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Review of Six Potato Processing Facilities in The Columbia Basin, Washington

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ABSTRACT

In 1994 concerns regarding the adequacy of permits authorizing the land application of process waste water at six major potato processing facilities were received by the Washington State Department of Ecology. In response to those concerns the Department conducted a comprehensive review of the adequacy of the six State Waste Discharge Permits and the spray field management techniques required by these permits to protect ground water as a drinking water source. The findings of this review indicate the current permits are adequate to protect ground water quality in and around the spray field area. Furthermore, the review confirmed spray fields are operating within requirements set forth in these permits. The evolution of current permit conditions coupled with past facility management practices; however, has resulted in overloading of nitrate-nitrogen compounds to some spray fields. As a result of the practices at these spray fields, localized nitrate contamination of ground water has occurred. There exists no current evidence that spray field operations conducted as specified in past or present permit conditions has resulted in contamination of either off site domestic or community water supply wells.

Introduction

In 1994, the US Environmental Protection Agency raised concerns regarding the adequacy of state issued permits to sufficiently protect ground water quality at the Lamb-Weston potato processing plants located in Connell, Pasco and Richland, Washington; the Nestle Brands potato processing plants located in Moses Lake and Othello, Washington; and the McCain Foods potato processing plant located in Othello, Washington. These concerns were raised in part due to recently published reports by the US Geological Survey indicating elevated concentrations of nitrate in ground water in localized areas throughout the mid-Columbia Basin.

As a result of these concerns and a desire by the Washington State Department of Ecology to assess the effectiveness of it's current land application permits, a comprehensive review was conducted at the facilities in question. This review assessed the adequacy of each permit to protect ground water quality and the degree to which implementation of the permit conditions had on ground water quality in areas near the facility.

The review consisted of an examination of both past and present operations and permit conditions for each of the six facilities. Operational records, environmental monitoring data, and annual spray field management reports were analyzed to determine 1) if past management practices applied to permitted spray fields resulted in either on-site or off site contamination of ground water sources used for drinking water supplies, 2) if current management practices are resulting in either on-site or off site contamination of ground water sources used for drinking water supplies, and 3) the future effects to current ground water quality given completion of planned facility upgrades.

The review indicates there is evidence to support the contention that previous facility operations and permit conditions resulted in localized overloading of nitrate-nitrogen compounds to areas used for the spray irrigation of process waste water. It is likely that as a result of these practices, localized nitrate contamination of ground water has occurred. However, there exists no current evidence that spray field operations conducted as specified in past or present permit conditions has resulted in contamination of either off site domestic or community water supply wells.

Current practices, as mandated by the permits, have significantly reduced effluent strength, reduced or eliminated winter application of process waste water, and improved cropping scheduling to maximize plant uptake of both water and nitrogen compounds. Taken together these improvements have resulted in sharp reductions of hydraulic and nutrient loading to spray field areas.

140 million gallons from winter spray field application and substantially reduce excess hydraulic and nitrogen loading to the spray field area.

Nestle Brands at Moses Lake, Washington

In 1994 Nestle Brands installed a 215 million gallon storage pond to contain wastewater during the non-growing season. As of 1995, winter application of process waste water has been halted. An additional 3,800 acres of land to apply waste water has been added to the permitted facility area during the 1993-1994 period. This acreage will be increased to 7201 acres beginning with the issuance of the 1996 State Waste Discharge Permit.

Nestle Brands at Othello, Washington

In 1989 a 260 million gallon storage pond was installed which has provided the ability to limit or eliminate winter application of process waste water. Application of process waste water has be halted during periods when the ground is frozen or crop irrigation requirements are extremely minimal. Considerable waste water treatment and conveyance system improvements to the facility have recently been made.

McCain Foods at Othello, Washington

McCain has upgraded the irrigation system and increased spray irrigated land from 500 acres to over 3700 acres. Commitment has been made to replace the storage lagoon during 1996. A two year study is currently underway to assess the impacts to ground water caused by leakage from the existing unlined storage lagoon. New mud facilities, which replace existing mud ponds, will be in service by June 1995.

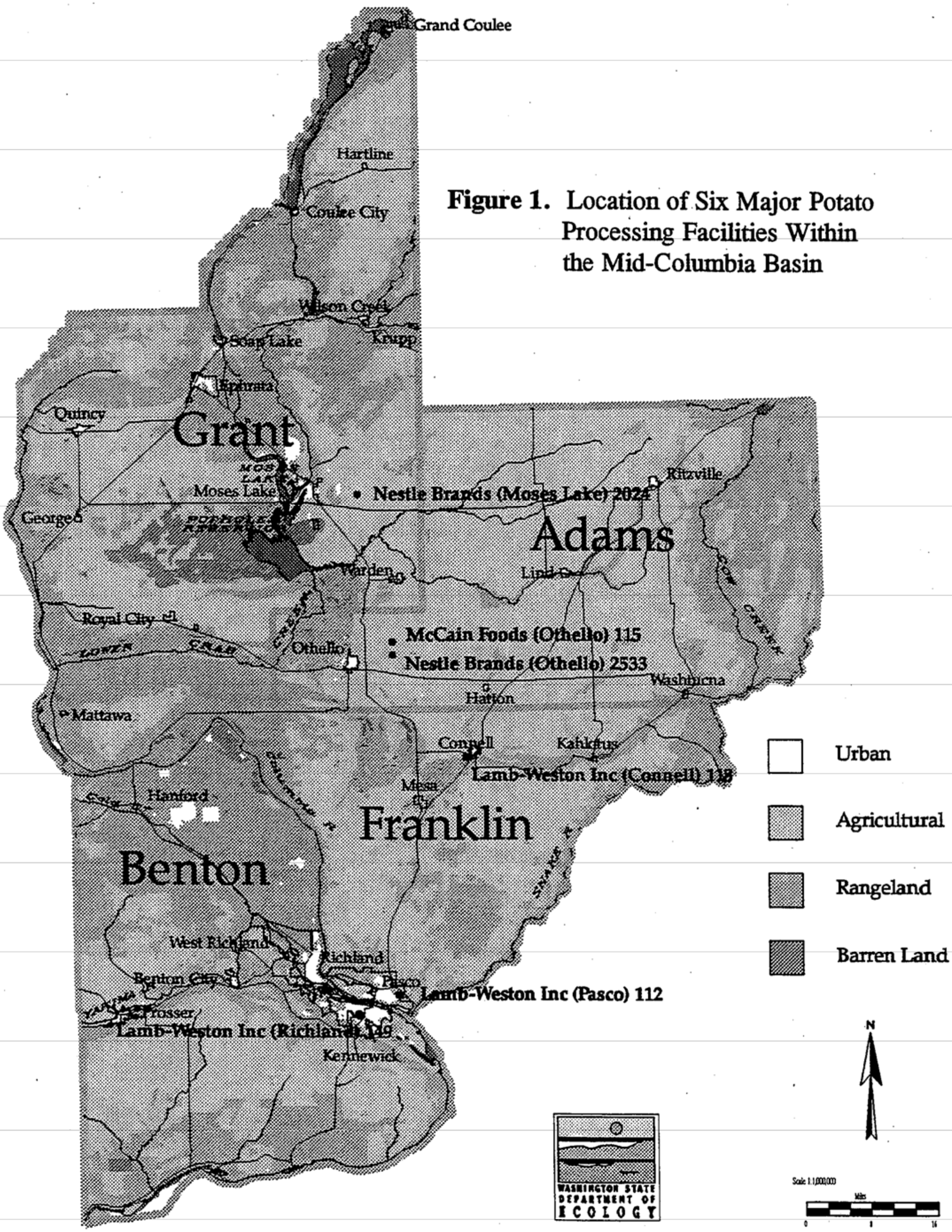


Figure 1. Location of Six Major Potato Processing Facilities Within the Mid-Columbia Basin

II. Assessment of Facility Performance

The performance of each facility is directly related to two items mandated in each specific facility permit. These items are the adequacy of process waste water pre-treatment processes and the adequacy of each facility's mandated spray field management plan.

To determine whether a facility is meeting the permit requirements for ground water quality protection, it is necessary to understand the importance of the spray field management in determining both hydraulic and nitrogen loading to the spray field. As a condition of each permit a facility is required to produce a management plan which sets forth the limits to which hydraulic and nitrogen loading may take place while maintaining ground water quality in accordance with the State's ground water quality standards. The management plan specifies operational practices which include loading rates and application schedules of both irrigation water and nitrogen based on the nutrient concentration of the process waste water, acreage of land used, crop type, and process waste water distribution methodology.

The goal of the management plan requirement is to prevent an excess in hydraulic and nitrogen loading beyond that required to maintain healthily crop growth such that the leaching of nitrogen through the soil column into the underlying ground water does not occur.

The following is a review of the adequacy of each management plan for the period 1993-1994 and explanation of methodologies used to develop these plans. This period represents the latest time at which full implementation of current permit conditions have been incorporated into each facilities spray field management plan.

IIA. Spray Field Hydraulic Loading

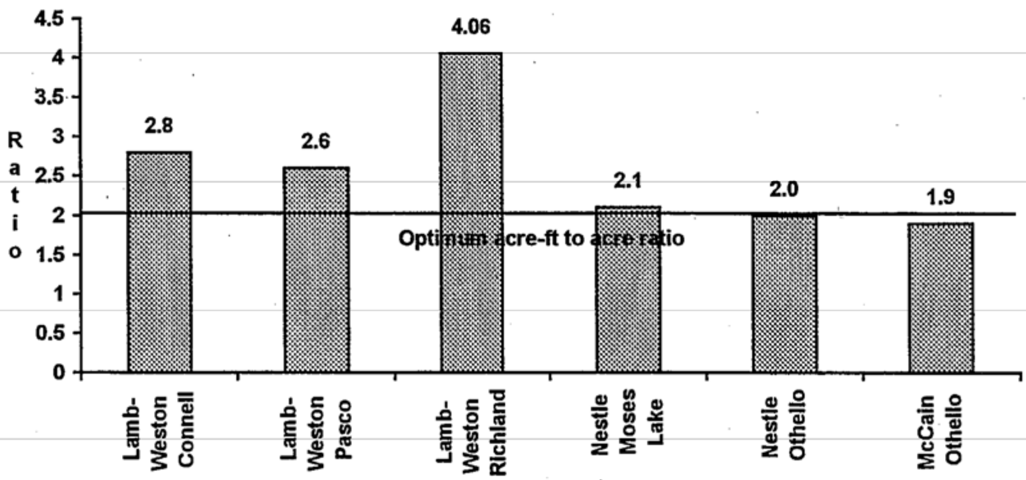
Facility spray field loading for each of the six potato processing facilities is based on several key factors. These include the size of the application area, type of crop to be raised, the geographic location of the application area, and method of delivery for the process waste and supplemental irrigation water.

<u>Application Area</u>

The size of the area to which process waste water is applied is an important factor in the design of an irrigation schedule which is protective of the ground water resource. The subject facilities each, produce from 1.0 to 2.5 million gallons per day of process waste water. The permitted acreage available to each facility for the application of process waste water varies greatly from 3722 acres at the McCain-Othello facility to 330 acres at the Lamb-Weston Richland facility. Generally, for the six facilities in question, the optimum application ration of irrigation water to spray field area is 2:1[1]. The irrigation water applied (both process waste water and supplemental irrigation water) to available application acreage ratio is illustrated in Figure Two.

