Appendix E

Analysis of Nitrogen Use Efficiency for Golden Sands Dairy Agricultural Fields

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The application of nitrogen-based fertilizers, manure and crop rotations with leguminous crops provide nitrogen to deficient soils and dramatically augments crop yield. The addition of nitrogen subsidies to food crops is one of the most important contemporary agronomic advancements in meeting global demand for food (Viers and others, 2012). The application of nitrogen to fields in excess of crop needs potentially makes nitrogen available for leaching to groundwater, volatilization to the atmosphere, denitrification and/or surface water runoff.

Historic agricultural practices in the Central Sands region and elsewhere in Wisconsin have been documented to have had adverse impacts on nitrogen concentrations in groundwater. A state wide survey of wells in 2007 indicated that nine percent of the wells in Wisconsin had nitrate concentrations that exceeded the MCL of 10 mg/L. A study of the Central Sands region in the late 1970's concluded that nitrate concentrations in the groundwater of the Central Sands region were significantly above background and that the main source was irrigated agriculture (Saffigna and Keeney, 1977). A detailed study of the impacts of agriculture on groundwater conducted in the Town of Port Edwards in Wood County, just west of the Wisconsin River and the GSD Project Area, in the mid-1990's showed that nitrate concentrations in groundwater were significantly elevated as the result of nitrogen applications to irrigated crops (Kraft and others, 1995). Average nitrate concentrations at the water table beneath these fields were 22.4 mg/L. Deeper groundwater, which was used to irrigate the fields, was reported to have a nitrogen concentration of about 0.5 mg/L.

The key to reducing the potential of nitrogen leaching to groundwater from agricultural fields is to increase nitrogen use efficiency by the agricultural cropping system (U.S. EPA Science Advisory Board, 2011; Harter and others, 2012). The nitrogen use efficiency is defined, in a steady state system, as the proportion of nitrogen inputs that is removed in the harvested crops (Cassman and others, 2002). A steady state system is one in which the organic matter content of the soil is relatively constant, which is typical of agricultural fields that have been cropped for a period of time. In new agricultural fields, or fields with different rotations, the soil organic matter content will be changing with time and this will affect the nitrogen use efficiency. All else being equal, when a higher nitrogen use efficiency is achieved without yield reduction, crops take up more of the applied nitrogen and incorporate it into its biomass, which leaves less of the applied nitrogen at risk for losses via leaching, volatilization or denitrification.

The nitrogen use efficiency is commonly calculated by a partial nitrogen balance[2] in which the common nitrogen inputs and outputs are tabulated. For example, in the Central

[1] This nitrogen analysis was only conducted for agricultural crop fields associated with the GSD Project that are proposed to be converted from pine plantation to vegetable and forage crops.

Valley of California, dairy waste discharge regulations require the preparation of the partial nitrogen balance and require the achievement of a nitrogen use efficiency of no less than 71 percent unless tissue testing indicates the need for additional nitrogen to obtain typical crop yields[3]. In the Town of Port Edwards Study referenced above, the nitrogen in harvested crops averaged 98 lbs/acre per year and the nitrogen input to the fields averaged 261 lbs/acre per year. Thus, the nitrogen use efficiency was 41 percent(110/293); that is, 41percent of the nitrogen input resided in the harvested crop[4].

The crop rotation and management systems for the GSD Project have been designed to maximize, to the extent technically and economically feasible, the nitrogen use efficiency on the GSD Agricultural Fields converted from pine plantation. The crop rotation and cultivation practices to be followed at the GSD Agricultural Fields converted from pine plantation are estimated to achieve a nitrogen use efficiency of approximately 83 percent; that is, the total nitrogen recovery in the harvested crops will be approximately 83 percent of the total applied nitrogen to the crop rotation. If achieved as planned, this will potentially leave only a small amount of the applied nitrogen available for potential leaching to groundwater, volatilization or denitrification.

As has been noted many times in the EIR, all nutrient applications will follow a DNR approved nutrient management plan. The crop rotation and management system as described in the nutrient management plan contains many additional protective management elements that are not required components of a nutrient management plan but are part of the Farming Full Circle concept that will be followed to maximize nitrogen use efficiency at the GSD Agricultural Fields converted from pine plantation. These measures include:

- Rotate crops from year to year and include crops in the rotation that have minimal nutrient requirements (alfalfa, peas, beans);
- Minimize fall applications of manure/fertilizers;
- Maximize multiple in-season application of nutrients such that nutrients are supplied when needed by the crops;
- Analyze plant tissue from crops frequently during growing season to determine nutrient status of the crop and adjust nutrient applications accordingly;
- Plant fall cover crops for additional nutrient uptake and to minimize wind erosion;
- Raise crops, to the extent practicable, in which the harvest removes most of the plant matter (silage, alfalfa);

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[2] Partial nitrogen balance, as used herein, refers to a nitrogen balance that assumes that soil nitrogen content is constant through time.

