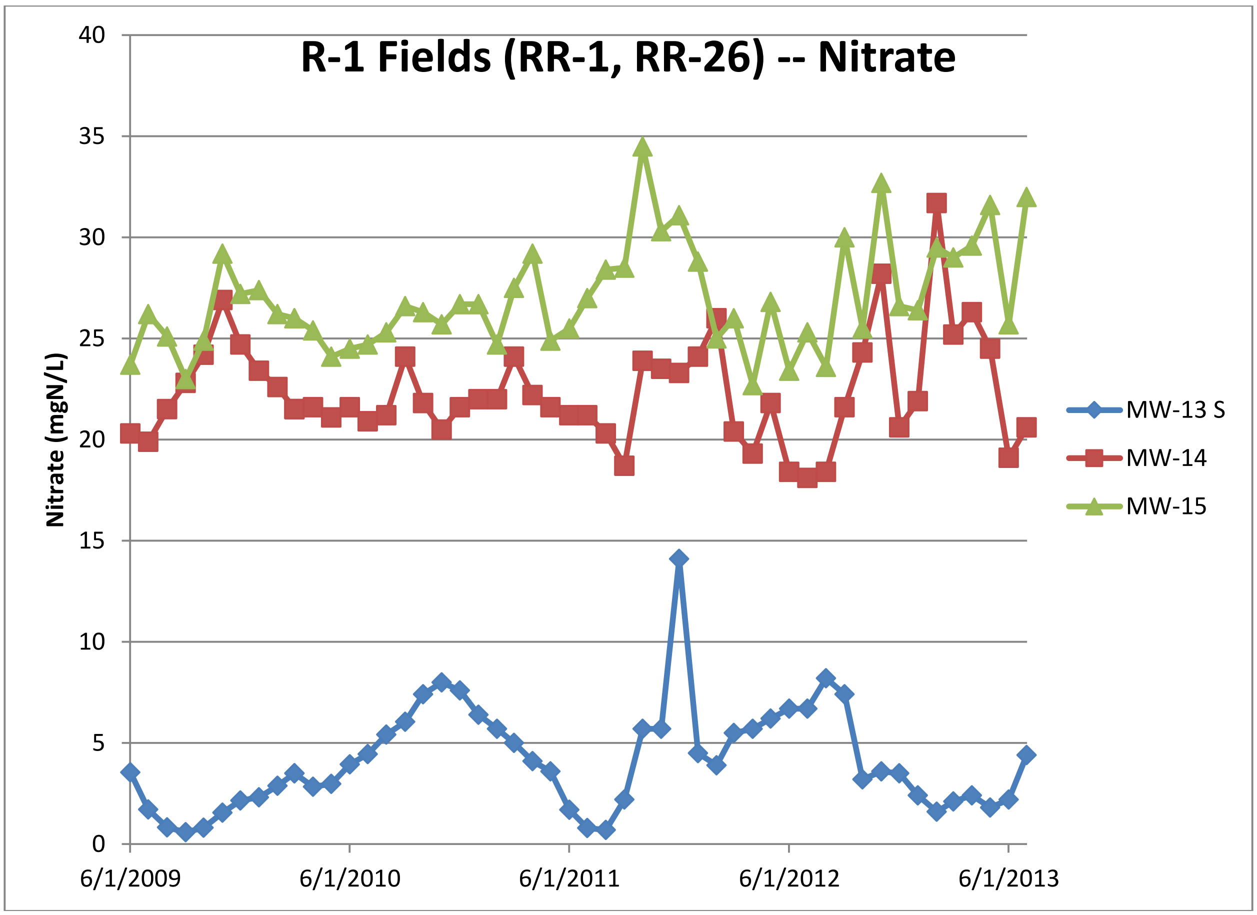

Figure 15. R-1 Fields: Upgradient and Downgradient Nitrate Concentrations.

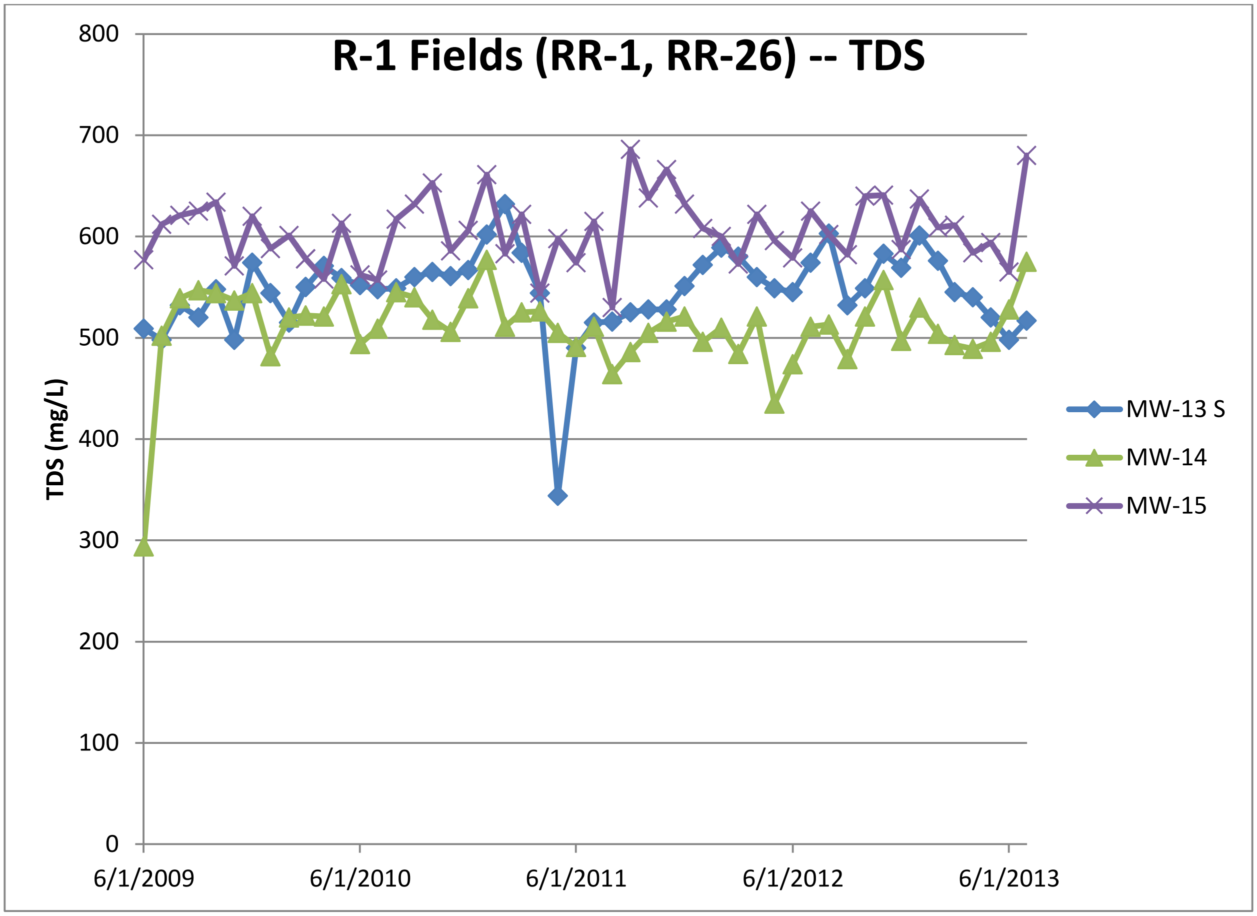

Figure 16. R-1 Fields: Upgradient and Downgradient TDS Concentrations.

R-2 Fields

Upgradient Wells: MW-14.

Downgradient Wells: MW-15.

Conclusion: Because downgradient monitoring wells exhibit higher nitrate and TDS concentrations than the upgradient wells, the current sprayfield treatment is degrading groundwater quality.

Table 19. R-2 Fields: Mean Nitrate and TDS Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-14	upgradient	22.32	510
MW-15	downgradient	26.92	605