As illustrated in Figure Two, hydraulic loading decreases as available land on which to apply irrigation water increases (as indicated by the decreasing water applied to acreage ratio). As the hydraulic loading decreases, so does the potential for excess moisture to migrate below the root zone into the uppermost saturated zone and with it excess nitrogen and/or agricultural chemicals. Agricultural requirements of irrigated areas necessitate some degree of moisture loss to the saturated zone to achieve leaching of nutrient salts required to maintain long term healthily plant growth within the spray field area. These salts originate from the process waste water being applied to the spray field and include potassium, calcium, magnesium, sodium, chloride, sulfate, and bicarbonate. Generally, this leaching is on the order of 8-10 percent of the total applied irrigation water but vary according to soil conditions and crop tolerance. A majority of the leaching occurs during the winter months when precipitation is high and crop water usage is low.

Figure 2. Ratio of Total Irrigation Water Applied (acre-ft) to Available Permitted Acreage



Note: Total Application quantities calculated based on 75% irrigation efficiency (April-October) and 85% efficiency (November-March).

Crop Selection

Crop selection, both the percentage of the permitted acreage dedicated to a specific crop and the specific crop type, are keys to achieving a well managed spray field. In order to achieve a goal of minimal loss of water to the saturated zone, spray field

1 This ratio is based on a weighted average of crops and their specific irrigation requirements as provided in Table One. At this ratio the average spray field irrigation requirements will be satisfied without excess water avalible for leaching below the vadose zone.

management plans require areas be cropped with deep rooted plants with large irrigation requirements (CIRs). Generally, the crops of selection by the six potato processing facilities is alfalfa and/or wheat. During the 1993 -1994 period 60 percent of the approximately 11,200 acres of spray field area was planted in either alfalfa, wheat, or a combination of the two. Table One presents the CIRs for crops grown in spray field areas at the six facilities during the 1993 - 1994 period.

Table 1. Average C I R's for Selected Crops in the Columbia Basin *

Specific Crop	Irrigation Requirements (Inches)
Alfalfa	33
Potatoes	30
Hay Grass	28
Wheat	26
Corn	22
Peas	22

* Totals are based on growing season water requirements (usually April through September). Requirements are based on averages of published data from Washington State University, Washington Cooperative Extension Service, and the US Natural Resource Conservation Service.

Crop irrigation requirements vary according to the time of year and geographic location of the specific spray field area. These factors, in turn, effect critical parameters used in the calculation of evapotranspiration and specific CIRs which form the basis for the establishment of hydraulic loading limits.

<u>Methodology for the Calculation of Hydraulic Loading</u>

Hydraulic loading for 1993-1994 was analyzed using facility data for total water application to spray fields obtained from individual discharge monitoring reports for the period. Crop irrigation requirements were calculated using the Blaney-Criddle formula (Appendix Three). Soil moisture changes were taken from the annual crop management reports for all the reviewed facilities.

<u>Facility Specific Water Budgets</u>

Each of the six potato processing facilities was required to prepare a spray field management plan, as specified in the individual State Waste Discharge Permits, which was designed to allow for application of process waste water without degrading ground water quality. These management plans consider size of the permitted spray field area, water usage of the specific crop or crops grown within the spray field area, and the method used to deliver process waste water to the spray field. The results of the performance of each of the six facilities is presented in Figures 3A-F.

Excess application, through either irrigation or normal precipitation is indicated when total irrigation exceeds the sum of the crop irrigation requirements (CIRs) and soil moisture requirements (SMRs). During these periods, leaching of excess moisture to the uppermost aquifer can be expected.

Figure 3A. 1993 - 1994 Water Budget at Lamb - Weston Connell, Washington

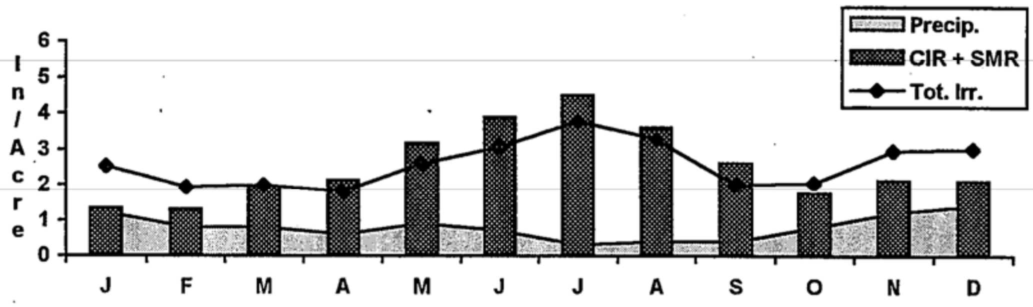


Figure 3A indicates that excess application of irrigation water[2] occurred during the 1993 - 1994 period. This excess was limited to the months of October - February. During this period approximately 3.9 inches of excess water was applied to the spray field area. This represents an excess of 35 percent of the moisture necessary to maintain crop growth and acceptable soil moisture.

Figure 3B. 1993 - 1994 Water Budget at Lamb - Weston Pasco, Washington

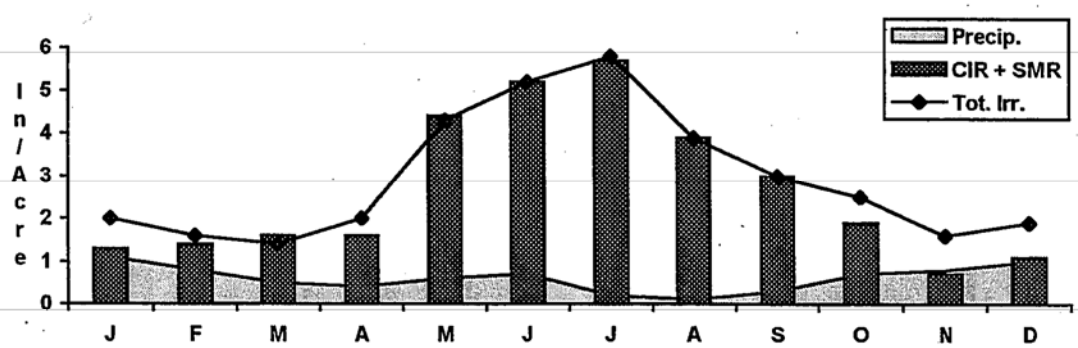


Figure 3B illustrates that excess application of irrigation water occurred during the months of October - February for period 1993-1994. Excess application during the month of April is considered to be a result of utilizing a weighted average of irrigation application for 1993 - 1994 and is not considered to be a routine occurrence. Total excess application to the spray field area is calculated to be

2 **For all facilities:** Excess application of irrigation water is determined based on Crop Irrigation Requirements (CIR) and Soil Moisture Requirements (SMR). Excess water required to leach soil salts is factored into determination of an irrigation excess or deficit. Factoring in soil salt leaching requirements will generally reduce irrigation excesses by 8% - 10% of the total CIR+SMR.

approximately 2.9 inches. This represents an excess of 25 percent of the total irrigation water applied to the spray field area for the October - February period.

Figure 3C. 1993 - 1994 Water Budget at Lamb - Weston Richland, Washington

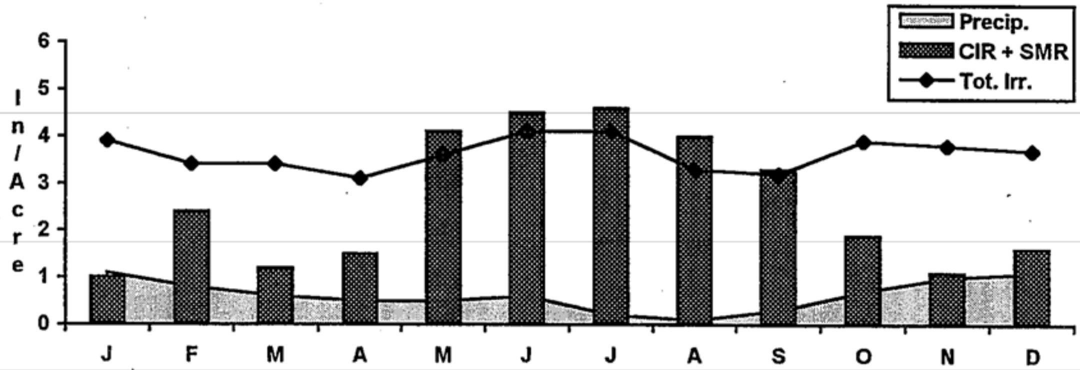


Figure 3C indicates a significant over application of irrigation water occurred at the Richland facility. Excess irrigation water application has occurred during the months of October - April for the 1993-1994 period. During this time approximately 15.4 inches of excess water was applied to the spray field area. This figure represents a 143 percent excess over what was required to maintain crop growth and acceptable soil moisture, for this time frame. Based on the results illustrated in the figure above, it can be expected that significant leaching of water has occurred past the vadose zone into the uppermost aquifer.

Figure 3D. 1993 - 1994 Water Budget at Nestle Brand Foods Moses Lake, Washington

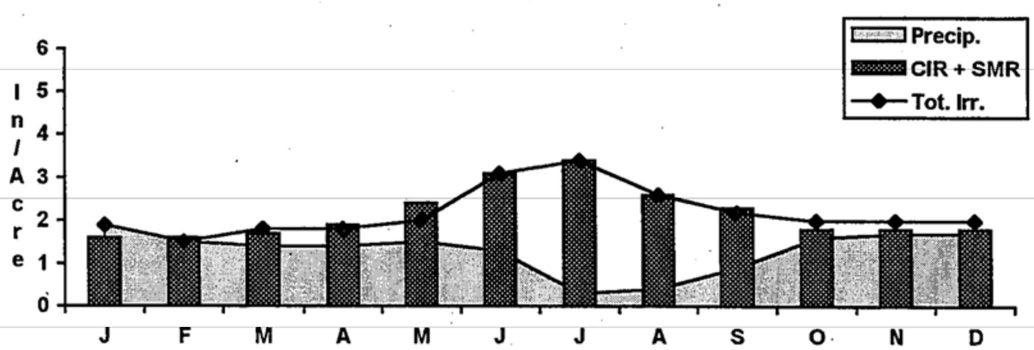


Figure 3D illustrates an over application of irrigation water for the period of October - December of 1993-1994. Winter application of process waste water did not occur during the months of January and February. During the October - December period approximately .6 inches of excess irrigation water was applied to the 3003 acre spray field area. This figure represents a 10 percent excess over what is required to maintain crop growth and acceptable soil moisture for the period November - February.