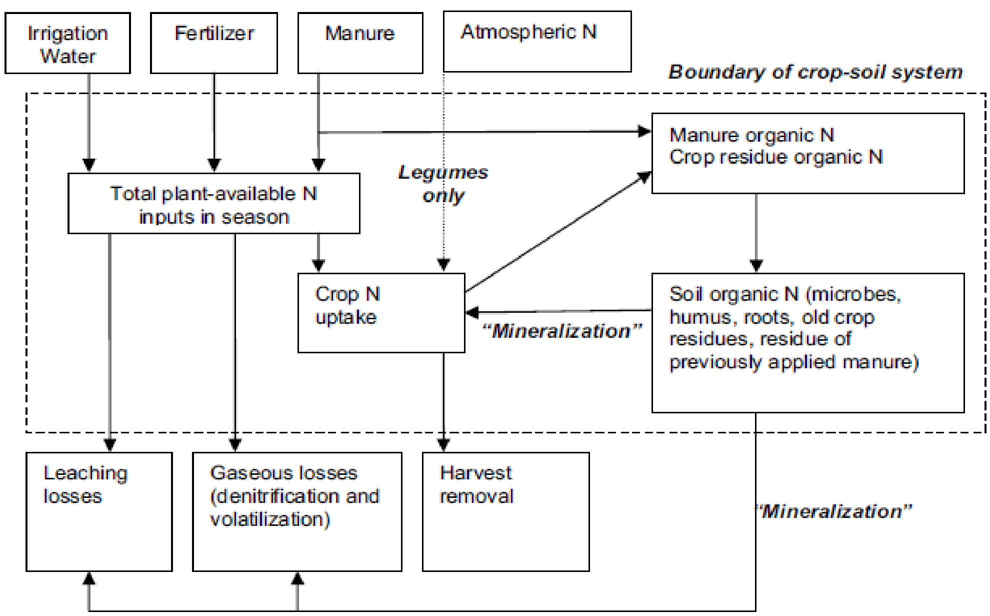
[3] California Regional Water Quality Control Board Central Valley Region, Order No. R5-2007-0035, Attachment C. The Order states: "*Application rates shall not result in total nitrogen applied to the land application areas exceeding 1.4 times the nitrogen that will be removed from the field in the harvested portion of the crop.*"

[4] Potatoes and sweet corn were grown on the fields in this study.

- Raise crops, to the extent practicable, that are deep rooted (corn and alfalfa);
- Manage crops for high yield and uniform stand conditions (single soil type, uniform irrigation application, uniform tillage, uniform nutrient application);
- Use precision planting methods, pest management, promotion of healthy crops, and
- Use manure to increase soil water and nutrient retention capacities and to stimulate microbial activity that increases crop resistance to pathogens and decreases need for pesticides.

These measures go far beyond the requirements of conventional nutrient management plans and are consistent with recommendation of the U.S. EPA Science Advisory Board (USEPA, 2011) for management practices to reduce nitrogen leaching to groundwater and recommendations in a recent report prepared for the California Water Resources Control Board to reduce nitrogen leaching in agricultural areas in California (Harter and others, 2012).

A mass balance is a method of analyzing physical systems by accounting for the amount of material entering and leaving a system of interest. This approach provides a means to approximate flows of materials, such as nitrogen, that otherwise are unknown or difficult to measure. A schematic of the components of the nitrogen balance for an agricultural field are shown below.



In the nitrogen balance shown above, the nitrogen inputs are nitrogen in irrigation water, nitrogen in fertilizer and manure and atmospheric nitrogen. The outputs of nitrogen to the environment are leaching losses, gaseous losses and harvest removal. The components of the mass balance within the rectangle outlined with a dashed line are transfers of nitrogen that occur between the crops, crop residuals and organic matter in the soil.