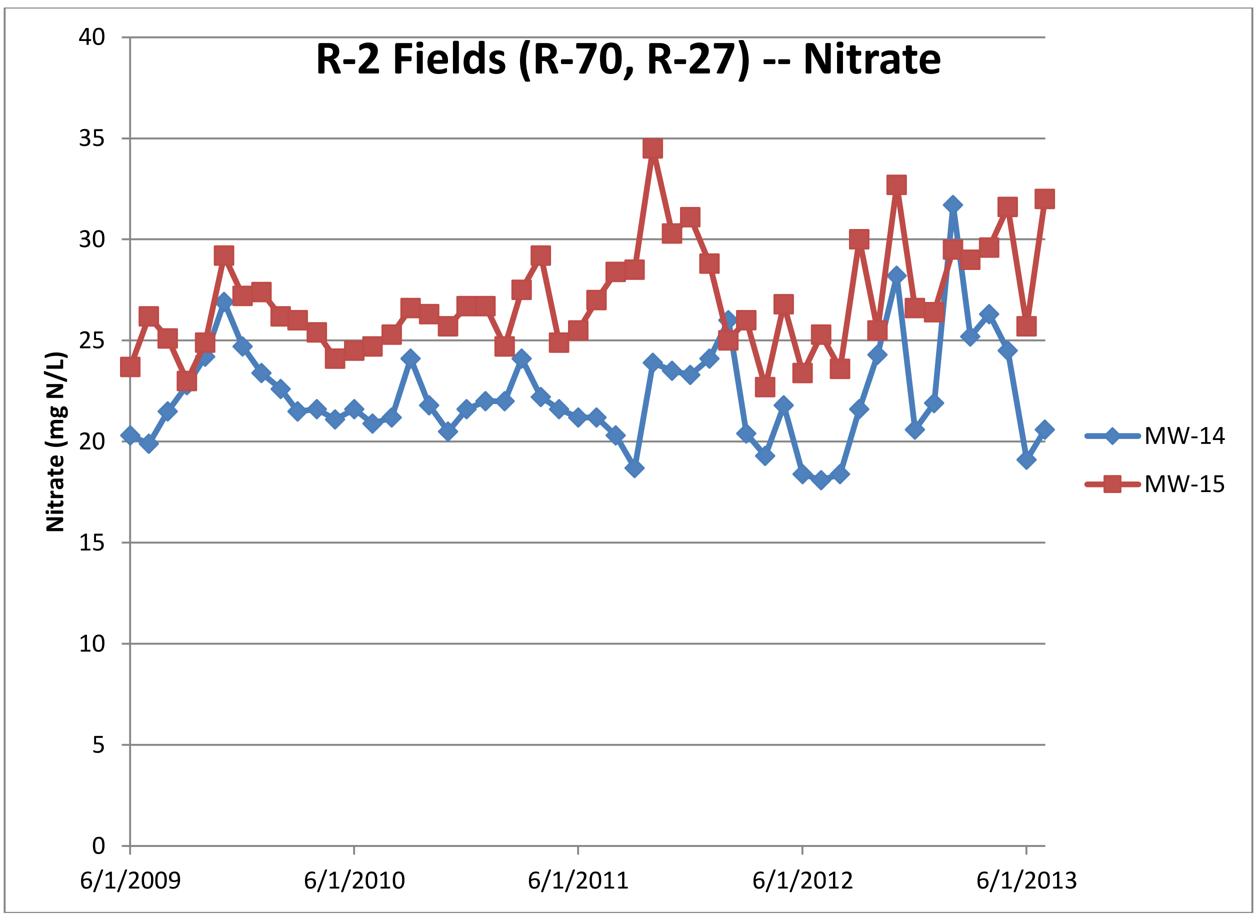

Figure 17. R-2 Fields: Upgradient and Downgradient Nitrate Concentrations.

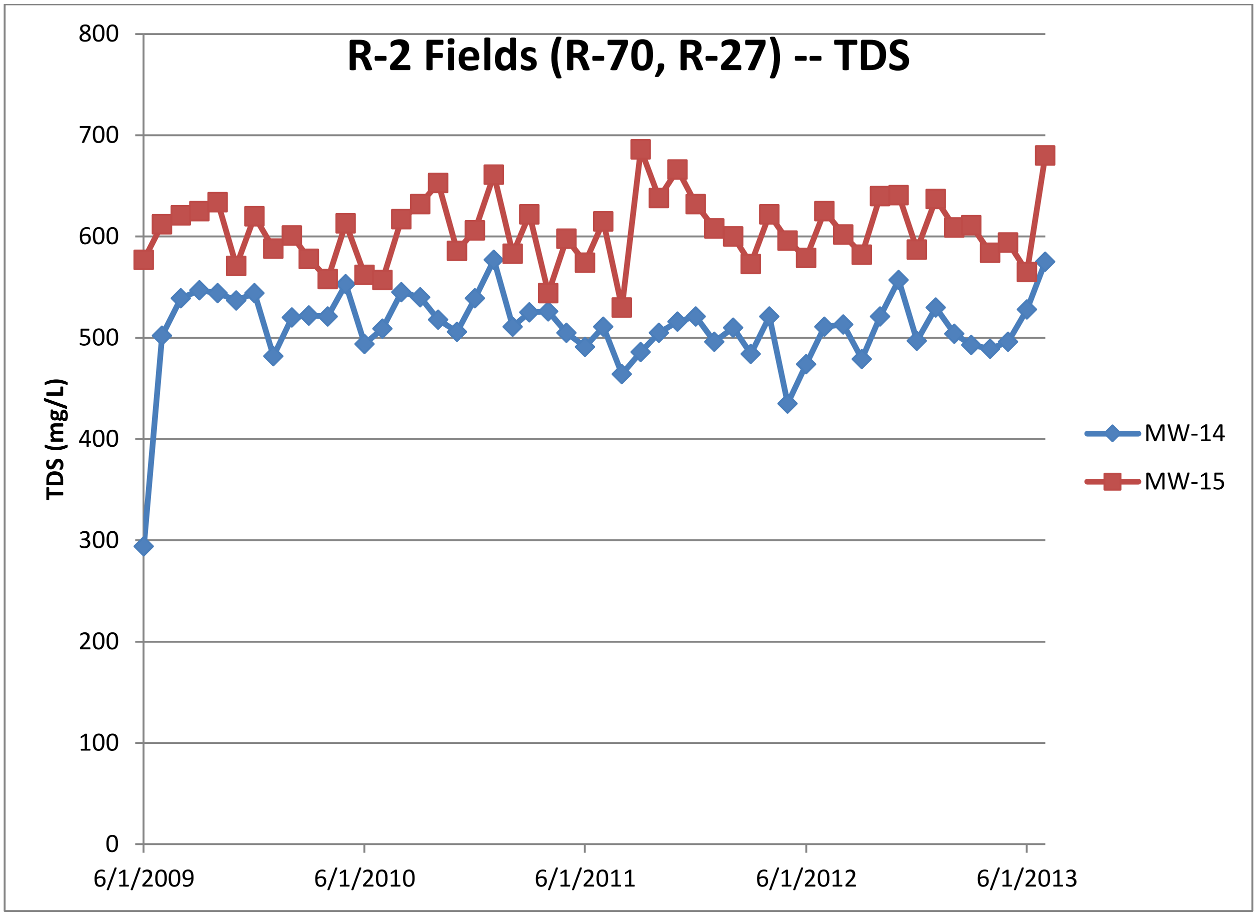

Figure 18. R-2 Fields: Upgradient and Downgradient TDS Concentrations.

J-1 Fields (J-8 – J-10, R-3)

Upgradient Wells: MW-13S.

Downgradient Wells: MW-16.

Conclusion: Because downgradient monitoring wells exhibit higher nitrate and TDS concentrations than the upgradient wells, the current sprayfield treatment is degrading groundwater quality.

Table 20. J-1 Fields: Mean Nitrate and TDS Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-13S	upgradient	4.11	546
MW-16	downgradient	24.64	628

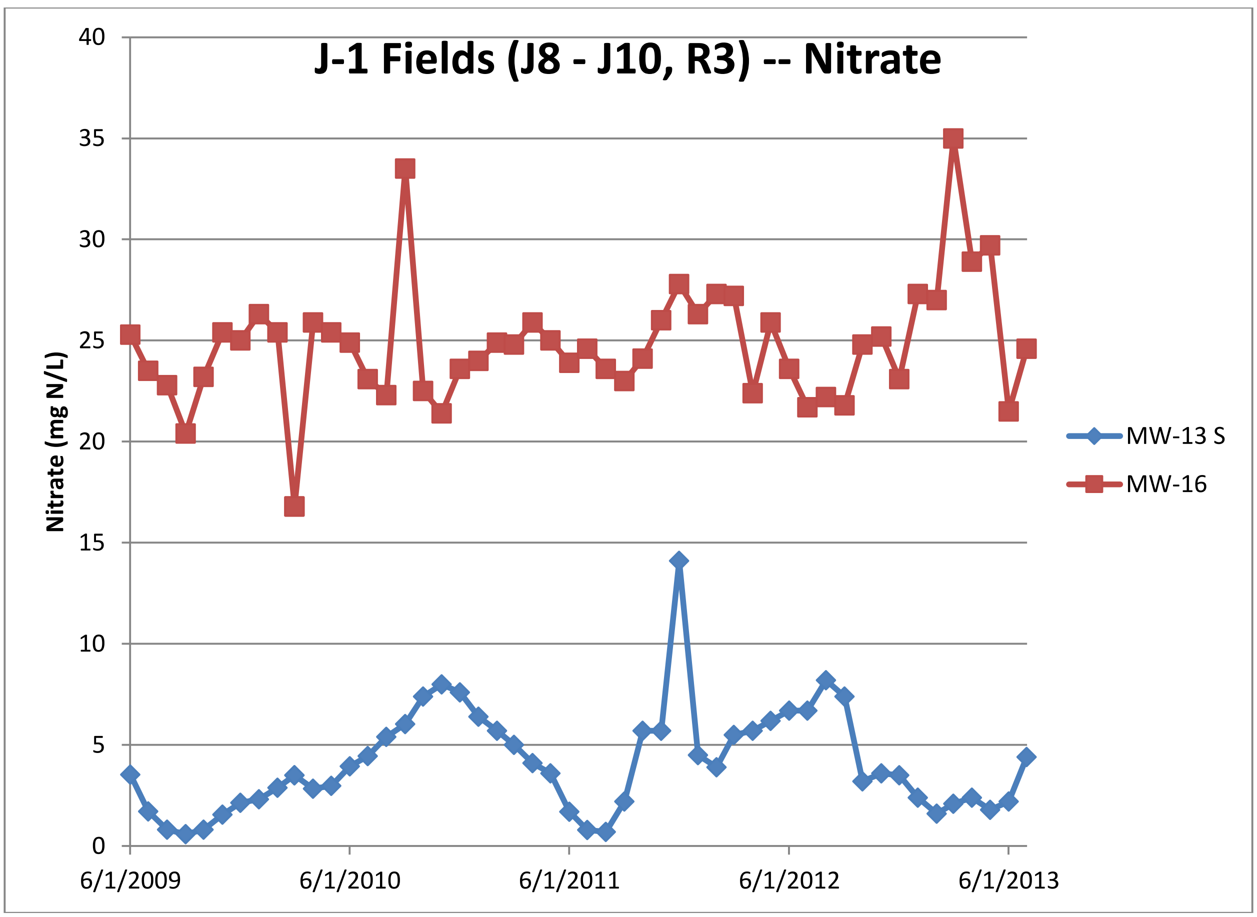

Figure 19. J-1 Fields: Upgradient and Downgradient Nitrate Concentrations.