Figure 3E. 1993 - 1994 Water Budget at Nestle Brand Foods Othello, Washington

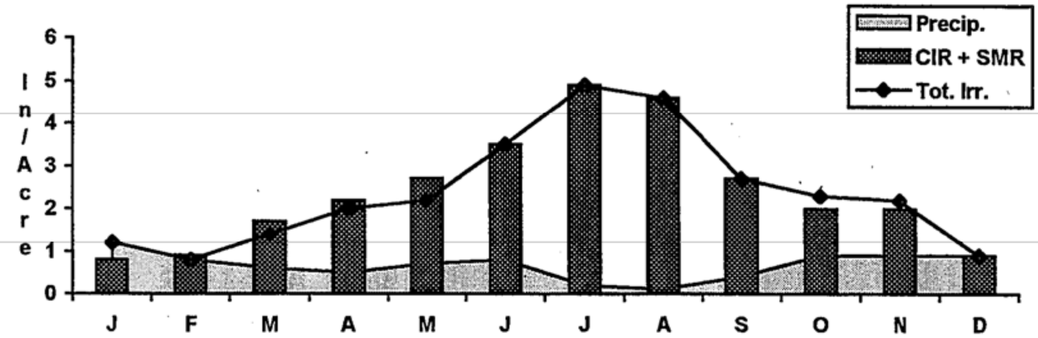


Figure 3E illustrates a small over application of irrigation water which occurred during the period October - November of 1993-1994. During the months of December and February normal precipitation meets CIRs. In January normal precipitation exceeded CIRs by .4 inches. During the period of October - November approximately .5 inches of excess irrigation water is applied to the permitted spray field area. During this two month period the excess irrigation water was 12 percent above that required to maintain crop growth and acceptable soil moisture.

Figure 3F. 1993 - 1994 Water Budget at McCain Foods Othello, Washington

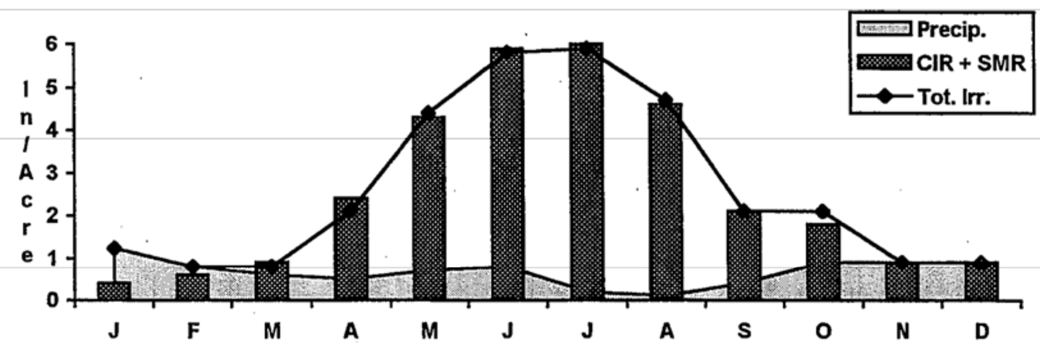


Figure 3F indicates a small over application of irrigation water occurred during the month of October for the 1993 -1994 period of approximately .3 inches. Over application of irrigation water does not occur during the months of November - February as found at several of the processing facilities. Normal precipitation does exceed CIRs during the months of January - February and is potentially leached to the uppermost aquifer in some areas of the 3722 acre spray field.

<u>Summary</u>

Hydraulic loading for four of the six potato processing spray fields appear to be acceptable in terms of protecting underlying ground water quality given the soil salt leaching requirements necessary to maintain agricultural viability of the spray field area. These facilities, Lamb-Weston at Pasco, Nestle Brands Foods at Moses Lake and Othello, and McCain Foods at Othello all appear to have been managed such that excessive hydraulic loading, beyond that required to maintain long term crop health and soil moisture, was not a significant concern. The Lamb-Weston facility at Connell, Washington appeared to be close to reaching acceptability.

The Lamb-Weston facility located in Richland, Washington was hydraulically overloading the permitted spray field by as much as twice that which was occurring at the other five facilities. The Richland facility operates the most constrained, permitted area, of the six facilities. The overloading which was occurring at Richland offers significant potential for leaching of both nutrient and chemical contaminants to underlying ground water. Modifications to process waste water management techniques at Connell and Richland will (beginning in 1996) eliminate any future excess hydraulic loading, particularly during the winter months.

IIB. Spray Field Nitrogen Loading

Nitrogen loading to spray fields occurs as a result of the presence of nitrogen containing compounds in potato processing waste water which is applied to the land surface. Generally, the compounds of concern contained in process water are ammonia nitrogen (NH_3-N), organic nitrogen expressed as total Kjeldahl nitrogen[3], and nitrate-nitrogen (NO_3^--N). These compounds contain the basics necessary for the microbiological production of nitrate (NO_3^-), which if produced above levels of crop uptake, can leach into underlying aquifers.

Methodology for the Calculation of Nitrogen Loading

Crop nitrogen requirements were calculated using published fertilizer application guides from the Washington State University and Oregon State University Cooperative Extension Services. These values were compared with individual crop nitrogen removal rates supplied by each facility and calculated for individual process water application areas. The average annual values for crop nitrogen requirements is presented in Table Two.

The hydraulic loading from the applied process waste water combined with any supplemental fresh water used in irrigation, was converted into pounds of nitrogen applied by considering the average concentration of total Kjeldahl nitrogen (TKN) and nitrate-nitrogen (NO_3-N) in both the process water and fresh water applied to the spray field area. Ammonia (NH_3-N) loading is accounted for within the results of the TKN analysis.

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3 The total Kjeldahl nitrogen method determines nitrogen in the tri-negative state. It does not account for nitrogen in the form of nitrate or nitrite. The method does account for ammonia nitrogen (NH_3-N) and organic forms of nitrogen.

Table 2: Average Crop Nitrogen Requirements in the Columbia Basin

Specific Crop	Nitrogen Requirements Lbs./Acre/Yr.
Alfalfa	425
Hay Grass	270
Potatoes	210
Corn	185
Wheat	140
Beans	67
Peas	50

Actual nitrogen loading to the specific crops, was considered by factoring in a range of 25 - 30 percent loss due to denitrification, mineralization, and volatilization of nitrogen applied to spray fields through the application of process waste water and supplemental irrigation water. The results of the calculated loading were then compared to the crop nitrogen requirements, based on a weighted average of crop type and acreage, to determine whether operational practices had resulted in a gross nitrogen surplus or deficit.

Facility Specific Nitrogen Budgets

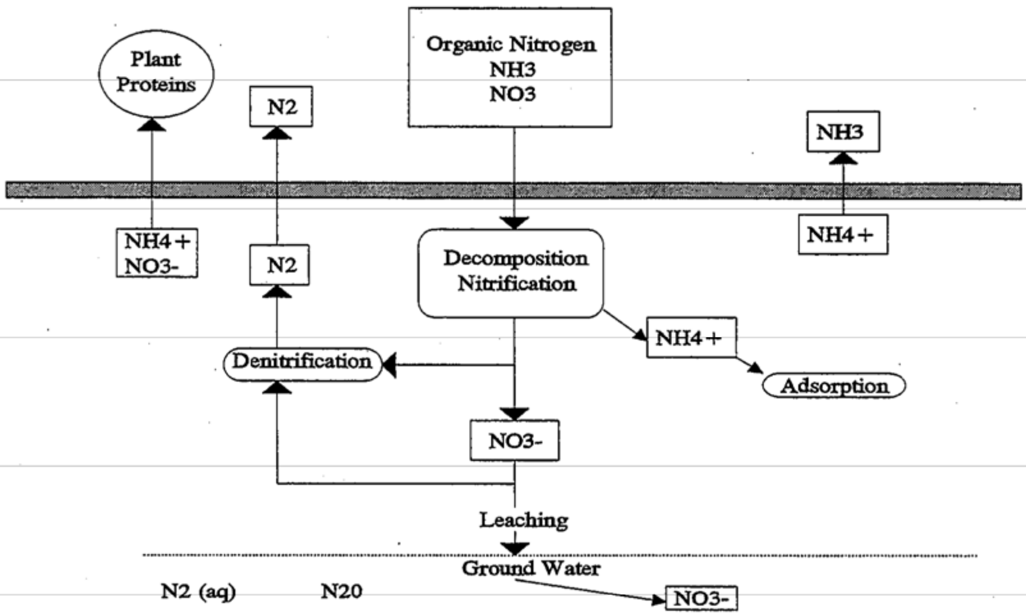
Each of the six potato processing facilities were required, as conditions of the permit, to prepare a spray field management plan which is designed to allow for application of nitrogen and other nutrients contained in irrigation water, without degrading ground water quality[4]. Generally, the main focus of these plans is the nitrogen loading as it is considered to represent the largest potential source for ground water contamination. As is the case with the hydraulic loading management plans, the nitrogen management plans must consider several factors.

Spray field nitrogen loading rates are calculated based on the amount of total nitrogen, contained in irrigation water, which when transformed to nitrate ($NO3^-$), nitrogen gas ($N2$) and ammonium ($NH4^+$)[5] either remain in the soil, pass into the atmosphere or leach into underlying ground water. In order to have an effective nitrogen management plan, the nitrogen loading limit must not exceed the total nitrogen utilized by the farmed crop, lost to the atmosphere, and/or adsorbed by the soil. These considerations are illustrated in Figure 4.

4 The requirement to prepare a yearly Spray Field Management Plan continues as part of each facility's current State Waste Discharge Permit.

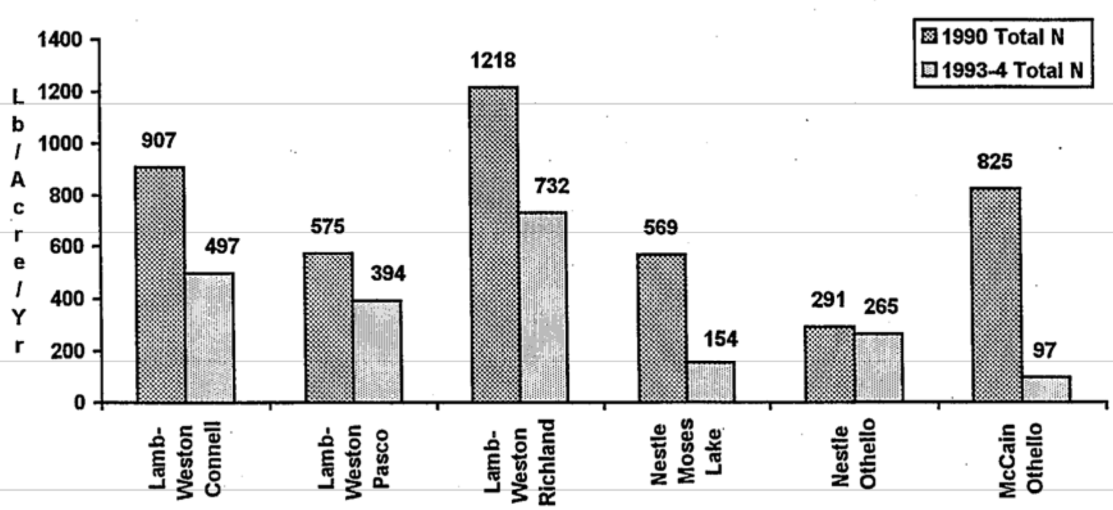
5 Transformation of nitrogen containing compounds in process and supplemental irrigation water is achieved through mircobiological activity under favorable conditions. A detailed description of the fate of nitrogen applied to the land surface can be found in Groundwater, pp 413-415: Freeze and Cherry (1979)