The nitrogen balance can be used to estimate the nitrogen potentially available for leaching to groundwater by 1) estimating all of the other input and output components except for losses to leaching and 2) assuming that the amount of nitrogen in crops, crop residuals and soil organic matter is constant from year to year. The calculation of the potential nitrate loading to groundwater from a nitrogen mass balance requires as a minimum: 1) estimation of nitrogen inputs to a field including fertilizer, manure, atmospheric sources and nitrogen in irrigation waters ($\mathbf{N_{inputs}}$), and 2) the amount of nitrogen outputs from the fields including nitrogen in harvested crops and atmospheric losses but excluding losses to groundwater ($\mathbf{N_{outputs}}$). The equation used to calculate the nitrogen potentially available for leaching is:

$\mathbf{N_{gw} = N_{inputs} - N_{outputs}}$ where $\mathbf{N_{gw}}$ is the nitrogen in groundwater.

A nitrogen mass balance of this type assumes long-term steady state dynamics of soil nitrogen. That is, the amount of nitrogen mineralized from soil organic matter is equal to that immobilized by microbes. Long-term in this sense is decades or longer. In the initial years of the GSD Project, soil nitrogen concentrations will be increasing as a result of a build up of organic matter as a result of manure applications. During this period, the nitrogen available to leach to groundwater will be less than indicated by the equation above as some of the applied nitrogen will go into storage in the soils.

In calculating the nitrogen potentially available for leaching to groundwater with the equation listed above, it is important to note that any uncertainty in the estimation of the terms in $\mathbf{N_{inputs}}$ and $\mathbf{N_{outputs}}$ is propagated to the estimate of $\mathbf{N_{gw}}$. As a result, the estimate of $\mathbf{N_{gw}}$ may have a large uncertainty associated with it.

A partial nitrogen balance was calculated for the converted GSD Agricultural Fields using the best available data to estimate long-term average nitrogen inputs and outputs from the converted agricultural fields. This estimate is referred to as the "most likely" estimate. The uncertainties associated with this estimate and a "best case" and "worst case" estimate are described in the final section of this appendix. The estimated annual partial nitrogen balance for the GSD Agricultural Fields converted from pine plantation based on the best estimates of mostly likely conditions is the following:

$\mathbf{N_{inputs}}$ = 287 lbs/acre

N in manure and fertilizer	231 lbs/acre
N from atmospheric fixation	48 lbs/acre
N from atmospheric deposition (wet and dry)	6 lbs/acre
N in irrigation water	1.6 lbs/acre

$\mathbf{N_{outputs}}$ **=** 250 lbs/acre (excluding leaching to groundwater)

N in harvested crops	239 lbs/acre
N in ammonia volatilization	11 lbs/acre
N losses from denitrification	0 lbs/acre
N atmospheric losses from plants	0 lbs/acre

Thus, the most likely potential nitrogen loss to groundwater is approximately 37 lbs/acre per year ($\mathbf{N_{gw} = N_{inputs} - N_{outputs}}$ = 287 – 250 = 37). The nitrogen use efficiency for the converted GSD Agricultural Fields, based on the nitrogen balance numbers listed above, is approximately 83 percent (239 lbs/acre in harvested crop divided by total nitrogen application of 287 lbs/acre). The nitrogen balance for the converted GSD Agricultural Fields is based on a crop rotation that includes alfalfa, corn silage, grain corn, sweet corn, peas and snap beans. A summary of estimated nitrogen use efficiency for the planned crop rotation at the Golden Sands Dairy and nitrogen use efficiencies by crops in the rotation is listed on Table 1. Estimated crop nitrogen use efficiencies vary from a low of 42 percent for peas to over 100 percent for alfalfa, and the overall nitrogen use efficiency of 83 percent is the result of a planned rotation that contains crops with very high nitrogen use efficiencies and crops with lower nitrogen use efficiencies. The analysis of potential impacts of the nitrogen loss to groundwater quality is presented below.

The methods and sources of information used to estimate the components of the nitrogen balance for the converted GSD Agricultural Fields are described in detail below.

Nitrogen in Manure and Fertilizer

The estimated nitrogen content in fertilizers and manure expected to be applied to each of the crops to be grown at the GSD is based on data from fields associated with the Central Sands Dairy[5]. The nitrogen and other nutrient application rates for fields associated with the Central Sands Dairy are listed on Table 1. The estimated amount of nitrogen to be applied to the converted GSD Agricultural Fields, by crop, is listed on Table 2. Since the cropping and dairying systems planned at the GSD are the same as at the Central Sands Dairy, the use of these data are scientifically appropriate.