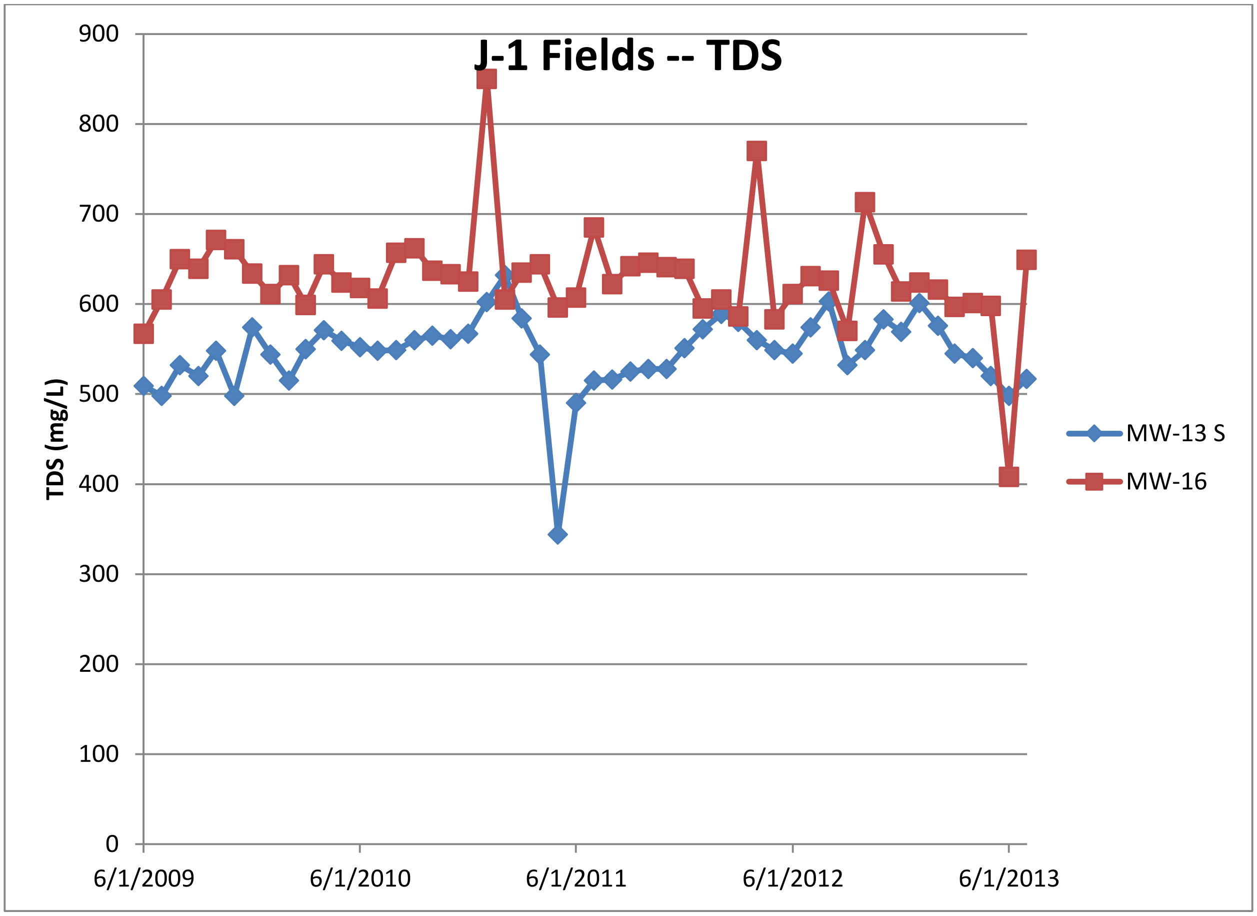

Figure 20. J-1 Fields: Upgradient and Downgradient TDS Concentrations.

Figure 21. ConAgra Foods: Groundwater Contours for the Southern Sprayfield Site.

J-2 Fields (J-11 – J-15)

Upgradient Wells: MW-26, MW-27.

Downgradient Wells: MW-17, MW-24.

Conclusion: Because downgradient monitoring wells exhibit higher nitrate and TDS concentrations than the upgradient wells, the current sprayfield treatment is degrading groundwater quality.

Table 21. J-2 Fields: Nitrate and TDS Mean Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-26	upgradient	21.69	628
MW-27	upgradient	14.61	433
MW-17	downgradient	38.72	824
MW-24	downgradient	31.50	731

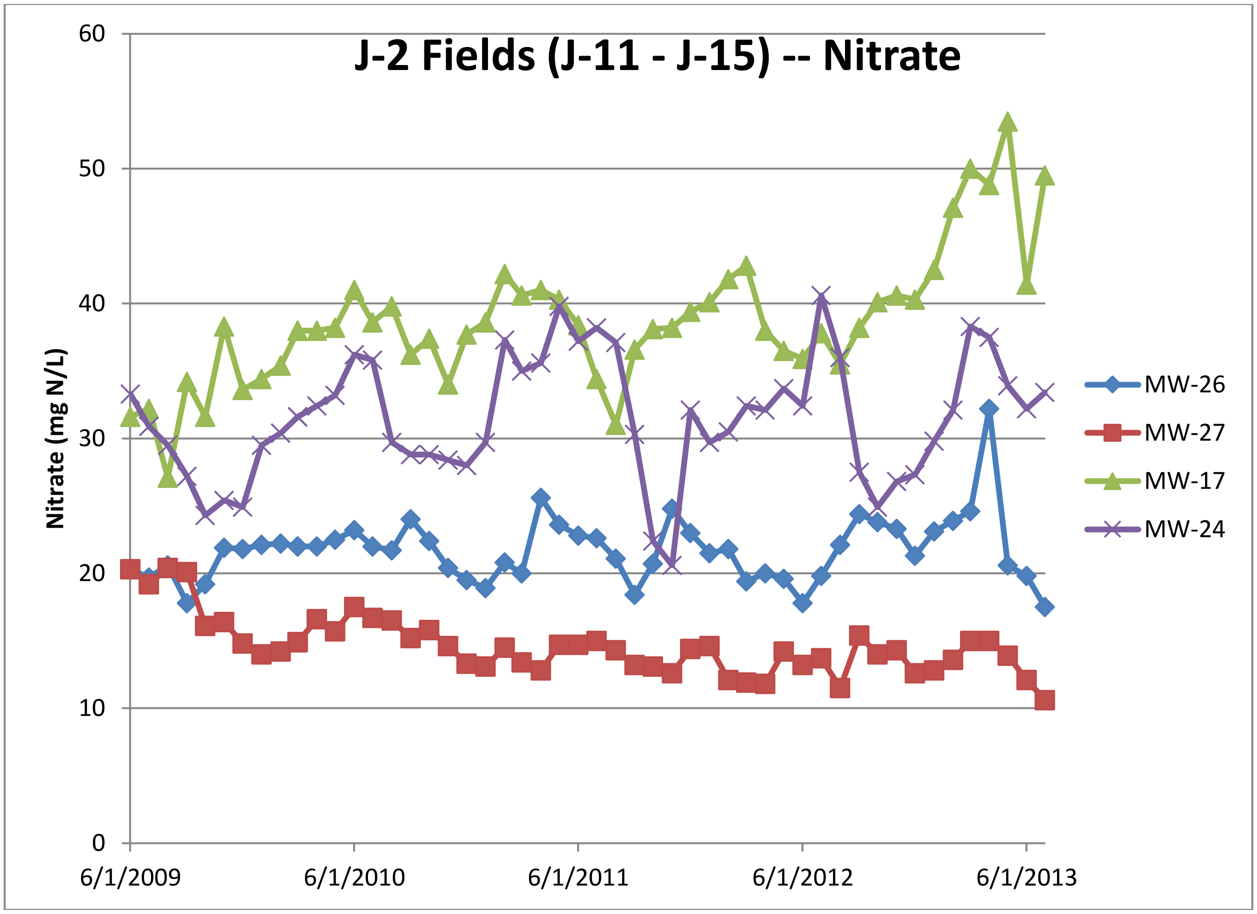

Figure 22. J-2 Fields: Upgradient and Downgradient Nitrate Concentrations.