Figure 4. Fate of Nitrogen Compounds at Potato Processing Facility Spray Fields
(from Freeze and Cherry, 1979)



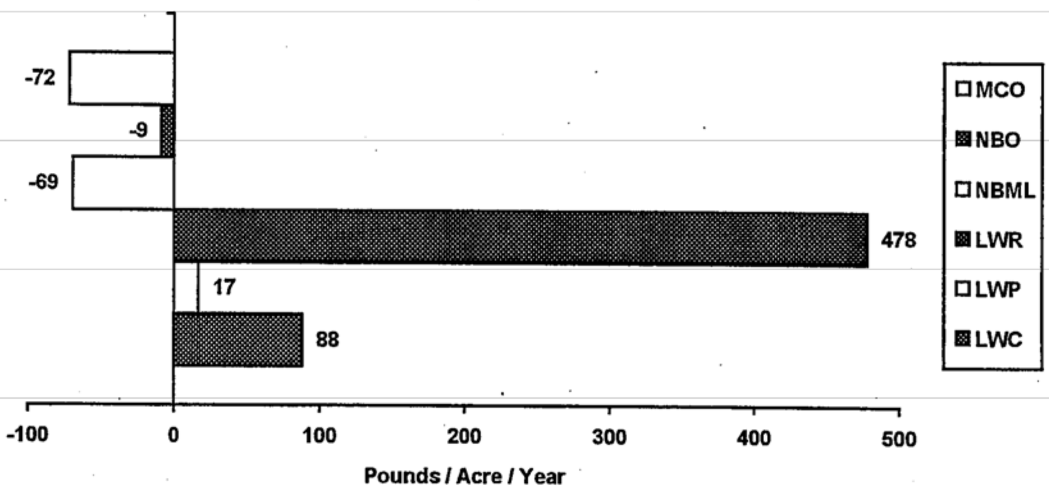
A review of gross nitrogen loading for each of the six potato processing facilities reveals a decline during the period 1990 - 1994, Figure 5. Anticipated improvements in process waste water treatment and land acquisition for the Lamb-Weston facilities and Nestle Brands at Moses Lake, by 1997, are expected to reduce 1993-1994 nitrogen loading rates by 29 percent to 355 lb./acre at Lamb-Weston, Connell; 42 percent to 227 lb./acre at Lamb-Weston, Pasco; 90 percent to 41 lb./acre at Lamb-Weston, Richland and 64 percent to 64 lb./acre at Nestle Brands, Moses Lake.

Figure 5. Total Loading of Nitrogen to Spray Field Areas 1990 - 1994



Spray fields for which an excess nitrogen and hydraulic loading has been calculated are the facilities to be considered at risk for the presence of ground water contamination due to nitrate. An estimate of the degree to which nitrate may leach into underlying ground water can be obtained through an analysis of nitrate and organic nitrogen contained within the soil column and ground water underlying the spray field. Estimates for nitrate-nitrogen losses at the three facilities exceeding crop nitrogen requirements during the 1993 - 1994 period range from 5 - 10 percent of the total excess applied[6]. It can be expected that some degree of ground water contamination has occurred as a result of the nitrate loss through the unsaturated zone.

Figure 6. Average Nitrogen Loading Excess / Deficit



<u>Summary</u>

Excess nitrogen loading of spray fields has occurred during the 1993 - 1994 period at three of the six potato processing facilities. The degree to which excess nitrogen has been applied has declined dramatically since 1990. Continued reductions in nitrogen loading is anticipated at several facilities due to improvements in process waste water pre-treatment and expansion of spray field application areas. The potential for ground water contamination to have occurred at facilities for which excessive loading has occurred is increased as a result of that nitrogen overloading. It is estimated that between 5 - 10 percent of the excess nitrogen applied to these spray field areas will leach as nitrate-nitrogen into shallow ground water underlying the respective spray fields. In some cases the percentage of lost nitrogen which may potentially become nitrate-nitrogen is significant. However, the exact amount of this leached nitrate-nitrogen entering underlying ground water can vary significantly depending upon site specific conditions.

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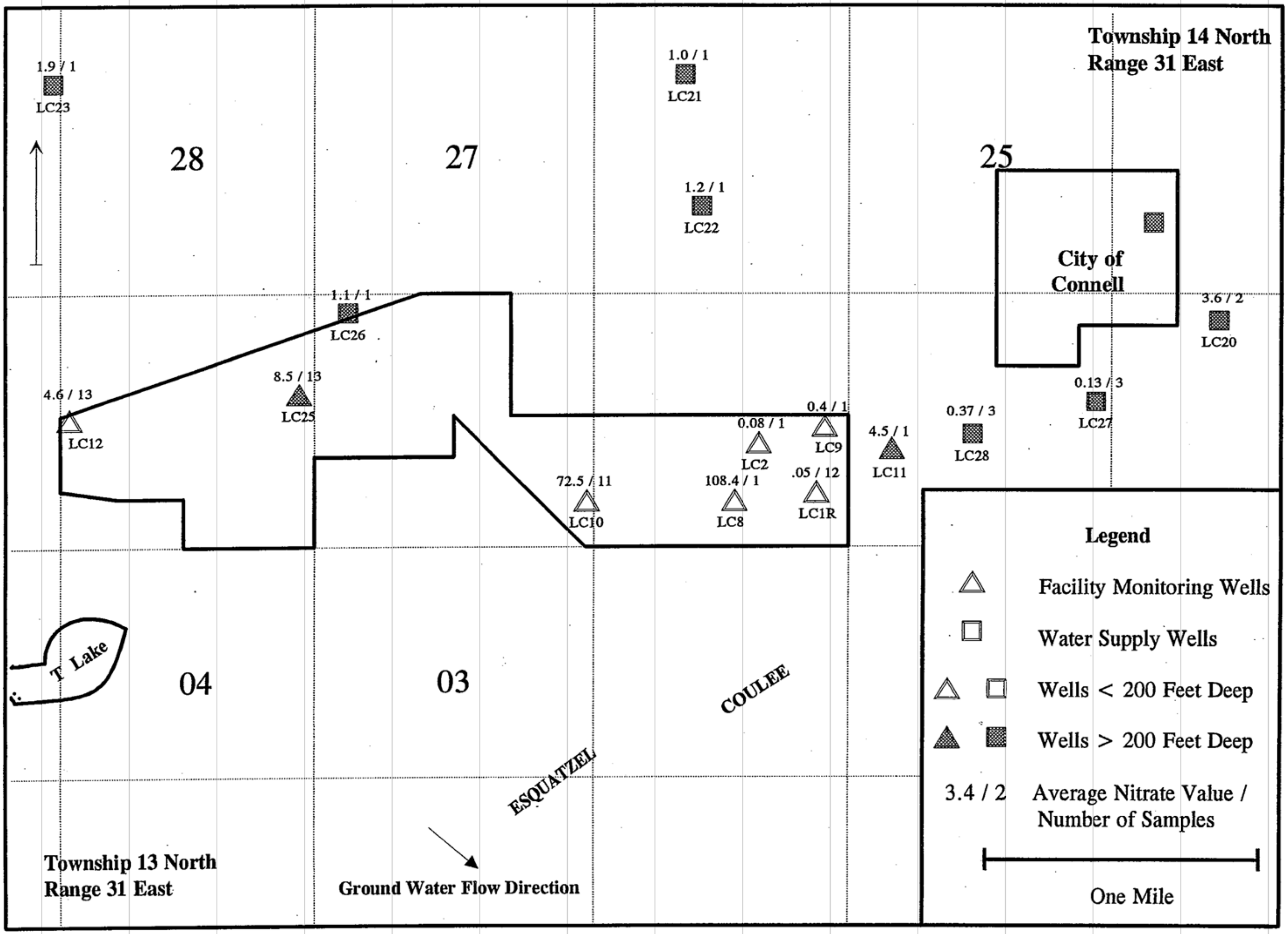
6 Percentage is derived from the calculation of nitrogen loadings for specific fields and compairing those figures with nitrate-nitrogen monitoring of various soil depths beneath the fields and reconciling that data with ground water monitoring results for well located within the specific field.

Figure 7. Process Water Application Area   Lamb-Weston at Connell, Washington



IIC. Ground Water Quality

Lamb-Weston at Connell

The hydrogeology of the Lamb-Weston facility at Connell has been characterized as required under provisions of the current State Waste discharge permit. The characterization document[7], completed in 1991, is based largely on the results of information acquired during installation of monitoring wells in January 1990 and June 1991. The current monitoring system consists of 12 specially constructed wells and one water supply well[8]. The existing monitoring system is capable of monitoring the two uppermost aquifer units underlying the facility area. These wells are required to be monitored on a quarterly basis for parameters specified under the current permit. Monitoring wells MW-2, MW-8, MW-9, MW-10, and MW-12 are installed in the surficial aquifer which extends to approximately 80-100 feet below land surface and exists under water table conditions. This aquifer appears to be discontinuous across the spray field area. Monitoring wells MW-1R, MW-11, and the Farm Well are installed in the underlying aquifer which exists at approximately 160 - 200 feet below land surface. Ground water flows underneath the Connell facility in an east-southeasterly direction at a gradient of .013 ft/ft.

Analysis of the ground water monitoring results collected from the period 1993 - 1994 indicated a statistically significant increase of nitrate above background for five of the downgradient monitoring wells. Wells demonstrating an impact and violating the Maximum Contaminant Level (MCL) of 10 mg/l for nitrate, were MW-2, MW-8, MW-10, and the Farm Well. Monitoring wells MW-1R, and MW-9, had not been significantly impacted. Monitoring well MW-11, while demonstrating a statistically significant increase over background water quality, did not demonstrate a violation of the Maximum Contaminant Level (MCL) of 10 mg/l for nitrate.

Records for eleven private or community water supply wells were identified within a one mile radius of the facility spray field. Of these, seven wells had nitrate analysis conducted within the past five years. This data was reviewed to determine if spray field management practices had resulted in impacts to water quality. These wells are located within basalt aquifers and range in depth from 330 to 1133 feet below land surface. A summary of recent nitrate data collected from these water supply wells is presented in Appendix Two.