Nitrogen from Atmospheric Fixation

Legumes, such as alfalfa, peas and beans, have specialized root structure onto which the bacteria *Rhizobium* attaches and converts nitrogen gas from the atmosphere into amino acids that the plants can use for growth. The conversion of nitrogen gas requires a significant contribution of energy from the plants and thus legumes use available nitrogen in the soil in preference to obtaining nitrogen by fixation (Lindemann and Glover, 2012; Feaga and others 2010). Alfalfa with its deep root system has been found to be very effective at capturing and utilizing nitrogen within the soil profile (Russelle, 2004). Because peas and snap beans have a short growing season and are harvested immature peas and snap beans generally obtain almost of all their nitrogen from available soil nitrogen when it is sufficient to supply their nitrogen demands. The amount of nitrogen fixed by alfalfa from the atmosphere was estimated by Mathews and Crohn (2010a, 2010b) as 20 percent of the nitrogen present in the harvested crop for estimating nitrogen balances on agricultural fields in California. For purposes of this analysis, it was assumed that first year alfalfa would utilize 60 lbs/acre of nitrogen in the soil from mineralization of plant residue and soil organic matter with atmospheric fixation equal to the difference

[5] The total nitrogen content in manure was used in calculating the nitrogen application rates for the crops. The use of total nitrogen is essential for purposes of calculating a nitrogen balance. In the Nutrient Management Plan, manure application rates are based on plant available nitrogen which is defined as a percentage of the total nitrogen per an algorithm in University of Wisconsin Extension Publication A2809 (Laboski and Peters, 2012). Thus, the nitrogen application rates described in this Appendix, which are based on total nitrogen content in manure, differ from the nitrogen application rates described in the Nutrient Management Plan, which are based on plant available nitrogen.

between nitrogen in the harvested crop and applied nitrogen plus nitrogen from the soil. For second year alfalfa, and for first cut alfalfa prior to planting sweet corn, it was assumed that there would be no available nitrogen in the soil and thus the amount of atmospheric fixation is equal to the amount of nitrogen in the harvested crop minus the nitrogen applied. Snap beans and peas were assumed to fix negligible amounts of nitrogen.

Nitrogen from Atmospheric Deposition

The amount of nitrogen in atmospheric deposition is estimated to be 6 lbs/acre per year based on data from the U.S. EPA's Clean Air Status and Trends Monitoring Network (CASTNET). The 6 lbs per year represents the average annual total nitrogen deposition measured at Stockton, Illinois and Perkinstown, Wisconsin for the period 2003 through 2012. The two CASTNET stations are the closest stations to the GSD project. Total nitrogen deposition includes both nitrogen in precipitation and nitrogen in dry atmospheric deposition.

Nitrogen in Irrigation Water

The nitrogen concentration is estimated to initially be about 0.5 mg/L in the irrigation water for the converted GSD Agricultural Fields. The concentration is not expected to increase significantly for at least the first ten years of operation.

Nitrogen in Harvested Crops

The estimated nitrogen content of the crops that will be grown on the converted GSD Agricultural Fields (alfalfa, potatoes, corn silage, field corn, sweet corn, peas, and snap beans) is listed on Table 2. The planned crop rotation for the converted GSD Agricultural Fields is that in each year approximately 35 percent of the acreage will be planted in alfalfa, 20 percent will be planted in potatoes, 18 percent will be planted in corn for silage, 5 percent will be planted in corn for grain, 12 percent will be planted in alfalfa that will be cut prior to end of May with fields then planted in sweet corn, and 10 percent of fields will be doubled cropped with peas followed by snap beans. The planned crop rotation was initially based on that followed at the Central Sands Dairy and evolved through several iterations to maximize nitrogen use efficiency to the extent technically and economically feasible.

The amount of nitrogen in harvested crops is a function of the crop yield and the nitrogen content of the crop. The average yields expected on the converted GSD Agricultural Fields were estimated based on current yields on fields farmed by the Wysocki Family of Companies in the vicinity of the Central Sands Dairy. Limited data are available on average nitrogen content in harvested crops. In addition, nitrogen content is a function of many factors (including yield, cultivation practices, climate and other factors) and thus varies from year to year and field to field. The sources of information used to estimate average nitrogen content of crops planned for cultivation on the converted GSD Agricultural Fields are described below and are listed on Table 2. The estimated amount of nitrogen in harvested crop per unit of harvested crop are listed on Table 2 and the total amount of nitrogen estimated in the harvested crop for each of the crops in the rotation cycle at the converted GSD Agricultural Fields are listed on Table 3.

Alfalfa – The nitrogen content of alfalfa was estimated as 60 lbs per ton of harvested crop. An average crude protein content of 22.5 percent in alfalfa, based on data from Central Sands Dairy, was used to derive this estimate of nitrogen content.