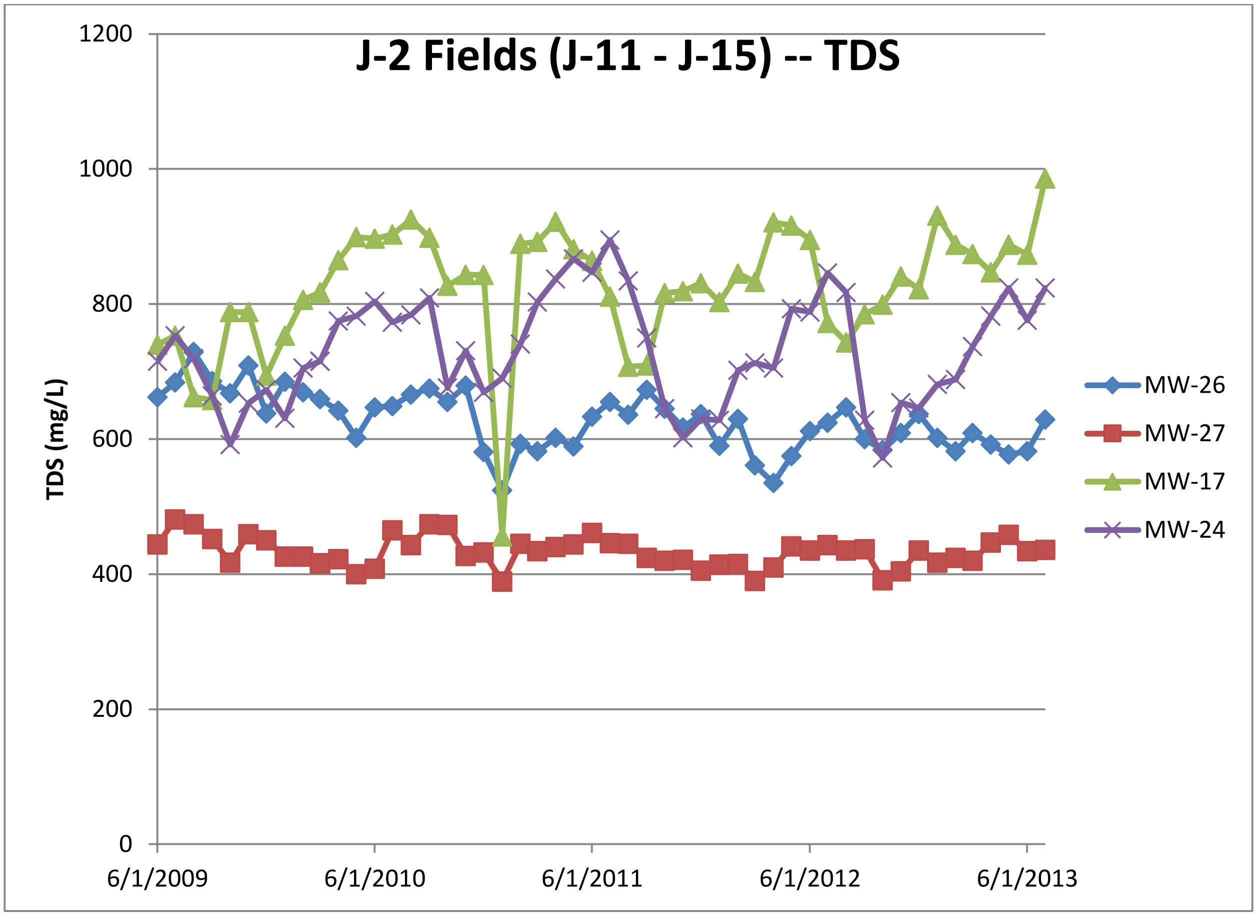

Figure 23. J-2 Fields: Upgradient and Downgradient TDS Concentrations.

LW-1 Fields (except LW-8 and A-5)

Upgradient Wells: MW-1, MW-2.

Downgradient Wells: MW-4, MW-5, MW-6, MW-19.

Conclusion: Some of the downgradient nitrate and TDS monitoring wells are higher than upgradient. Downgradient MW-4 has a mean nitrate concentration 0.03 mg N/L less than one of the upgradient wells but 0.6 mg N/L higher than the other upgradient well. Because generally the downgradient monitoring wells exhibit higher nitrate and TDS concentrations than the upgradient wells, the current sprayfield treatment is degrading groundwater quality.

Table 22. LW-1 Fields: Mean Nitrate and TDS Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-1	upgradient	17.83	504
MW-2	upgradient	18.46	524
MW-4	downgradient	18.43	546
MW-5	downgradient	21.05	564
MW-6	downgradient	27.56	751
MW-19	downgradient	20.59	584

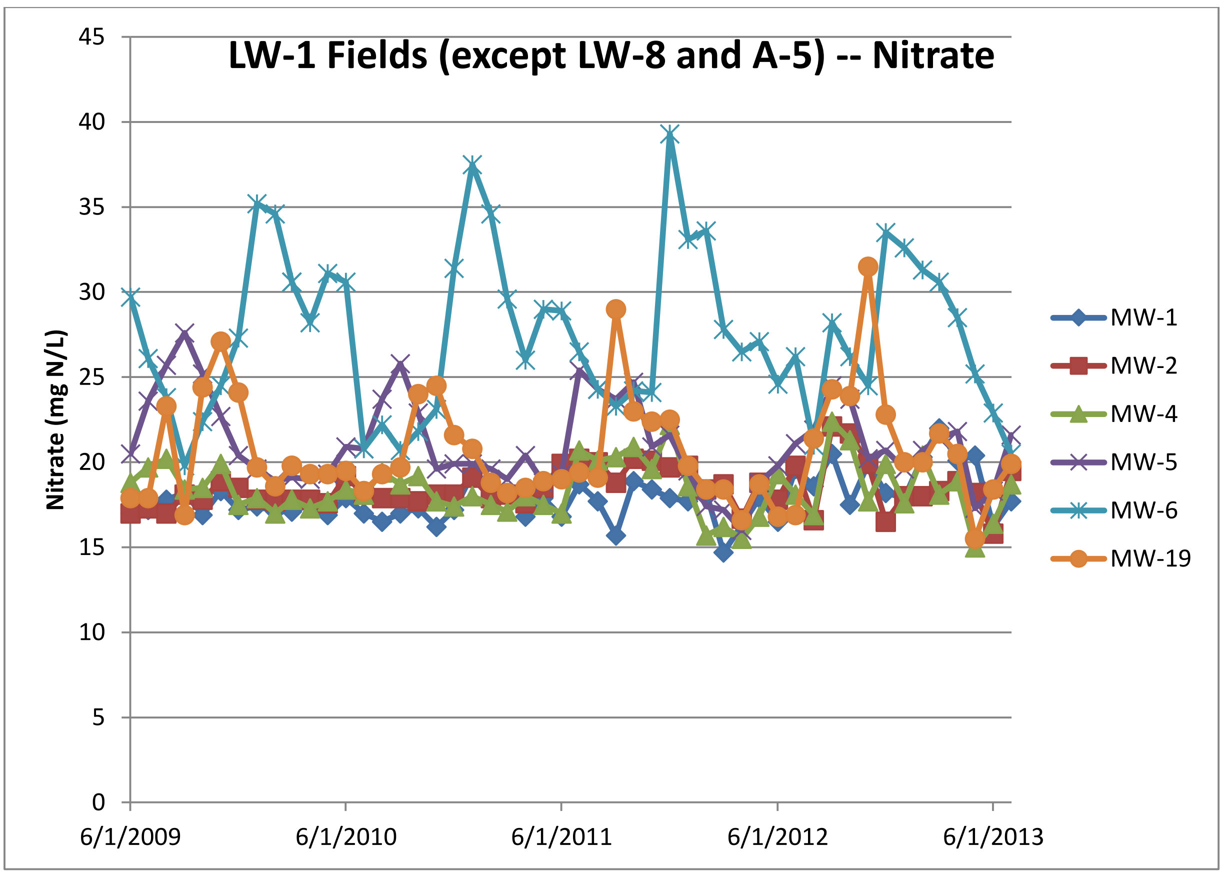

Figure 24. LW-1 Fields: Upgradient and Downgradient Nitrate Concentrations.

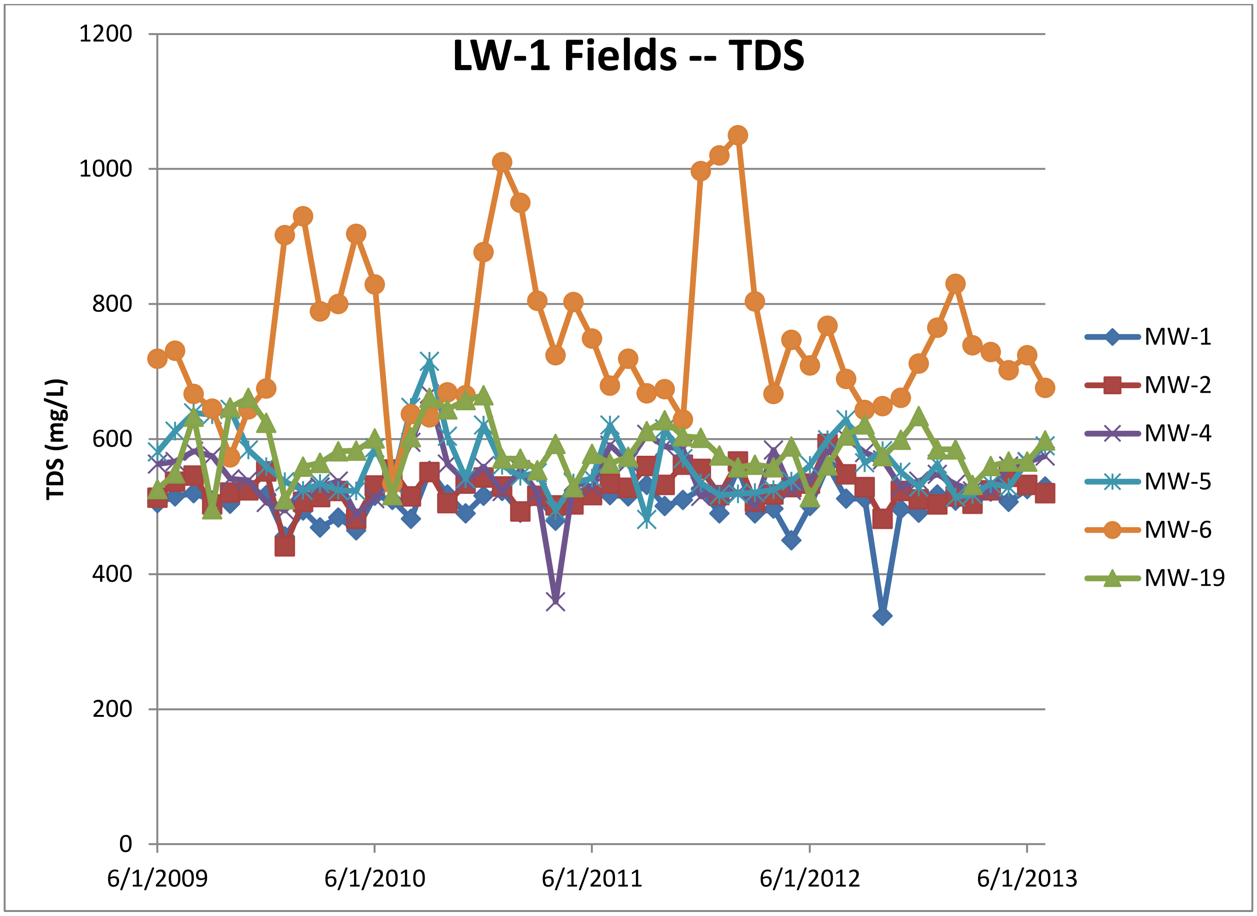

Figure 25. LW-1 Fields: Upgradient and Downgradient TDS Concentrations.