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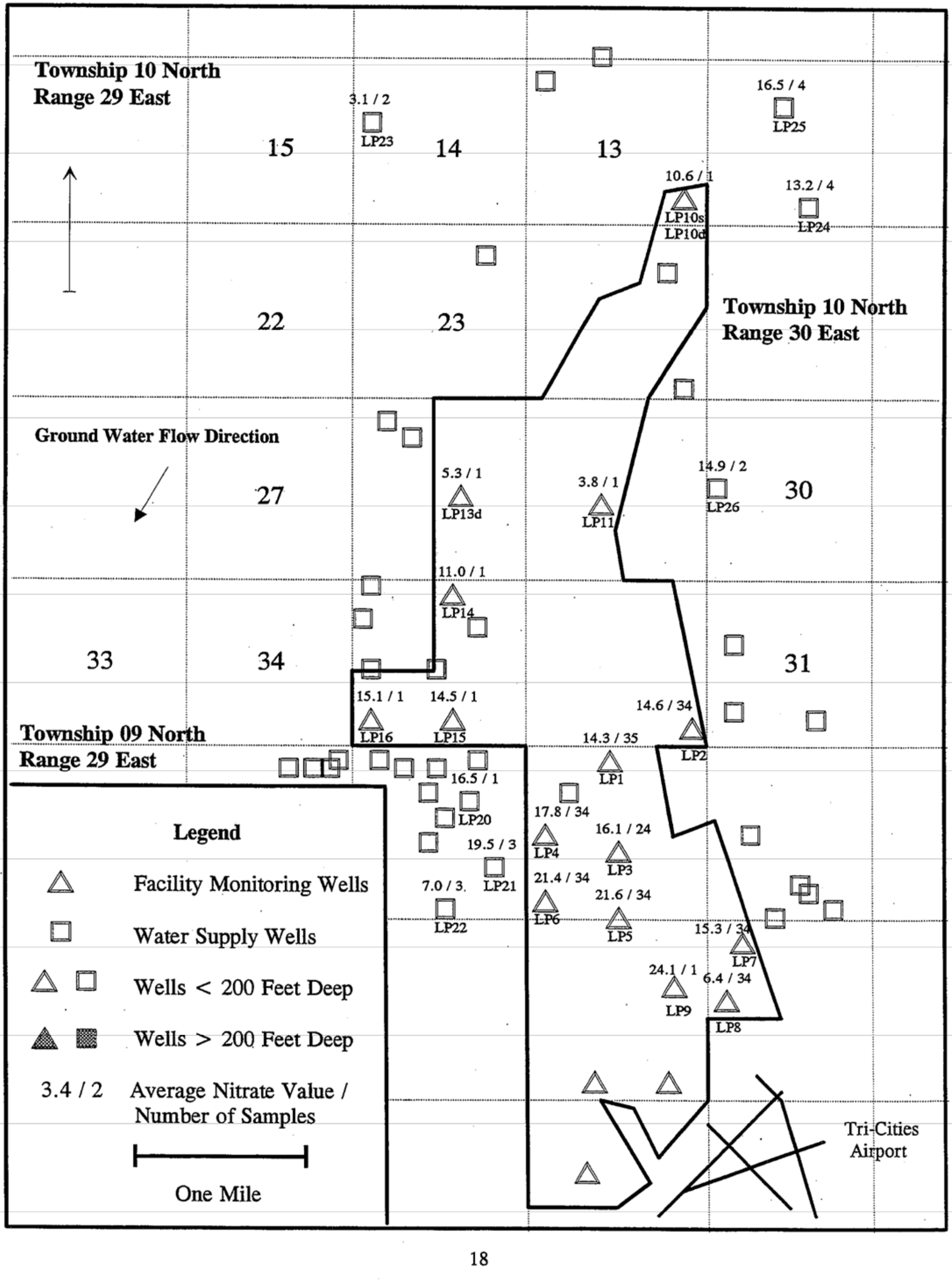
7 For additional information regarding the hydrogeologic characterization of the Connell facility, the reader is directed to the document "Lamb-Weston Connell Facility Engineering Report for Wastewater Disposal, Cascade Earth Sciences, 1991"

8 As of December 1994, eight monitoring wells were constructed and were being monitored. An additional four monitoring wells were planned to be installed and monitored beginning in early to mid- 1995.

Figure 8. Process Water Application Area
Lamb-Weston at Pasco, Washington



Wells located outside the permitted spray field did not appear to have been impacted by past management practices. Areas within the spray field demonstrating the most significant impact lie within the area currently monitored by wells MW-2, MW-8, MW-9 and MW-10. Review of historical records indicates that this area was previously overloaded with process waste water. Migration of nitrate contaminated ground water off site of the facility could not be directly determined due to the lack of downgradient monitoring or water supply wells from which to obtain ground water nitrate values.

Limited off site nitrate migration is suspected near MW-8 and MW-10 based on two dimensional modeling of contaminant transport within the shallow uppermost aquifer[9]. Model results indicate a predicted decline during the next three to four years, in nitrate levels as a result of decrease hydraulic and nitrogen loading.

Lamb-Weston at Pasco

The Lamb-Weston facility at Pasco has been required to conduct a hydrogeologic assessment[10] and install a ground water monitoring system surrounding the spray field areas. Currently this system is comprised of eight wells and three piezometers. These wells are required to be monitored on a quarterly basis for parameters specified under the current permit. Seven additional wells were added as a result of planned expansion of the spray field operations. These wells were installed by late 1994. Additional wells were installed in September 1995.

All wells installed as part of the Lamb-Weston at Pasco monitoring system are completed within the Pasco Formation which consists of sands, sandy gravel's, and indurated silts. Ground water is encountered at approximately 50 - 100 feet below land surface with depth increasing toward the south. The uppermost aquifer underlying the spray field is unconfined. Ground water gradients across the site have been calculated at between .0023 to .0045 ft/ft toward the west-southwest.

Statistical analysis of the ground water monitoring results collected for the period 1992 - 1994 indicated three of the ten downgradient monitoring were exceeding background[11] nitrate levels. Analysis was conducted at the 90 percent confidence level. Wells which had been impacted are MW-3, MW-5, and MW-6. Monitoring wells MW-2, MW-7, and MW-8 had not been significantly impacted.

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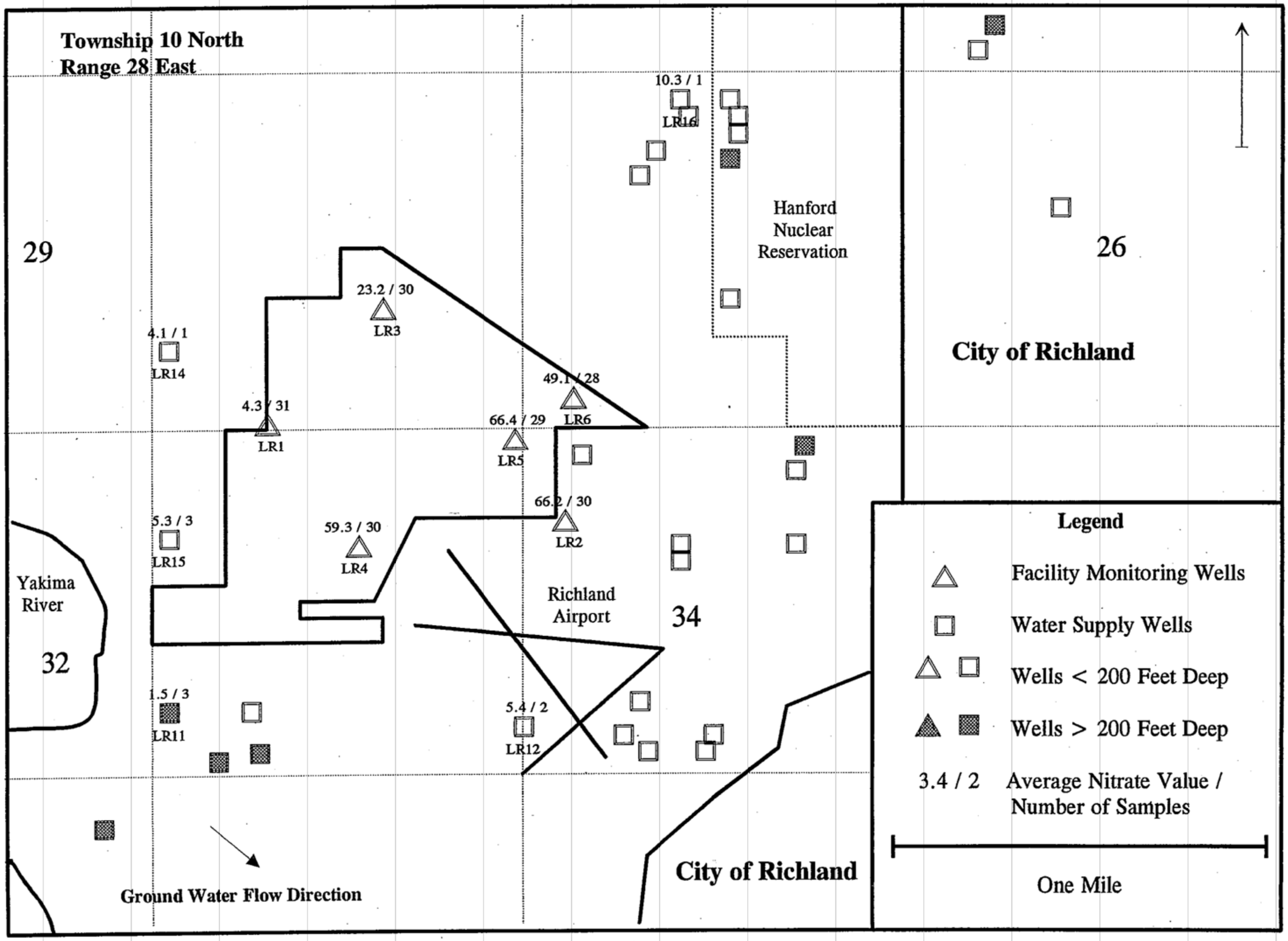
9 Two dimensional modeling conducted using Random Walk code (Prickett, Naymikn and Lonnquist-1981). Input parameters approximated where field data was lacking. Results are to be consider approximations only.

10 For additional information regarding the hydrogeologic characterization of the Pasco facility the reader is directed to "Hydrogeologic Characterization Process Water Recycling System Expansion Sites", Cascade Earth Sciences, 1994 and 1995

11 Insufficient data exist to conduct valid statistical analysis on newly installed monitoring wells.

Figure 9. Process Water Application Area Lamb-Weston at Richland, Washington



A review of the existing ground water data indicated the existence of 62 water supply wells within a one mile radius of the spray field. Twenty-eight of these wells were listed as domestic water supply wells, 20 as irrigation wells, 3 as public water supply wells with the remainder as industrial or test wells. Previous ground water analysis for nine of these wells indicated nitrate contamination within the uppermost aquifer which routinely exceeded the drinking water standards of 10 mg/l. However, because of the relatively high background concentration of nitrate in ground water, a definitive link between operation of the spray field area with nitrate contamination of surrounding water supply wells was not made.

Data records for the three community water supply wells, identified to lie within a mile of the spray field operations, indicated all three had at least one nitrate violation of 15 mg/l or more. The effected community water supply wells appeared to be located cross gradient from the spray field operations and are therefore, unlikely to had been impacted by facility operations.

Lamb-Weston at Richland

The Lamb-Weston facility at Richland had been required to conduct a hydrogeologic assessment and install a ground water monitoring system surrounding the spray field areas[12]. Currently this system is comprised of six wells (one upgradient, five downgradient wells) ranging in depth from 20 to 80 feet. These wells were required to be monitored on a monthly basis for parameters specified within the current permit[13]. All wells comprising the Richland monitoring system was installed within the uppermost aquifer underlying the spray field. This aquifer is composed of permeable sands and gravel's of what has been previously identified as the Pasco Gravel's and middle Ringold unit (Childs 1991). This aquifer is unconfined. Water levels lie approximately 18 -20 feet below land surface. Ground water flow within the spray field area is toward the south-southeast at a gradient of .002 ft/ft.

Statistical analysis of the ground water monitoring results collected for the period 1993 - 1994 indicated all of the five downgradient monitoring wells MW-2, MW-3, MW-4, MW-5, and MW-6) had a statistically significant increase of nitrate above background. In all of the five downgradient monitoring wells the statistical increase was accompanied by monitoring results which routinely exceeded the federal drinking water standards for nitrate of 10 mg/l.