Potatoes – The nitrogen content of potatoes was estimated at 0.37 lbs per 100 pounds of potatoes. This estimate is based upon data obtained in recent field studies at the Hancock Agricultural Research Station (Bero and others, 2013a and 2013b). Recent work at the University of Wisconsin suggests nitrogen content can range from about 0.34 lbs to about 0.46 lbs per 100 pounds of potatoes (AJ Bussan, personal communication, 2014). A nitrogen content of 0.37 lbs per hundred pounds of potatoes is consistent with a crude protein content of 2.25 percent in the harvested potatoes.

Corn Silage – The nitrogen content of corn silage was estimated as 10.6 lbs per ton of silage based on feed analyses at Central Sands Dairy. This value is consistent with nitrogen content of mature corn plants determined in a study of nitrogen uptake by corn by Mengel (1995) at Purdue University.

Field Corn – The nitrogen content of field corn was estimated as 0.9 lbs per bushel based on data on the UW Extension Corn Agronomy web site(http://corn.agronomy.wisc.edu/Management/L025.aspx).

Sweet Corn – The nitrogen content of sweet corn was estimated as 8.16 pounds per ton based on data from unpublished studies at the University of Wisconsin (personal communication, Bussan, AJ, Department of Horticulture, 2014; and personal communication, Ruark, M, Department of Soil Sciences, 2014).

Peas – The nitrogen content of peas was estimated as 17.3 lbs per ton. This estimate is based on a protein content of 5.42 percent in shucked raw peas on a fresh weight basis and a nitrogen content in the protein of 16 percent (protein content estimate from Del Monte Foods).

Snap Beans -- The nitrogen content of snap beans was estimated as 8.7 lbs per ton based on data from unpublished studies at the University of Wisconsin (personal communication, Bussan, AJ, Department of Horticulture, 2014; and personal communication, Ruark, M, Department of Soil Sciences, 2014).

Nitrogen from Volatilization

Ammonia losses from manure applied to the GSD Agricultural Fields was estimated using an ammonia volatilization model developed at Clemson University (Chastain, 2006). The estimated ammonia losses average 11 lbs/acre per year. The method used to estimate ammonia volatilization is discussed in detail in Section 2.6.4 of the EIR.

Nitrogen in Ammonia Losses from Plants

Several researchers have observed significant ammonia losses directly from plants. Francis and others (1993) analyzed nitrogen fertilizer recovery in irrigated corn by nitrogen isotope techniques and concluded that 40 to 72 lbs of nitrogen per acre was lost as the result of direct volatilization from plants. As there are little data in the literature to substantiate the reported observations, for purposes of calculating a nitrogen balance for the GSD Agricultural Fields this term was set to zero.

Nitrogen losses from Denitrification

The soils at the converted GSD Agricultural Fields are low in soil organic matter content and are well drained. As a result, denitrification losses of nitrogen are expected to be small though unlikely to be zero. We are not aware of studies that have quantified denitrification rates at agricultural fields in the Central Sands. Therefore, for purposes of calculating a nitrogen balance for the converted GSD Agricultural Fields no denitrification was assumed to occur. In practice, the application of manure will create locally within the soil anaerobic conditions conducive to denitrification.

Potential Impacts on Groundwater

The most likely potential loss of 37 lbs/acre per year of nitrogen to groundwater is equivalent to a nitrogen concentration of approximately 8 mg/L in the water that infiltrates beneath the rooting depth of the plants and recharges the groundwater table[6]. In the groundwater, almost all of the nitrogen will be present as nitrate. In the initial years of farming the converted GSD Agricultural Fields, some of the nitrogen applied as manure will go into storage in the soils. As a result, the most likely average annual potential loss to groundwater will be less than 37 lbs/acre. The most likely loss to groundwater is also likely to be less than 37 lbs/acre because potential losses of nitrogen directly from the plants and from denitrification have been assumed to be zero.

We are aware of only one study in Wisconsin, the Port Edwards study described above, that has attempted to determine the relationship between the amount of nitrogen estimated to be lost to groundwater from irrigated fields and the actual loss that occurs. In the Port Edwards study the calculated nitrogen loss to groundwater from the nitrogen balance analysis was 163 lbs/acre per year, which is equivalent to a calculated nitrogen concentration in the water that infiltrates to the water table below the irrigated fields of 37 mg/L. In the study, nitrogen concentrations at the water table were measured in water samples collected from monitoring wells constructed across the water table, and average nitrogen concentrations at the water table were determined to be 22.4 mg/L.[7] Thus, the nitrogen loss to groundwater calculated with the nitrogen balance overestimated the actual amount of nitrogen at the water table by about a factor of 1.65. This overestimation likely occurred either because nitrogen losses to the atmosphere were underestimated and/or nitrogen was accumulating in the soil zone during the period of the study. This result suggests that the most likely nitrogen losses estimated for the converted GSD Agricultural Fields from a nitrogen balance may also result in an overestimate of nitrate concentrations in groundwater.