LW-2 Fields (LW-8 and A fields except A-5)

Upgradient Wells: MW-7.

Downgradient Wells: MW-8, MW-20, MW-21, MW-22, MW-23.

Conclusion: Some of the downgradient nitrate wells are the same or lower than the upgradient. wells. The downgradient TDS wells are higher than the upgradient wells. Because downgradient monitoring wells exhibit higher TDS concentrations than the upgradient wells, the current sprayfield treatment is degrading groundwater quality.

Table 23. LW-2 Fields: Mean Nitrate and TDS Concentrations.

Well	Location	Mean Nitrate (mg N/L)	Mean TDS (mg N/L)
MW-7	upgradient	22.24	551
MW-8	downgradient	10.90	608
MW-20	downgradient	20.74	575
MW-21	downgradient	21.53	618
MW-22	downgradient	23.89	695
MW-23	downgradient	22.79	711

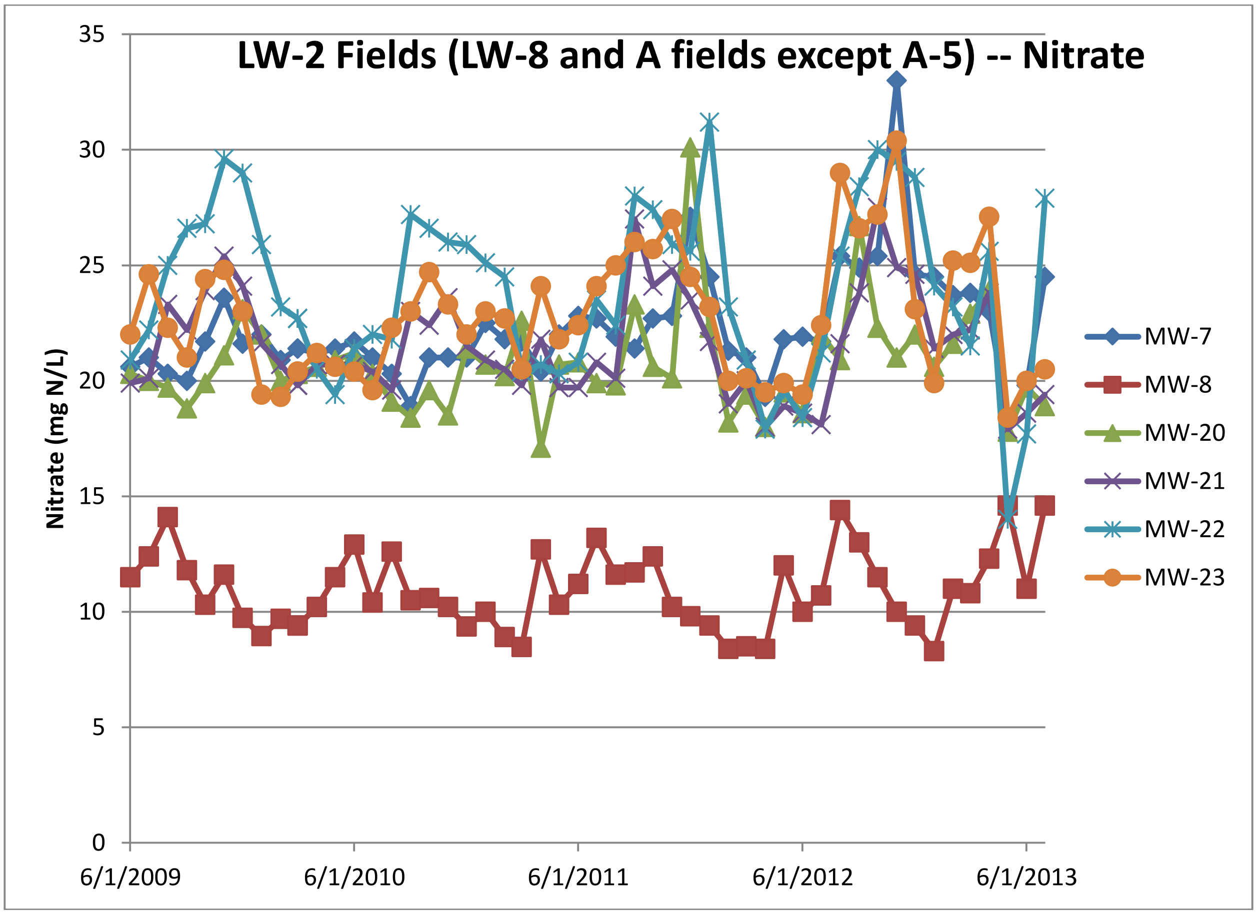

Figure 26. LW-2 Fields: Upgradient and Downgradient Nitrate Concentrations.

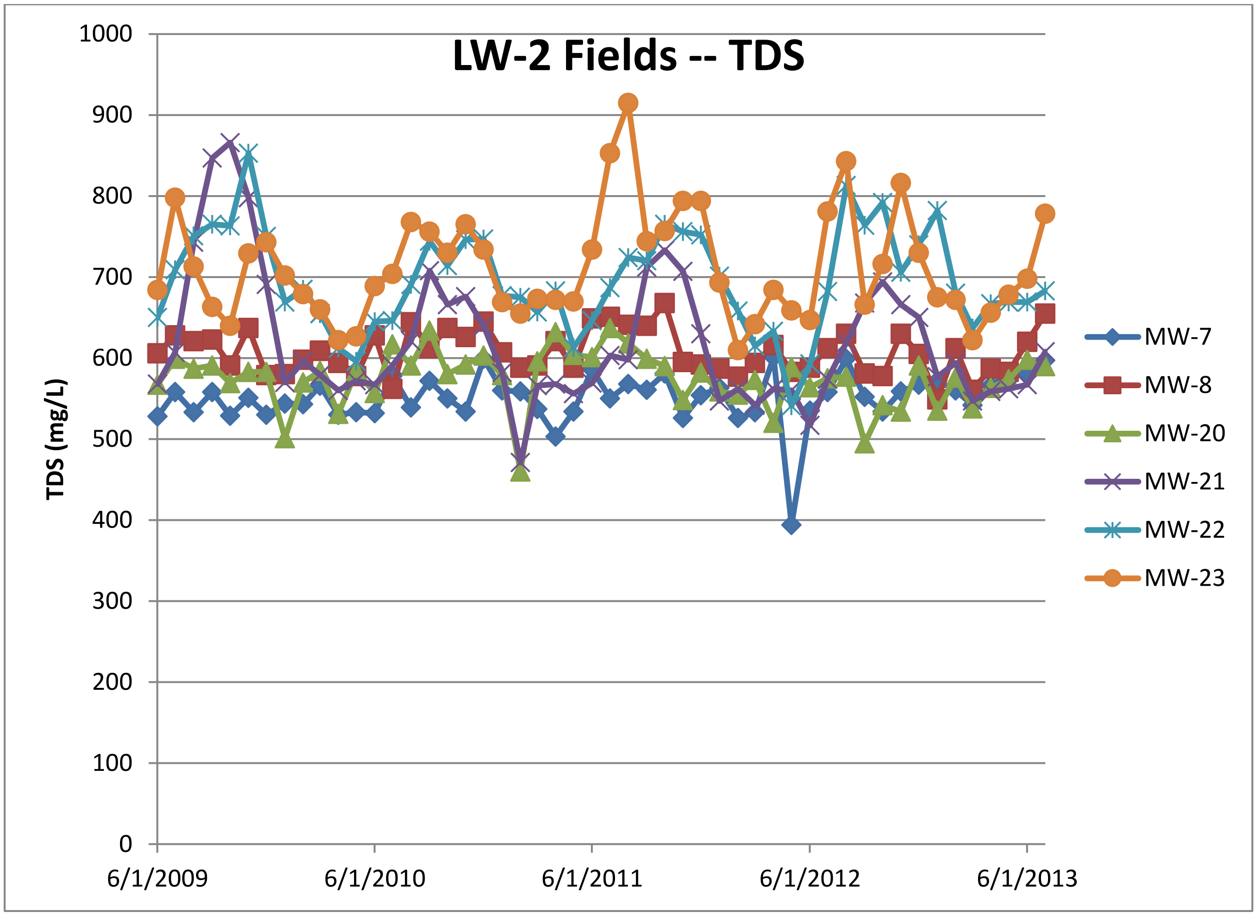

Figure 27. LW-2 Fields: Upgradient and Downgradient TDS Concentrations.

Within the seven sub-areas, two monitoring wells (MW-14 and MW-15) are used as downgradient wells for more than one sub-area. This makes it challenging to discern which field is causing water quality impacts.

MW-14 is designated as a downgradient well for two sub-areas and is also designated as an upgradient well for another sub-area.

Using the sub-area approach to measure impacts to groundwater quality presents some regulatory challenges to measuring compliance with standards.

Groundwater Quality and Trends

ConAgra has 30 monitoring wells located across their 3,000-acre sprayfield site. Eleven of these wells are upgradient wells and reflect ambient conditions (MW-1, MW-2, MW-7, MW-10S, MW-10D, MW-11, MW-12S, MW-13S, MW-13D, MW-26, and MW-27). Impacted water quality from these wells indicates contributions from other area activities, not activities from ConAgra. Nineteen of the monitoring wells are downgradient wells. A comparison of water quality from the downgradient wells with water quality from the upgradient wells reflects the impacts from ConAgra.

Groundwater monitoring is the best way to measure compliance with the groundwater quality standards (Chapter 173-200 WAC). ConAgra has 30 monitoring wells and collects over 300 soil nitrate samples every year. These data were evaluated to attempt to distinguish impacts from ConAgra activities from existing regional groundwater contamination. An evaluation of the groundwater monitoring data from September 2009 to July 2013 is summarized in Table 24.