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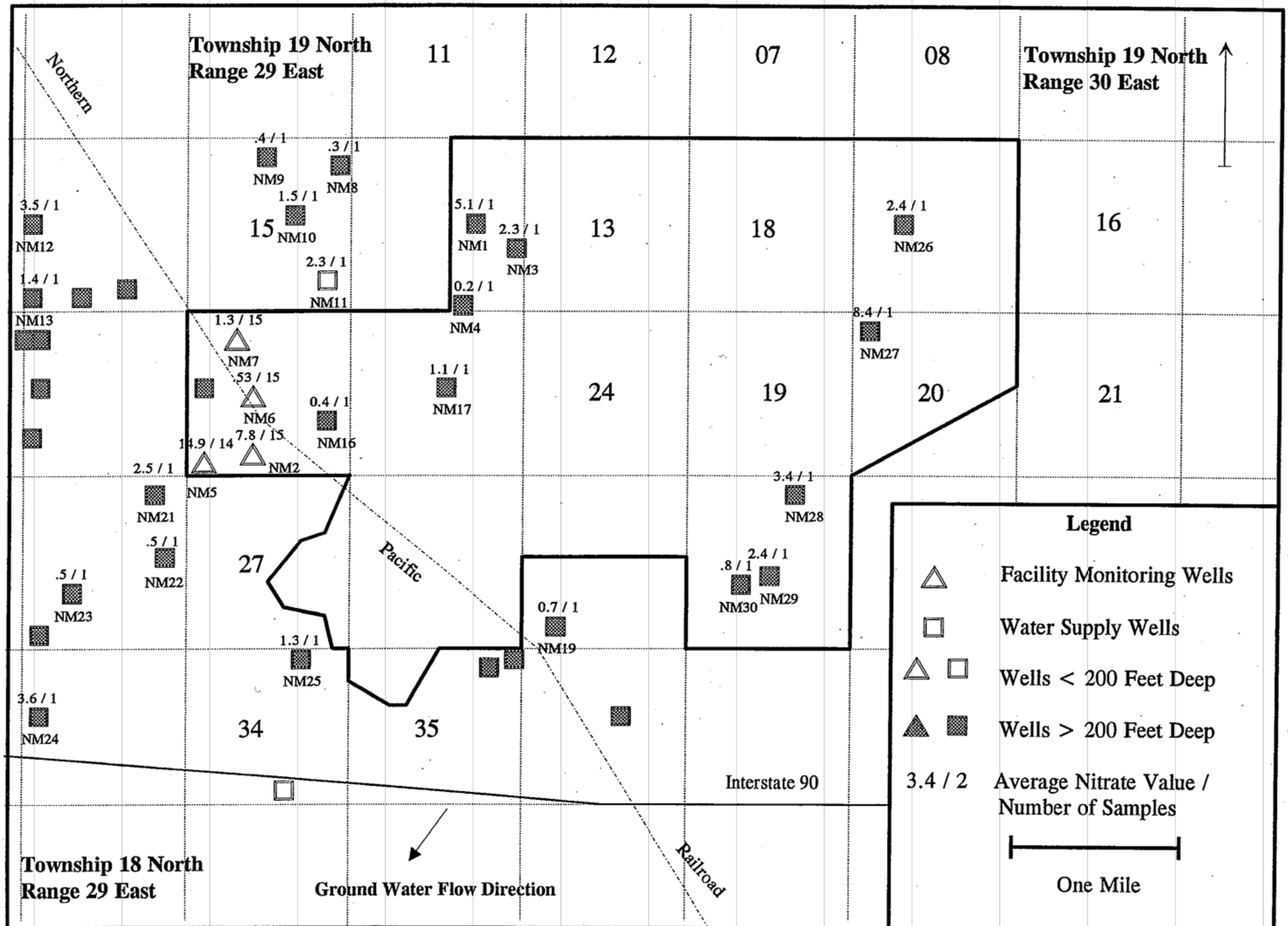
12 For additional information concerning the hydrogeologic assessment of the Richland facility, the reader is directed to "Lamb-Weston Richland Facility-Draft Engineering Report Permit ST-5530", Cascade Earth Sciences, 1993

13 This requirement remains part of the facility's current permit

Figure 10. Process Water Application Area   Nestle Brands at Moses Lake, Washington



Nitrate contamination of ground water increased toward the downgradient boundary of the spray field area in proximity of MW-2 through MW-6. A water supply well located downgradient of the spray field tended to showed a slight elevation of nitrate levels compared to water supply wells located upgradient of the facility; however, the well is located near several other potential nitrate sources and may not be representative of spray field activities. The extent of the off site nitrate contamination is suspected to be limited in scope based on two dimensional modeling of contaminant transport within the uppermost aquifer[14]. Model results also indicate a declining nitrate level in ground water as a result of significant reductions in both hydraulic and nitrogen loading of the spray filed as a result of improved waste water pre-treatment. Gradual declines in nitrate levels should be realized beginning within one to two years of instituting waste water treatment improvements.

Three community water supply wells were identified to lie within two miles of the spray field operations. Data records for the past five year for these wells indicated at least one violation of the nitrate MCL of 10 mg/l. Each of the community water supply wells are located either upgradient or cross gradient of the spray field and are therefore not impacted by spray field operations.

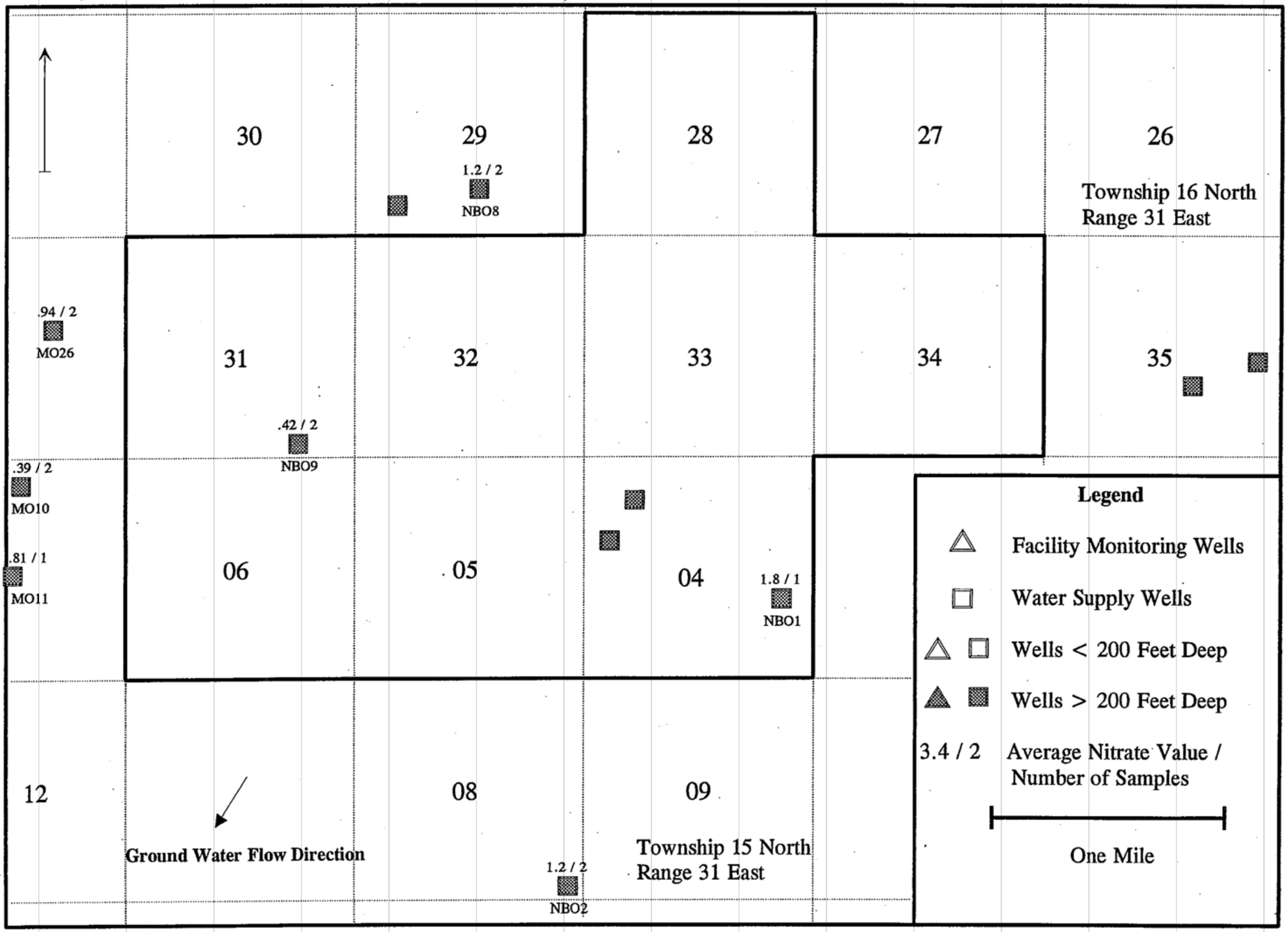
Nestle Brands at Moses Lake

A majority of the permitted spray field area associated with the Nestle Brands facility near Moses Lake, Washington has not been required to install a ground water monitoring system based on the current understanding of the local hydrogeologic conditions. A ground water monitoring system has been required for the settling pond and storage lagoon area located in section 22 of Township 19 N., Range 29 E.

This system consists of five shallow monitoring wells located within the southwestern half of the section. Within the settling pond area, ground water exists at shallow depths, averaging 10 to 15 feet below land surface. These conditions are due to leakage from the East Low Canal operated by the US Bureau of Reclamation as part of the Columbia Basin Irrigation Project. The existence of shallow ground water is locally confined to the areas near the canal and is seasonal in nature. A majority of the permitted spray field area has been characterized as lacking a well defined shallow aquifer. Discontinuous lenses of ground water exist underlying the area; however, these areas are due largely to seasonal conditions. The presence of calcified sandy silts within the overburden limits ground water movement below this layer into the underlying basalt's in which the uppermost aquifer has been identified. The uppermost aquifer exists between 150 and 300 feet below land surface and lies within the Wanapum Basalt's. This aquifer exists under confined conditions and does not

[14] Two dimensional modeling conducted using Random Walk code (Prickett, Naymikn and Lonnquist-1981). Input parameters approximated where field data was lacking. Results are to be consider approximations only.

Figure 11. Process Water Application Area   Nestle Brands at Othello Washington



appear to be readily susceptible to the migration of contaminants originating at the land surface.

Statistical analysis of the ground water monitoring results collected for the period 1993 - 1994 indicated that in two of the four downgradient monitoring wells a statistically significant increase of nitrate above background existed. Analysis was conducted at the 90 percent confidence level. Wells which had been impacted were MW-2 and MW-5. Monitoring well MW-6 had not been impacted.

Thirty-nine water supply wells exist either in or within a one mile radius of the permitted spray field area[15]. Thirteen of these wells had been identified as private domestic water supply sources which generally are installed at between 150 and 200 feet below land surface. One public water supply well had been identified within the one mile radius. This well belongs to the City of Moses Lake. Its location appears to be cross gradient of the regional ground water flow.