Nitrogen concentrations in groundwater downgradient of the converted GSD Agricultural Fields will be less than the concentrations that occur at the water table directly beneath the agricultural fields because of mixing with groundwater in storage and mixing with

[6] The average recharge rate beneath the irrigated fields is estimated to be 20.5 inches per year as described in Appendix B to the EIR.

[7] The estimate of 163 lbs/acre per year is based on data collected in 1992 and 1993 at four irrigated fields. Data were collected from one of the fields for two additional years. The calculated average annual nitrogen loading to groundwater beneath this field for the two additional years was calculated to be 162 lbs/acre/year and average nitrate concentration at the water data was monitored at 20 mg/L (Stites and Kraft, 1997).

groundwater originating upgradient of the fields. The nitrogen concentrations that could occur in residential wells, if any, downgradient of the converted GSD Agricultural Fields is a function of time after start of farming activities, location of residential well, and location of screened interval of domestic well relative to the water table.

The groundwater model described in Appendix B of the EIR, in conjunction with the computer model MT3D, was used to estimate nitrogen concentration in groundwater downgradient of the converted GSD Agricultural Fields. MT3D is the most commonly used groundwater transport model and it was used in tandem with MODFLOW to evaluate potential migration of nitrogen in groundwater. The model was set up such that the nitrogen concentration in groundwater was specified at background levels and the model was run for 50 annual irrigation cycles with recharge beneath the irrigated fields specified with the estimated most likely nitrogen concentration of 8 mg/L. Dispersion in the model domain was specified as zero. In the model, nitrogen concentrations in groundwater reached steady state after twenty years.

The results of the modeled most likely scenario indicated that nitrogen concentrations in a hypothetical well located approximately 300 feet downgradient of the edge of the westernmost converted GSD Agricultural Fields gradually increase during the first twenty years after irrigation begins and then reach a relative steady concentration of about 3.4 mg/L.

The potential for increases in nitrate concentrations in Sevenmile Creek and Tenmile Creek from the application of nutrients to the converted GSD Agricultural Crop Fields was quantitatively evaluated also using the groundwater flow model described in Appendix B of the EIR. The groundwater flow model was used to delineate the contribution area for the perennial reach of Sevenmile Creek between Rangeline Road and County Road Z and the contribution area for the perennial reach of Tenmile Creek between County Road U and County Road Z. These contribution areas define the surface area where the groundwater discharging to the streams in these reaches originates from infiltrating precipitation and irrigation waters. For purposes of this analysis it was then specified that water infiltrating to the water table beneath the converted GSD Agricultural Crop Fields would have an average nitrate concentration of 8 mg/L and that precipitation infiltrating elsewhere in the contribution areas would have a nitrate concentration at background concentrations. During periods when Sevenmile Creek is dry upstream of Rangeline Road, it was calculated that the average nitrate concentration at County Road Z would increase from 0.3 mg/L under existing conditions to 1.6 mg/L after approximately 20 years of production at the converted GSD Agricultural Crop Fields. Average nitrate concentration in Tenmile Creek under existing conditions at Rangeline Road is approximately 3.8 mg/L and this average concentration is calculated to increase to about 4.15 mg/L after about 20 years of production at the converted GSD Agricultural Crop Fields.

Uncertainties in the Analysis

There are a number of significant uncertainties in the most likely estimate of potential nitrogen leaching to groundwater described above. As a result of these uncertainties it is possible that the actual nitrogen leaching to groundwater could be less than or greater than described above. The primary reasons why the “most likely” estimate might overestimate the actual nitrogen leaching is because future changes in cultivation practices and varietal changes were not considered as the nitrogen use efficiency was assumed to be constant with time, denitrification and direct atmospheric losses from crops were assumed to be negligible, and changes in soil nitrogen content as organic matter accumulates in the soils were not considered in the analysis. Primary reasons why the “most likely” estimate might underestimate that actual nitrogen leaching are that it considers average conditions and may not appropriately factor in nitrogen losses that could occur as the result of crop failures and unexpected precipitation events.