Table 24. Statistical Summary Comparing Downgradient Wells to Upgradient Wells.

Statistical Measure	Downgradient Wells		Upgradient Wells	
	Number (n = 19)	Percent	Number (n = 11)	Percent
Nitrate				
Mean	19	100%	6	55%
95%	19	100%	7	64%
Never exceeded the standard	0	0%	2	18%
Consistently exceeded the standard	19	100%	9	82%
TDS				
Mean	19	100%	6	55%
95%	19	100%	7	64%
Never exceeded the standard	0	0%	4	36%
Consistently exceeded the standard	8	42%	1	9%

Nitrate Concentrations and Trends

Table 25 summarizes the groundwater nitrate data for each well.

Table 25. Groundwater Nitrate Summary, September 2009 to July 2013.

Well	Upgradient	Trend	Mean	95%	Maximum	Minimum
MW-1	yes	↑	17.8	20.4	22	14.7
MW-2	yes	↑	18.5	20.2	22.1	15.8
MW-3		–	19.9	22.3	25.6	15.8
MW-4		–	18.4	21.1	22.4	15
MW-5		–	21.1	25.6	27.6	16
MW-6		–	27.6	34.9	39.3	19.8
MW-7	yes	↑	22.2	25.4	33	18.4
MW-8		–	10.9	14.3	14.6	8.3
MW-9		–	26.6	29.8	30.6	18.9
MW-10S	yes	↑	13.0	16.9	19.6	6.6
MW-10D	yes	–	8.3	9.6	10.4	6.8
MW-11	yes	–	4.3	5.3	5.9	3.3
MW-12S	yes	–	9.8	11.2	12.7	8
MW-13S	yes	–	4.1	7.8	14.1	0.6
MW-13D	yes	↑	6.7	8.11	8.6	4.9
MW-14		–	22.3	26.6	31.7	18.1
MW-15		↑	26.9	31.8	34.5	22.7
MW-16		–	24.6	29.3	35	16.8
MW-17		↑	38.7	49.2	53.5	27.1
MW-18S		–	16.4	18.9	20.5	9.5
MW-18D		–	17.4	20.1	22	14.6
MW-19		–	20.6	25.8	31.5	15.5
MW-20		–	20.7	23.6	30.1	17.1
MW-21		–	21.5	25.2	27.5	17.9
MW-22		–	23.9	29.6	31.2	14
MW-23		–	22.8	27.2	30.4	18.4
MW-24		–	31.5	38.3	40.6	20.6
MW-25		–	32.7	43.7	45.4	10.3
MW-26	yes	–	21.7	24.7	32.2	17.5
MW-27	yes	↓	14.6	19.7	20.4	10.6

Orange > groundwater criteria.

Findings presented in Table 25

- Twenty-three percent (n=7) of all the monitoring wells have a statistically significant increasing trend of nitrate over time. Five of these wells are upgradient wells. Two of the 19 downgradient wells (11%) have a statistically significant increasing nitrate trend. One upgradient well had a decreasing nitrate trend, and 73% (n=22) of all the monitoring wells have no statistically significant nitrate trend.

- Eighty-three percent (n=25) of all the monitoring wells have mean nitrate concentrations that exceed (do not meet) the groundwater quality standard of 10 mg N/L. This includes 6 of the upgradient wells (55%) and all of the 19 downgradient wells (100%).

- Eighty-six percent (n=26) of all the monitoring wells exceed the nitrate standard 95% of the time. This includes 7 of the upgradient wells (64%) and 19 of the downgradient wells (100%).

- Seventy-seven percent (n=23) of all the monitoring wells consistently exceeded the nitrate standard for each sampling event. This includes 5 of the upgradient wells (45%) and 17 of the downgradient wells (89%).

- Six percent (n=2) of all the monitoring wells never exceeded the nitrate standard. Both of these wells (MW-11 and MW-13D) are upgradient wells. No downgradient wells were consistently below the nitrate standard for every sampling event during the evaluation timeframe.

- Zhao et al. (2006) raise concerns about the potential for ammonium to leach to groundwater at the ConAgra sprayfield site. Ammonium is rarely found in groundwater unless conditions exist such as soils with a low cation exchange capacity, low organic matter, high sand content, and wastewater that has a high potassium content.

Figure 28 illustrates the groundwater sub-areas that are impacted by increases in nitrate concentrations (comparing upgradient to downgradient).

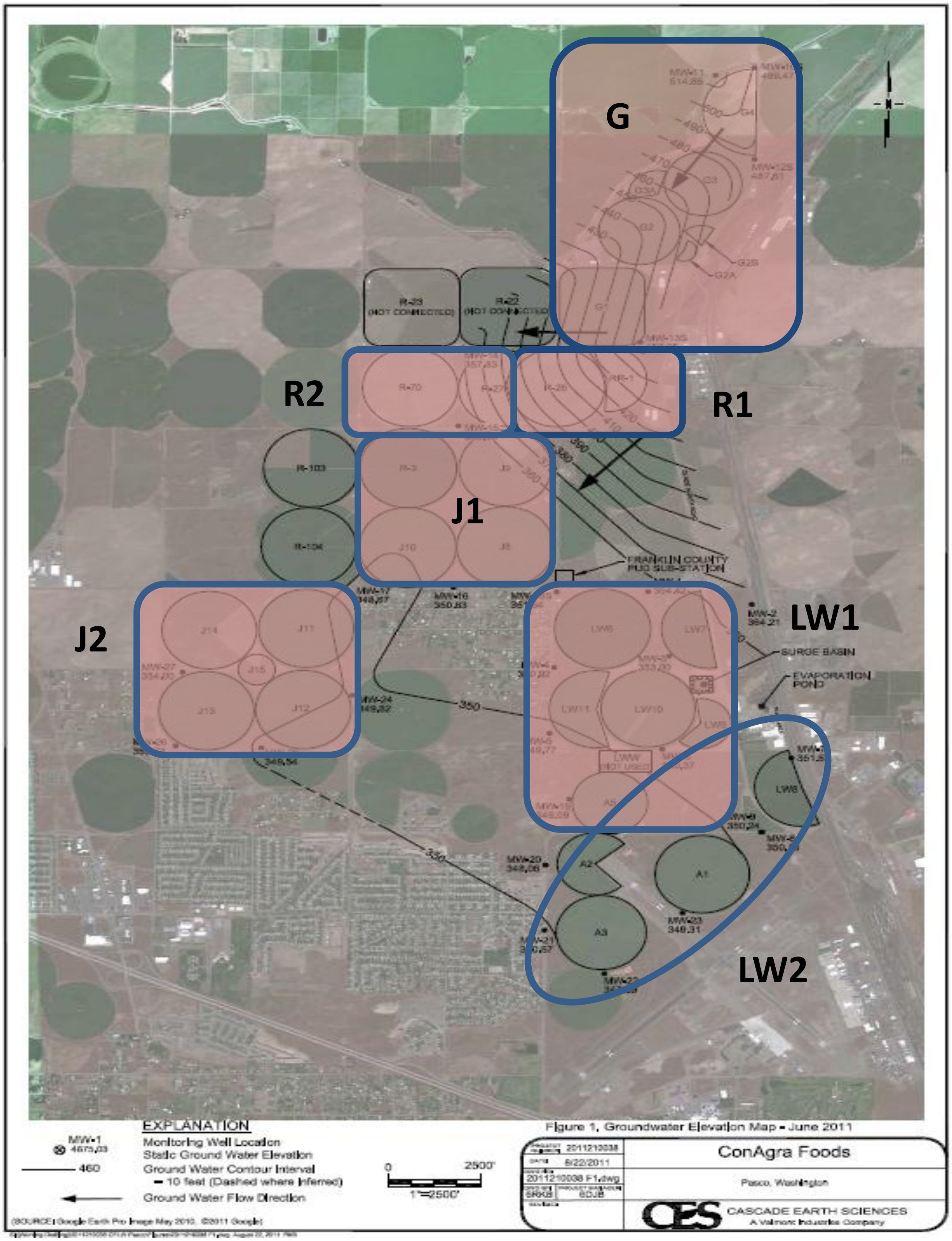

Figure 28. Nitrate Impacted Fields.

TDS Concentrations and Trends

Table 26 summarizes the groundwater total dissolved solids (TDS) data.

Table 26. Groundwater TDS Summary, September 2009 to July 2013.

Well	Upgradient	Trend	Mean	95%	Maximum	Minimum
MW-1	yes	–	504	543	561	338
MW-2	yes	–	524	561	593	441
MW-3		–	551	590	597	403
MW-4		–	546	599	667	359
MW-5		–	564	642	715	481
MW-6		–	751	1004	1050	534
MW-7	yes	↑	551	598	601	394
MW-8		–	608	650	668	549
MW-9		↓	796	876	926	529
MW-10S	yes	–	478	525	559	380
MW-10D	yes	–	373	397	487	321
MW-11	yes	–	357	395	426	219
MW-12S	yes	–	418	451	464	332
MW-13S	yes	–	546	602	632	344
MW-13D	yes	–	526	568	670	393
MW-14		–	510	555	577	294
MW-15		–	605	664	686	530
MW-16		–	628	699	850	408
MW-17		↑	824	924	986	456
MW-18S		–	515	547	562	462
MW-18D		–	512	535	578	480
MW-19		–	584	660	665	496
MW-20		–	575	625	637	460
MW-21		–	618	771	866	471
MW-22		–	695	787	853	541
MW-23		–	711	830	915	610
MW-24		–	731	847	895	572
MW-25		–	731	896	928	580
MW-26	yes	↓	628	686	729	524
MW-27	yes	–	432	474	481	420

Orange > groundwater criteria

Findings presented in Table 26

- Six percent (n=2) of all the monitoring wells have a statistically significant increasing trend of TDS over time. One of these is an upgradient well and one is a downgradient well. Six percent (n=2) of the wells had a decreasing TDS trend: one upgradient well and one downgradient well. Eighty-seven percent (n=26) of all the wells had no statistically significant TDS trend.