Ground water analyses for 24 of the surrounding wells was reviewed for evidence of off site migration of nitrate due to spray field management practices. Elevated nitrate values were found to be confined to three wells within Section 22 and one within Section 20. The remaining data for wells identified near the spray field area failed to indicate impact from the current management practices.

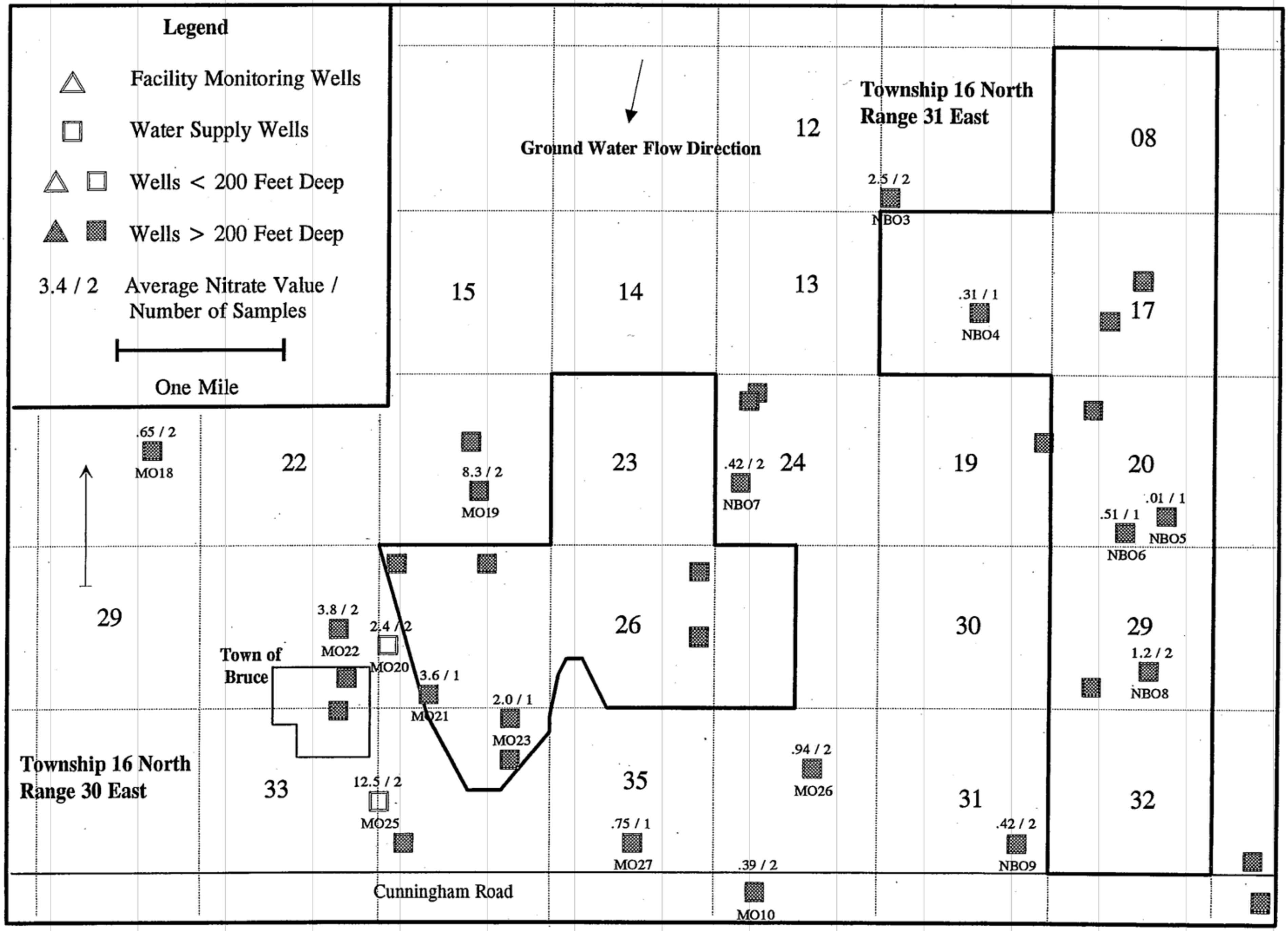
Nestle Brands at Othello

The Nestle Brands spray field facility located near Othello, Washington has not been required to install a ground water monitoring system. The facility is required to conduct soils monitoring, on a yearly basis, in order to determine the potential for loss of nutrient compounds to the underlying aquifer. The lack of a ground water monitoring requirement for the Nestle Brands facility is based on the current understanding of the local hydrogeologic conditions. The uppermost aquifer, underlying the spray field, exists within the Wanapum Basalt's at a depth of between 250 and 300 feet below land surface. This aquifer exists under confined conditions and does not appear to be readily susceptible to the migration of contaminants under current conditions. Small, discontinuous saturated lenses exist beneath the spray field area. These lenses are seasonal in nature and are of limited use for facility performance monitoring purposes. Yearly soil monitoring has been accepted as an alternative to ground water monitoring.

Fourteen water supply wells were identified within one mile of the spray field operational area. All of these wells are below 200 feet in depth with most lying below 450 feet in depth. The primary use of a majority of these wells was identified as agricultural (irrigation). Within a one mile radius of the spray field exists five

15 Based on existing water well drilling reports on record with the Washington State Department of Ecology.

Figure 12. Process Water Application Area McCain Foods at Othello Washington



wells used to supply domestic water for human consumption[16]. Recent nitrate levels obtained from six wells near the spray field area did not indicate any evidence of ground water contamination having occurred as a result of spray field management activities.

McCain Foods at Othello

The McCain Foods spray field facility located near Othello, Washington has not been required to install a ground water monitoring system. The facility is required to conduct soils monitoring, on a yearly basis, in order to determine the potential for loss of nutrient compounds to the underlying aquifer

The lack of a ground water monitoring requirement for the McCain Foods facility is based on the current understanding of the local hydrogeologic conditions. The uppermost aquifer, underlying the spray field, exists within the Wanapum Basalt's at a depth of between 250 and 300 feet below land surface. This aquifer exists under confined conditions and does not appear to be readily susceptible to the migration of contaminants under current conditions. Small, discontinuous saturated lenses exist beneath the spray field area. These lenses are seasonal in nature and are of limited use for facility performance monitoring purposes. These conditions appear to be not unlike those encountered at the Nestle Brands spray field area located directly south of the McCain Foods site. Yearly soil monitoring has been accepted as an alternative to ground water monitoring.

Thirty-nine water supply wells were identified within one mile of the spray field operational area. All of these wells are below 200 feet in depth with most lying below 550 feet in depth. The primary use of a majority of these wells were identified as agricultural (irrigation). Within a one mile radius of the spray field exists 15 wells used to supply domestic water for human consumption[17]. One public water supply well was identified to lie within one mile of the spray field.

In 1994, McCain Foods conducted a survey of 16 surrounding irrigation and domestic water supply wells. These wells were monitored for nitrogen compounds and other nutrients. Nitrate levels obtained from 14 of these wells indicated no evidence of ground water contamination having occurred as a result of spray field management activities. Two wells located in section 34 and section 22 of Township 16 N., Range 30 E. have previous nitrate levels significantly above that found in surround wells. The cause of the high nitrate levels appear to be local in nature. Because of the locations of these wells, their depth, and regional hydrogeologic conditions spray field management practices are not likely to have caused the nitrate increases.

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16 Based on existing water well drilling reports on record with the Washington State Department of Ecology.

17 Based on existing water well drilling reports on record with the Washington State Department of Ecology.

III. Conclusions

Recent State Waste Discharge Permits, issued by the Washington State Department of Ecology, are adequate to protect ground water for all currently existing public and private water supply wells located near managed spray fields operated by selected potato processing facilities. However, past implementation of permits at some of these facilities has resulted in ground water contamination due to the over application of nitrogen compounds to some spray field operations. The effect of this contamination appears to be localized and varied according to such factors as time of year, application rate, soil moisture content, and process water strength.

The potato processing industry in cooperation with the State of Washington has implemented comprehensive measures to reduce both actual and potential ground water contamination resulting from facility operations. These improvements have resulted in an average reduction of nitrogen application to spray fields of 48 percent. This reduction has resulted in significantly reducing or eliminating the application of excess nitrogen to the land surface thereby reducing the potential for contamination of local and regional ground water resources. Further reduction of nitrogen is anticipated as several large scale process water treatment systems are brought "on-line" during the next two years.

The need to assess both on-site and off-site ground water contamination at spray field facilities will likely increase as additional demand for ground water increases. Current facility monitoring appears to address the on-site concerns related to facility operation. However, the lack of routine ground water monitoring directly off-site (for spray fields with high off-site migration potential) raises concern regarding the extent to which future uses of ground water near these facilities may be impacted.

Improvement of ground water quality throughout the mid-Columbia Basin will depend on the success of identifying existing point and non-point sources of nitrogen contamination and providing for correction of those activities shown to be contributing to the problem. In order to fully address the extent of the nitrate contamination issue in the mid-Columbia Basin area, it will be necessary to analyze all activities including residential, agricultural, and industrial that may contribute to ground water contamination.

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Appendices

Appendix One
Monitoring Frequencies As Required Under Permit
Facility Process Waste Water

	L-W Connell	L-W Pasco	L-W Richland	Nestle Moses Lk	Nestle Othello	McCain Othello
Flow	Cont.	Cont.	Cont.	Cont.	Cont.	Cont.
pH	Daily	Daily	Weekly	Hourly	Hourly	Hourly
TDS			Monthly	Monthly	Monthly	Weekly
BOD_5			Weekly			Monthly
TSS	Monthly	Monthly	As Needed	Monthly	Monthly	Monthly
COD	Monthly	Monthly	As Needed	Monthly	Monthly	Monthly
TKN	Monthly	Monthly	Weekly	Quarterly	Quarterly	Monthly
NO3-NO2			Weekly	Quarterly	Quarterly	Monthly
NH3						Monthly
NH4	Monthly	Monthly	Weekly			
Ortho-PO4			Monthly	Quarterly	Quarterly	Monthly
Cond.	Monthly	Monthly	Weekly	Hourly	Hourly	Monthly
Na			Quarterly	Quarterly	Quarterly	
Ca				Quarterly	Quarterly	
Mg				Quarterly	Quarterly	
K			Quarterly			
SO4			Quarterly			
Cl			Monthly			
Oil & Grse	Monthly	Monthly				

Irrigation Waste Water

	L-W Connell	L-W Pasco	L-W Richland	Nestle Moses Lk	Nestle Othello	McCain Othello
Flow	Cont.	Cont.		Cont.	Cont.	Daily
pH	Daily	Daily		Monthly	Monthly	Daily
TDS				Monthly	Monthly	Monthly
BOD_5	Monthly					Monthly
TSS				Monthly	Monthly	Monthly
COD	Monthly	Monthly		Monthly	Monthly	Monthly
TKN	Monthly	Monthly		Monthly	Monthly	Monthly
NO3-NO2	Monthly	Monthly		Monthly	Monthly	Monthly
NH3				Monthly	Monthly	Monthly
NH4	Monthly	Monthly				
Ortho-PO4		Quarterly		Monthly	Monthly	Monthly
Cond.	Monthly	Monthly		Monthly	Monthly	Monthly
Na	Quarterly	Quarterly		Monthly	Monthly	Monthly
Ca	Quarterly	Quarterly		Monthly	Monthly	Monthly
Mg	Quarterly	Quarterly		Monthly	Monthly	Monthly
K	Quarterly	Quarterly		Monthly	Monthly	Monthly
SO4	Quarterly	Quarterly		Monthly	Monthly	
Cl	Quarterly	Quarterly		Monthly	Monthly	