It is very likely that the nitrogen use efficiency of the converted GSD Agricultural Fields will increase with time as the result of improvements in the ability to synchronize nitrogen delivery with crop demands and in the ability of crops to utilize nitrogen. Nitrogen use efficiency has increased dramatically in the last decades and improvements are likely to accelerate in the future with advances in understanding and ability to modify the building blocks of plant proteins. A review of improvements in nitrogen use efficiency by corn over the past few decades is described in Ciampitti and Vyn (2013). The improvements in nitrogen use efficiency that will occur in the future were not considered in the development of the nitrogen balance primarily because the magnitudes of the changes that will occur are unknown. A realistic consideration of likely changes in nitrogen use efficiency indicates that potential losses of nitrogen to groundwater will gradually decrease with time.

In the “most likely” nitrogen balance described above, the only nitrogen losses considered from the fields was nitrogen in the harvested crops, ammonia volatilization, and leaching to groundwater. It is very possible that other significant losses have not been included such as denitrification and direct atmospheric losses from the plants. As noted above, in the nitrogen balance prepared for the Port Edwards Study there were apparently some significant losses that were not included in the analysis as the measured groundwater concentrations implied that nitrogen leaching as calculated by the nitrogen balance approach was overestimated by a factor of 1.6. Denitrification was specified in the “most likely” estimate of potential nitrogen leaching as negligible because the organic matter content in the subsurface materials beneath the GSD Agricultural Fields currently is low and no studies have quantified the magnitude of denitrification in groundwater in the Central Sands. A study of groundwater conditions in the Central Sands near Stockton by Kraft and others (2004) found some evidence for denitrification in groundwater, though the amount of denitrification appeared to be small except possibly in areas treated with manure. Saad (2008) in a study of nitrate in groundwater in the Central Sands suggested that some denitrification may occur in deeper groundwater. As the organic matter content in the soils at the GSD Agricultural Fields increases with time as the result of manure applications, denitrification will be enhanced and may become an important component in the nitrogen balance.

To evaluate the potential impact of both an overestimate and underestimates of nitrogen losses to groundwater in the “most likely” estimate of the nitrogen balance a “best-case” scenario and a “worst-case” scenario were evaluated. In the best-case scenario, it is assumed that technological improvements will occur within the fifty year period that brings this nitrogen balance to steady state, such that the long term potential impacts to groundwater are reduced. It is estimated that in a best-case scenario, the potential nitrogen loss to groundwater could be one-half the amount estimated in the "most likely" scenario. Best-case circumstances include, but are not limited to:

- Higher yield and nitrogen recovery rates than expected due to varietal changes and/or other technological improvements;
- Water management and weather prediction technologies improve to allow better planning and management to avoid leaching due to precipitation events;
- Alfalfa roots mining more nitrogen from the soil than is currently and conservatively assumed to leach in the "most likely" scenario;
- Improvements in cover crop ability to capture applied nitrogen and retain it until the following growing year; and
- Improvements in nitrogen inhibitor technology.

In the worst-case scenario, it is assumed that technology will not improve at all within the fifty year period that brings this nitrogen balance to steady state. The worst-case scenario also assumes significant crop losses, which if realistic would also assume significant economic losses that could not be sustained for a fifty year period. In sum, the worst-case scenario described herein is extremely unlikely to occur. It is estimated that in a worst-case scenario, the potential nitrogen loss to groundwater could be twice the amount estimated in the "most likely" scenario. Worst-case circumstances include, but are not limited to:

- Significant and consistent crop failures and yield reductions beyond those assumed in the "most likely" scenario;
- Significant and consistent rainfall events ("climate change") greater than those assumed in the "most likely" scenario; and
- Lower yield and nitrogen recovery rates than expected due to varietal changes and/or other technological issues.

In the "best-case" scenario, the potential nitrogen loss to groundwater is 18.5 lbs/acre per year, which results in a nitrate concentration of 4 mg/L in the water that infiltrates beneath the rooting depth of the plants and recharges the groundwater table. The resulting calculated groundwater concentration in a hypothetical well located 300 feet downgradient of the converted GSD Agricultural Fields is 2 mg/L after 20 years of agricultural activities. The average annual nitrate concentration in Sevenmile Creek increases after 20 years to about 0.95 mg/L and the average annual nitrate concentration in Tenmile Creek increases to about 3.9 mg/L.