- Eighty-three percent (n=25) of all the monitoring wells have mean TDS concentrations that exceed the groundwater quality standard of 500 mg/L. This includes 6 of the upgradient wells (55%) and all of the 19 downgradient wells (100%).

- Eighty-six percent (n=26) of all the monitoring wells exceed the TDS standard 95% of the time. This includes 7 of the upgradient wells (64%) and 19 of the downgradient wells (100%).

- Thirty percent (n=9) of all the monitoring wells consistently exceeded the TDS standard for each sampling event. This includes one upgradient well and 8 of the downgradient wells (42%).

- Thirteen percent (n=4) of all the monitoring wells never exceeded the groundwater quality standard for TDS. All four of these wells are upgradient wells. No downgradient wells were consistently below the TDS standard for every sampling event during the evaluation timeframe.

Figure 29 illustrates the groundwater sub-areas that are impacted by increases in TDS concentrations (comparing upgradient to downgradient).

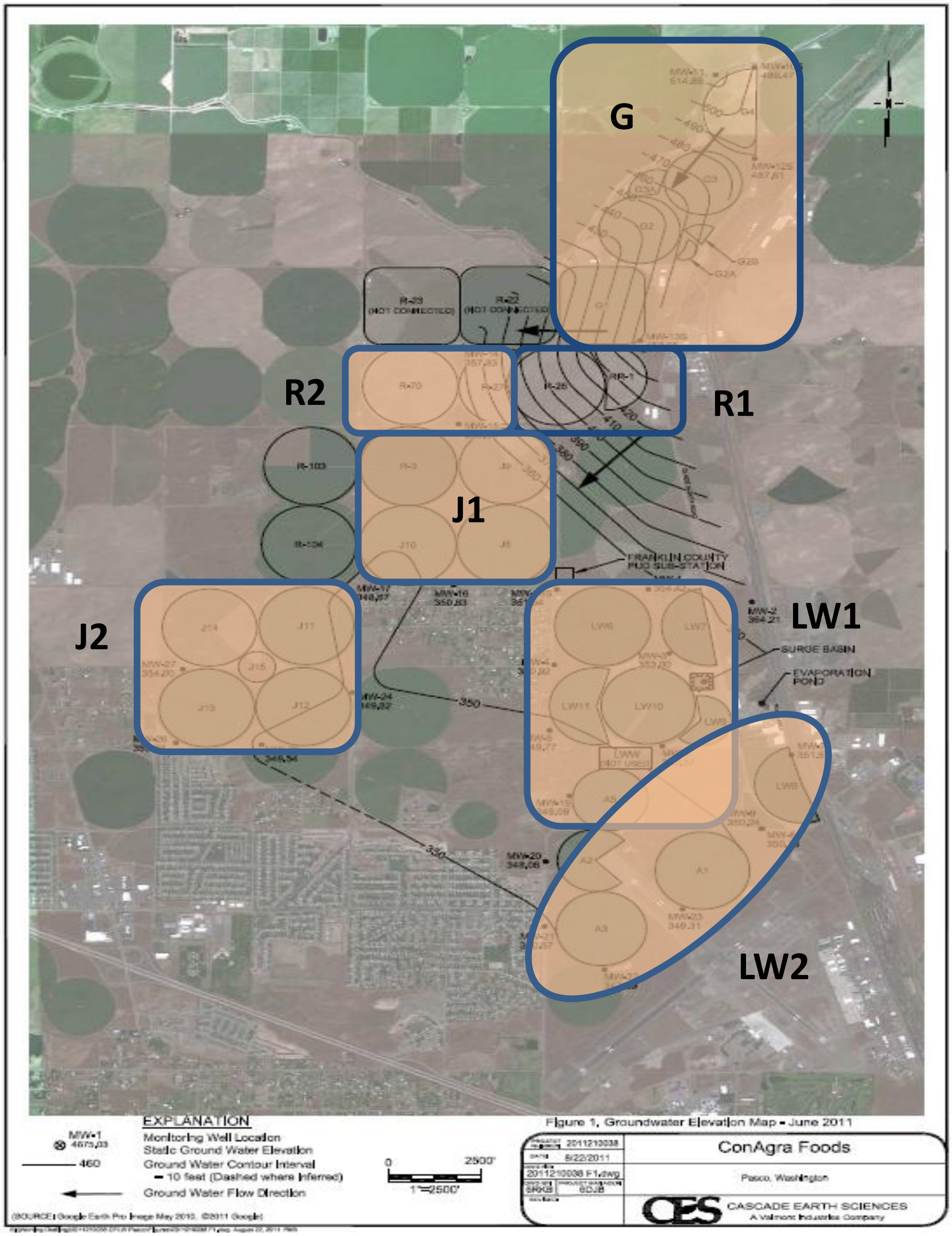

Figure 29. TDS Impacted Fields.

Conclusions

ConAgra Foods Lamb Weston Inc. Pasco (ConAgra) has a large land treatment (sprayfield) site that is extensively monitored. Results of this monitoring provide excellent information for evaluating the performance and impacts of ConAgra's wastewater discharge on the environment.

Impacts to Groundwater Quality

Washington State groundwater quality standards are exceeded (not met) in the Columbia River Basin and at the ConAgra sprayfield site. The definition of groundwater contamination relates to the antidegradation policy as well as established criteria for nitrate and total dissolved solids (TDS) in the groundwater quality standards (Chapter 173-200 WAC). Groundwater is defined as contaminated when it exceeds a groundwater criterion.

Groundwater monitoring is the best way to measure compliance with the groundwater quality standards. ConAgra has 30 monitoring wells and collects over 300 soil nitrate samples every year. Data from this monitoring were evaluated to attempt to distinguish impacts from ConAgra activities from existing regional groundwater contamination.

An evaluation of the groundwater monitoring data from September 2009 to July 2013 indicates the following:

- Groundwater quality in the region has existing elevated nitrate and TDS concentrations.
- Groundwater quality is being further degraded at the ConAgra sprayfield site. This conclusion is based on the following observations:
    - Groundwater collected from 100% of the downgradient groundwater monitoring wells had mean concentrations exceeding the groundwater standard for both nitrate (10 mg N/L) and TDS (500 mg/L).
    - Groundwater collected from 100% of the downgradient wells exceeded the standards for both nitrate and TDS 95% of the time.
    - Groundwater collected from 89% of the downgradient wells consistently had nitrate concentrations that exceeded the standard, and 42% had TDS concentrations that consistently exceeded the standard.
    - All of the downgradient wells exceeded the standards for nitrate and TDS at some point during the evaluation time period. There were no downgradient wells that were consistently below (meeting) the standards.
    - A comparison of groundwater samples collected from upgradient and downgradient monitoring wells across the entire sprayfield site indicated that groundwater from downgradient wells had higher concentrations for both nitrate and TDS.
    - The following sub-areas also had downgradient groundwater concentrations higher than upgradient groundwater concentrations for both nitrate and TDS (Figures 28 and 29):
        - G fields
        - R-2 fields

    - J-1 fields
    - J-2 fields
  - Groundwater collected from downgradient wells from field R-1 exhibited higher nitrate concentrations than upgradient wells, but TDS concentrations were the same upgradient and downgradient.
  - Generally, groundwater collected from downgradient wells from field LW-1 had higher nitrate and TDS concentrations than from all of the upgradient wells, except well MW-4 which was the same as the upgradient.
  - Groundwater collected from the downgradient wells from field LW-2 had higher TDS concentrations than the upgradient wells, and nitrate concentrations were the same for upgradient and downgradient, except for well MW-8 which was lower than the upgradient concentration.

Salt Leaching

The need to leach accumulated salts from the soils creates an increased risk of nitrate being leached to groundwater when additional process water is used to promote leaching of salts.

ConAgra's process wastewater contains an average of 1,913 mg/L of TDS, while fresh irrigation water from irrigation wells contains an average of 558 mg/L of TDS. Use of process wastewater for salt leaching is counterproductive to the goal of improving soil conditions, since the additional load of salt from wastewater will increase salt content in the soil, which in turn increases the leaching requirement. Best management practices (BMPs) for salt leaching recommend using freshwater or precipitation. This avoids introducing additional salts and other contaminants present in the wastewater. Precipitation typically contains 15 mg/L of TDS. (Hem, 1989)

Soil salinity is a recognized issue that needs to be addressed to maintain the health of the soils; however, soil management measures must be consistent with the groundwater quality standards (Chapter 173-200 WAC). The need to leach salts from the soil is not an acceptable reason to contaminate groundwater.

Soil Nitrate

Soil nitrate concentrations indicate increasing trends at 65% of the ConAgra sprayfields. This does not meet the ConAgra-proposed compliance metric of stable or declining soil nitrate trends. Additionally, in 2009 Ecology noted that 8 of the 27 sprayfields used by ConAgra (30%) were achieving this proposed compliance metric.

Evaluating the fall soil nitrate concentration with the following spring soil nitrate concentration is a valuable indicator of whether additional nitrogen applications are necessary during the winter non-growing season. Annual soil data indicate that there is an increasing fall soil nitrate trend for 20 of the 33 fields (61%). This indicates that the residual fall soil nitrate is not being utilized completely by the winter cover crops and that excess nitrogen is accumulating in the soils. It is unknown whether this is from (1) mineralization of organic soil nitrogen, (2) addition of commercial fertilizer, or (3) additional nitrogen loads applied from process wastewater.

Soil Storage

Researchers have cautioned that the practice of storing nutrients in soils during the winter, for use by crops in the spring, poses a risk to groundwater. Mineralization continues during the winter. Climatic conditions such as temperature and precipitation, and subsequently nitrogen transformations, are not elements that can be precisely controlled. These uncontrolled elements can promote nitrate leaching.

If ConAgra were adequately storing excess nitrogen in the sprayfield soils during the non-growing season and capturing it later, it is expected that the following conditions would exist:

- Downgradient groundwater quality would not be elevated above upgradient groundwater quality.
- All fields would have stable or declining fall soil nitrate trends as crops utilize this nitrogen reserve.
- There would not be an increase in soil nitrate from the fall to the spring.

Using the soil horizon within the root zone to store nutrients during the winter poses a risk to groundwater.

Mass Balance

Mass balance calculations are an important tool for managing nutrients and water at this ConAgra land treatment site. Using the most accurate information will generate the best results for effectively managing process wastewater.

Nitrogen Losses

If nitrogen loss assumptions are made, researchers recommend typical volatilization losses of 5% and denitrification losses of 10%. Site-specific studies are important if loss assumptions greater than those recommended by the literature will be used. ConAgra uses a combination of 25% loss for denitrification and 50% for volatilization when they develop the nitrogen mass-balance budget for the fields. If these values are not accurate, nitrogen will be over-applied which creates a risk to groundwater.

The difference in the assumption for the percentage of nitrogen loss is significant (24% to 35%), and this difference results in an average underestimation of nitrogen loading of greater than 202,453 lbs N/year. This possible error in the mass-balance calculation is too great to continue to use without verification. This assumes that large nitrogen losses could result in excessive nitrogen application and impacts to groundwater quality.

Zhao et al. (2006) determined site-specific losses for this sprayfield site of 15% to 20% for volatilization and 4% to 5% for denitrification. These result in combined losses of 8% to 10% total nitrogen loss, with a difference of 27% to 37% from what is used in ConAgra's Irrigation and Crop Management Plans (ICMPs). This results in an average underestimation of nitrogen loading of 217,038 lbs N/year.

Groundwater Recharge

The ICMPs indicate there is minimal leaching from this sprayfield site. However, the conceptual model proposed by ConAgra is not supported by hydrographs, water quality data, and physical hydrogeologic characteristics at this site.

Hydrographs of the static water levels for monitoring wells at this site indicate that groundwater levels are stable, not declining. This provides assurance that the designation of upgradient and downgradient wells is adequate, regardless of the season. However, this is not what is expected if there were minimal recharge over the 3,000-acre sprayfield site.

Reconciling the source of groundwater recharge is a challenge since groundwater underflow for this 3,000-acre site could not physically occur over the course of one year, especially since the subsurface materials are predominantly coarse sediments, with groundwater velocities of 15 to 60 feet/year.

The increasing nitrate and TDS concentrations in groundwater also indicate that the source of recharge water must be occurring where these constituents are present.

Crop Uptake

Crop uptake values average 81% which is above the "extremely high" category typical of agricultural systems. This high rate is indicative of overestimating nitrogen losses.

Consistent Nitrogen Deficit

The ICMPs indicated that the sprayfield was managed over the last four consecutive years with nitrogen deficits for all years, with an average of -105 lbs/ac/year, for a total nitrogen deficit over the sprayfield of -326,820 lbs N/year. This consistent nitrogen deficit is indicative of overestimating nitrogen losses.

Sources of Nitrogen

The literature recommend including all nitrogen sources in the mass-balance calculations to determine application rates (i.e., fertilizer applied by the land owner, residual nitrogen, and mineralized nitrogen).

Compliance Metrics

The compliance metrics suggested by ConAgra to assess environmental impacts of their process wastewater at the sprayfield site are not adequate for (1) evaluating impacts to the environment or (2) preventing degradation of groundwater beneath the site. Additionally, the proposed compliance metric of stable or declining fall soil nitrate levels has not been achieved across the site.

AKART Determination

AKART for land treatment systems is generally considered to be the agronomic application of wastewater and wastewater storage in a lined lagoon during the non-growing season. ConAgra uses their process wastewater to spray irrigate year-round to grow crops. ConAgra does not have a lined lagoon for winter storage, but instead uses the soil horizon to store wastewater and its associated nutrients and salts during the winter. This wastewater management strategy has been in place since 1965.

Ecology considers year-round application of wastewater an alternative treatment option (Ecology, 2004). Ecology determined that prior to approving an alternative treatment option as AKART, it must be demonstrated that the alternative treatment will meet Washington State water quality standards and be at least as protective to groundwater as a conventional or proven treatment technology. Site-specific environmental evidence is a necessary element to demonstrate that an alternative treatment option is achieving the AKART goal.

Continuous elevated concentrations of nitrate and TDS in the downgradient wells higher than the upgradient concentrations, in an area with excessively drained soils and year-round land application, is an indication that this alternative practice is not working as proposed. At ConAgra's sprayfield site, impacts to groundwater quality are evidence that the proposed wastewater treatment system is not adequate for protecting groundwater quality and that the alternative treatment is not equivalent to AKART.

Recommendations

AKART

Since ConAgra applies excessive nitrogen at their land treatment (sprayfield) site, their wastewater treatment process should be re-evaluated to reduce the nitrogen load. Proven precautionary measures that will protect groundwater quality should be used for this site. This can be achieved by the following:

- Discontinue the practice of year-round application of wastewater.
- Apply process wastewater only in amounts and at times necessary to maintain a viable crop.
- Limit process wastewater applications to growing seasons based on established crop, climatic, and site-specific conditions.
- Manage wastewater during the non-growing season without relying on soil storage.
- Specify control and management strategies in the Irrigation and Crop Management Plan (ICMP). This should include all sources of nitrogen including soil nitrogen that mineralizes, residual soil nitrate, and nitrogen that is applied to fields by other land owners.
- Establish control mechanisms for the process wastewater treatment system. Wastewater should be applied only where there is full control over management of the treatment process. These fields are part of the treatment system; therefore, ConAgra should control all additions to these fields.
- Provide additional protection measures in vulnerable aquifers. Regional groundwater quality issues suggest that the aquifer under the sprayfield site is a vulnerable aquifer that requires greater protection.
- Apply freshwater, rather and process wastewater, if salt leaching is required.
- Develop ICMPs using either standard nitrogen losses of 5% volatilization and 10% denitrification or site-specific (Zhao et al., 2006) nitrogen losses of 15% - 20% volatilization and 5% denitrification. If ConAgra believes their nitrogen losses are different, they should conduct a site-specific study to develop defensible site-specific nitrogen loss factors.
- Include ammonium as a constituent to monitor in groundwater.

Compliance

Environmental evidence is needed to verify AKART (All Known, Available and Reasonable Methods of Prevention, Control and Treatment) is being provided at ConAgra's sprayfield site. Enforcement limits are usually established in groundwater as close to the wastewater discharge as technically feasible. Early warning values, in conjunction with enforcement limits established for groundwater, are useful tools to manage process wastewater:

- Early warning values can be established in soil. Soil nitrate should not be used as the sole indicator of groundwater protection. Levels of soil nitrate can indicate when excessive nitrate is present in the soils and poses a risk to leach to groundwater, but soil nitrate levels cannot provide assurance that groundwater has been protected.

- Enforcement limits should be established in groundwater based on upgradient wells either for the entire sprayfield site or for individual sub-areas.

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Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

Antidegradation: Protection of background water quality as defined in WAC 173-200-030.

Contamination: When a constituent of concern exceeds (does not meet) a criterion as defined in Chapter 173-200 WAC.

Effluent: An outflowing of water from a natural body of water or from a man-made structure. For example, the treated outflow from a wastewater treatment plant.

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

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

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

pH: A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

Point source: Sources of pollution that discharge at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites that clear more than 5 acres of land.

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

Root zone: The part of the soil that is or can be penetrated by roots.

Sprayfield site: The land that ConAgra owns or leases to land apply process wastewater for land treatment.

Total dissolved solids: A parameter that represents the total concentration of dissolved material in water.

Volatile dissolved solids (VDS): The organic portion of total dissolved solids which includes sugars and starches

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

Acronyms and Abbreviations

AKART	All Known, Available and Reasonable Methods of Prevention, Control and Treatment
bls	Below land surface
BMP	Best management practices
ConAgra	ConAgra Foods Lamb Weston Inc. in Pasco, Washington
Ecology	Washington State Department of Ecology
GWMA	Groundwater Management Area
ICMP	Irrigation and Crop Management Plan
LW	Lamb-Weston
MW	Monitoring well
N	Nitrogen
POTW	Publicly Operated Treatment Works
TDIS	Total dissolved inorganic solids
TDS	Total dissolved solids – volatile + fixed
TKN	Total Kjeldahl nitrogen
TOC	Top of casing
Tri-Cities	Richland, Kennewick, and Pasco
USGS	U.S. Geological Survey
VDS	(See Glossary above)
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WSU	Washington State University
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams
lbs	pounds

m	meter
mg	milligram
MG	million gallons
mg/d	million gallons per day
mg/Kg	milligrams per kilogram (parts per million)
mg/L	milligrams per liter (parts per million)
mg N/L	milligrams of nitrogen per liter
mL	milliliters
ppm	parts per million
s.u.	standard units
ug/g	micrograms per gram (parts per million)
ug/Kg	micrograms per kilogram (parts per billion)
ug/L	micrograms per liter (parts per billion)
umhos/cm	micromhos per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity

Appendices

The appendices for this report are linked to the report on the web:
https://fortress.wa.gov/ecy/publications/SummaryPages/1503023.html

Appendix A. Nitrate Concentration Time Series Graphs

Appendix B. TDS Concentration Time Series Graphs

Appendix C. Ions Concentration Time Series Graphs

Appendix D. Groundwater Nitrate Trends

Appendix E. Groundwater TDS Trends

Appendix F. Monitoring Well Construction Data

Appendix G. Groundwater Quality Data

Appendix H. Soil Nitrate Profiles and Trends by Field

Appendix I. Hydrographs for Monitoring Wells
(with Overlay of Nitrate and TDS Concentrations)