In the "worse-case" scenario, the potential nitrogen loss to groundwater is 74 lbs/acre per year, which results in a nitrate concentration of 16 mg/L in the water that infiltrates beneath the rooting depth of the plants and recharges the groundwater table. The resulting calculated groundwater concentration in a hypothetical well located 300 feet downgradient of the converted GSD Agricultural Fields is 8 mg/L after 20 years of agricultural activities. The average annual nitrate concentration in Sevenmile Creek increases after 20 years to about 3 mg/L and the average annual nitrate concentration in Tenmile Creek increases to about 4.6 mg/L.

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Table 1
Crop Yields, Nitrogen Applied, and Nitrogen in Harvested Crops
Central Sands Dairy

Crop	Yield (per acre)		Nitrogen Applied (lbs/acre)			Nitrogen in Harvested Crop	Comments
	Average	Range	Average	Range for Manure	Range for Fertilizer		
alfalfa	5.5 tons	4.3-6.2	178	6-64	110-158	60 lbs/ton	CSD data
potatoes	485 cwt	215-627	412	1-174	281-431	0.37 lbs/cwt	Ruark, UW data
corn silage	25.4 tons	17.3-28.7	265	14-156	100-262	10.8 lbs/ton	CSD data
field corn	230 bu	152-279	265	14-156	100-262	0.9 lbs/bu	UW data
sweet corn	9.8 tons	7.5-12	204	32-167	97-236	8.16 lbs/ton	UW data
peas	2.5 tons	1.8-3.3	100	50-155	31-115	17.3 lbs/ton	Del Monte Foods
snap beans	7.3 tons	5.7 - 11.1	121	11-189	114-147	8.7 lbs/ton	UW data

Table 2

Crop Yields, Nitrogen Applied, and Nitrogen in Harvested Crops Central Sands Dairy[1]

Crop	Yield (per acre)		Average Nitrogen Applied (lbs/acre)[2]	Nitrogen in Harvested Crop
	Average	Range		
alfalfa	5.5 tons	4.3-6.2	178	60 lbs/ton[3]
potatoes	485 cwt	215-627	412	0.37 lbs/cwt[4]
corn silage	25.4 tons	17.3-28.7	265	10.6 lbs/ton[5]
field corn	230 bu	152-279	265	0.9 lbs/bu[6]
sweet corn	9.8 tons	7.5-12	204	8.16 lbs/ton[7]
peas	2.5 tons	1.8-3.3	100	17.3 lbs/ton[8]
snap beans	7.3 tons	5.7 - 11.1	121	8.7 lbs/ton[9]

Notes:

1. The crop yields and nitrogen application rates reported on this table are based on 2013 data from lands farmed by the Wysocki Family of Companies in Juneau County.
2. The average nitrogen application rates are based on the total nitrogen content in the manure and in the fertilizers applied to the crops. Fields generally received some nitrogen from manure and some from fertilizers. The table lists ranges in the amount of nitrogen in the manure and in the fertilizer applied to individual fields in Juneau County.
3. An average crude protein content of 22.5 percent in alfalfa, based on data from Central Sands Dairy, was used to derive the estimate of nitrogen content in alfalfa.
4. This estimate is based upon data from recent field studies at the Hancock Agricultural Research Station (Bero and others, 2013a and 2013b). Recent work at the University of Wisconsin suggests nitrogen content can range from about 0.34 lbs to about 0.46 lbs per 100 pounds of potatoes (AJ Bussan, personal communication, 2014). A nitrogen content of 0.37 lbs per hundred pounds of potatoes is consistent with a crude protein content of 2.25 percent in the harvested potatoes.
5. The nitrogen content of corn silage was estimated based on silage feed analyses at Central Sands Dairy.
6. The nitrogen content of field corn was estimated as 0.9 lbs per bushel based on data on the UW Extension Corn Agronomy web site (http://corn.agronomy.wisc.edu/Management/L025.aspx).
7. The nitrogen content of sweet corn was estimated based on data from unpublished studies at the University of Wisconsin (personal communication, Bussan, AJ, Department of Horticulture, University of Wisconsin, 2014; personal communication, Ruark, M., Department of Soil Science, University of Wisconsin, 2014).
8. The nitrogen content in peas is based on a protein content of 5.42 percent in shucked raw peas on a fresh weight basis and a nitrogen content in the protein of 16 percent (protein content estimate from Del Monte Foods).
9. The nitrogen content of snap beans estimated from unpublished studies at the University of Wisconsin (personal communication, Bussan, AJ, Department of Horticulture University of Wisconsin, 2014; personal communication, Ruark, M., Department of Soil Science, University of Wisconsin, 2014).