Appendix One
Monitoring Frequencies As Required Under Permit
Mud Pond/Settling Pond

	L-W Connell	L-W Pasco	L-W Richland	Nestle Moses Lk	Nestle Othello	McCain Othello
Flow	Cont.	Cont.				Daily
pH	Quarterly	Quarterly				Quarterly
TDS						Quarterly
BOD_5						Quarterly
TSS	Quarterly	Quarterly				Quarterly
COD	Quarterly	Quarterly				
TKN	Quarterly	Quarterly				Quarterly
NO3-NO2	Quarterly	Quarterly				Quarterly
NH3	Quarertly	Quarterly				Quarterly

Note: Lamb-Weston at Richland, Nestle Brands at Moses Lake and Othello do not use mud ponds separate from settling/storage lagoons

Appendix A Soils Environmental Monitoring

	L-W Connell	L-W Pasco	L-W Richland	Nestle Moses Lk	Nestle Othello	McCain Othello
pH	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	Yearly
Ferrous Fe			Weekly			
ESP	Yearly	2/5 Year	2 Yearly			
CEC	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	Yearly
SAR			2 Yearly			
COD			2 Yearly			
Organic Matter	Yearly					
TKN	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	Yearly
NO3-NO2	Yearly	2/5 Year	2 Yearly			Yearly
NH3						Yearly
NH4	Yearly	2/5 Year				
Ortho-PO4		2/5 Year	2 Yearly	Yearly	Yearly	Yearly
Total P	Yearly					
Cond.	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	Yearly
Na	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	Yearly
Ca	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	
Mg	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	
K	Yearly		2 Yearly	Yearly	Yearly	Yearly
SO4	Yearly	2/5 Year	2 Yearly	Yearly	Yearly	
Cl			2 Yearly	Yearly	Yearly	

Appendix One
Monitoring Frequencies As Required Under Permit
Surface Water Environmental Monitoring

	L-W Connell	L-W Pasco	L-W Richland	Nestle Moses Lk	Nestle Othello	McCain Othello
Temperature				Cont.		Quarterly
pH	Monthly			Yearly		Quarterly
BOD_5						Quarterly
TSS						Quarterly
COD	Monthly			Yearly		
TKN	Monthly			Yearly		Quarterly
NO3-NO2	Monthly			Yearly		Quarterly
NH4	Monthly					
NH3						Quarterly
Ortho-PO4				Yearly		Quarterly
Cond.	Monthly			Yearly		Quarterly
Na				Yearly		
Ca				Yearly		
Mg				Yearly		
Cl	Monthly					Quarterly

Ground Water Environmental Monitoring

	L-W Connell	L-W Pasco	L-W Richland	Nestle Moses Lk	Nestle Othello	McCain Othello
pH	Monthly	Mon/Yrly		Quarterly		Yearly
Static WL	Monthly	Monthly	Monthly			
Alkalinity			Monthly			
F. Coli			Monthly			
TDS			Monthly			Yearly
TOC			Monthly			
COD	Monthly	Mon/Yrly		Quarterly		
TKN	Monthly		Monthly	Quarterly		Yearly
NO3-NO2	Monthly	Mon/Yrly	Monthly	Quarterly		Yearly
NH3						Yearly
NH4	Monthly	Mon/Yrly	Monthly			
Ortho-PO4			Monthly	Quarterly		Yearly
Cond.	Monthly	Mon/Yrly		Quarterly		Yearly
Na		Mon/Yrly	Monthly	Quarterly		Yearly
Ca		Mon/Yrly	Monthly	Quarterly		
Mg		Mon/Yrly	Monthly	Quarterly		
K		Mon/Yrly	Monthly			Yearly
SO4		Mon/Yrly	Monthly			
Cl	Monthly	Mon/Yrly	Monthly			Yearly

Note: Lamb-Weston at Pasco shall monitor wells MW1 - MW8 monthly for 1st two years of permit
Monitoring wells UIW 1-4, 6, 7, 9 and 10 shall be monitored yearly

Appendix Two
Ground Water Nitrate Data for Wells Within One Mile of Facility Sprayfield Areas (1985-1994)

Map #	Well Location	Well Type	Well Depth	Nitrate Levels Detected (mg/l) Min.	Max.	Avg.	Sample #
LP1	09N/29E-01B01	MW01-DG	102	12.1	15.9	14.3	35
LP3	09N/29E-01G01	MW03-DG	100	13.7	19.6	16.1	24
LP4	09N/29E-01E01	MW04-DG	106	13.8	22.1	17.8	34
LP5	09N/29E-01N01	MW05-DG	120	13.5	51.1	21.6	34
LP6	09N/29E-01Q01	MW06-DG	101	13.5	47.9	21.4	34
LP20	09N/29E-02G01	PWS	155	16.5	16.5	16.5	1
LP21	09N/29E-02H01	PWS	120	18.8	20.5	19.5	3
LP22	09N/29E-02Q01	DW	122	5.6	8.2	7.0	3
LP2	09N/30E-06D01	MW02-DG	112	12.4	16.7	14.6	34
LP7	09N/30E-07C01	MW07-UG	91	13	18.3	15.3	34
LP8	09N/30E-07E01	MW08-DG	107	2.9	10.3	6.4	34
LP9	09N/30E-07E02	MW09-DG	70	24.1	24.1	24.1	1
LR16	10N/28E-27C01	UNK	54	10.3	10.3	10.3	1
LR6	10N/28E-27N01	MW06-DG	20	1	260	49.1	28
LR3	10N/28E-28K01	MW03-DG	59.5	3	62	23.2	30
LR1	10N/28E-33C01	MW01-UG	34	0.9	10	4.3	31
LR4	10N/28E-33G01	MW04-DG	80	0.1	135	59.3	30
LR11	10N/28E-33N01	DW	210	0.9	2.4	1.5	3
LR5	10N/28E-34D01	MW05-DG	30	37	111	66.4	29
LR2	10N/28E-34F01	MW02-DG	28	19.4	142	66.2	30
LR12	10N/28E-34N01	DW	185	4.2	6.5	5.4	2
LR15	10N/28E-33E01	DW	75	4.8	5.7	5.3	3

Appendix Two
Ground Water Nitrate Data for Wells Within One Mile of Facility Sprayfield Areas (1985-1994)

Map #	Well Location	Well Type	Well Depth	Nitrate Levels Detected (mg/l) Min.	Max.	Avg.	Sample #
LP10s	10N/29E-13R01	MW10-UG	44	10.6	10.6	10.6	1
LP10d	10N/29E-13R02	MW10-UG	70	10.6	10.6	10.6	1
LP23	10N/29E-14E01	DW	136	3	3.2	3.1	2
LP11	10N/29E-25K01	MW11-UG	25	3.8	3.8	3.8	1
LP13d	10N/29E-26G02	MW13-UG	47	5.3	5.3	5.3	1
LP14	10N/29E-26Q01	MW14-DG	112	11	11	11	1
LP16	10N/29E-35N01	MW16-DG	127	15.1	15.1	15.1	1
LP15	10N/29E-35Q01	MW15-DG	98	14.5	14.5	14.5	1
LP24	10N/30E-18F01	DW	90	10.3	15.5	13.2	4
LP25	10N/30E-18Q01	DW	99	15.8	17.2	16.5	3
LP26	10N/30E-30E01		0	14.3	15.4	14.9	2
LC21	14N/31E-26B01	I	1133	1	1	1	1
LC22	14N/31E-26L01	I	900	1.2	1.2	1.2	1
LC23	14N/31E-29H01	DW	360	1.9	1.9	1.9	1
LC25	14N/31E-33H01	IW	330	4.3	10.8	8.5	13
LC12	14N/31E-33M01	MW12-UG	104	4.2	5.15	4.6	13
LC26	14N/31E-34D01	DW	525	1.1	1.1	1.1	1
LC10	14N/31E-34R02	MW10-DG	68	60	90.5	72.5	11
LC9	14N/31E-35J01	MW09-DG	63	0.4	0.4	0.4	1
LC2	14N/31E-35K01	MW02-DG	45	0.08	0.08	0.08	1
LC8	14N/31E-35Q01	MW08-DG	70	108.4	108.4	108.4	1
LC1R	14N/31E-35R01	MW1R-UG	183	0.01	0.2	0.05	12

Appendix Two
Ground Water Nitrate Data for Wells Within One Mile of Facility Sprayfield Areas (1985-1994)

Map #	Well Location	Well Type	Well Depth	Nitrate Levels Detected (mg/l) Min.	Max.	Avg.	Sample #
LC27	14N/31E-36J01	PWS	989	0.1	0.2	0.13	3
LC28	14N/31E-36L01	PWS	475	0.2	0.5	0.37	3
LC11	14N/31E-36M01	MW11-DG	180	4.5	4.5	4.5	1
LC20	14N/32E-31D01	PWS	650	3.5	3.7	3.6	2
MO10	15N/30E-01C01	DW	445	0.23	0.54	0.39	2
MO11	15N/30E-01F01	IW	740	0.81	0.81	0.81	1
NBO1	15N/31E-04D01	DW	570	1.8	1.8	1.8	1
NBO2	15N/31E-08R01	DW	475	0.9	1.5	1.2	2
MO18	16N/30E-21G01	DW	350	0.59	0.71	0.65	2
MO19	16N/30E-22K01	IW	639	3.43	13.12	8.3	2
MO20	16N/30E-27M01	DW	197	2.11	2.68	2.4	2
MO21	16N/30E-27M02	IW	858	3.64	3.64	3.6	1
MO22	16N/30E-28J01	ID	900	3.43	4.11	3.8	2
MO23	16N/30E-34A01	IW	625	1.96	1.96	2.0	1
MO25	16N/30E-34M01	DW	0	11.8	13.22	12.5	2
MO27	16N/30E-35Q01	DW	231	.75	.75	.75	1
MO26	16N/30E-36G01	IW	700	0.51	1.37	0.94	2
NBO3	16N/31E-07N01	DW	425	1.57	3.41	2.5	2
NBO4	16N/31E-18K01	IW	725	0.31	0.31	0.31	1
NBO5	16N/31E-20Q01	IW	945	0.01	0.01	0.01	1
NBO6	16N/31E-20Q02	IW	1280	0.5	0.5	0.51	1
NBO7	16N/31E-24M01	DW	500	0.2	0.64	0.42	2

Appendix Two
Ground Water Nitrate Data for Wells Within One Mile of Facility Sprayfield Areas (1985-1994)

Map #	Well Location	Well Type	Well Depth	Nitrate Levels Detected (mg/l) Min.	Max.	Avg.	Sample #
NBO8	16N/31E-29K01	DW	510	1.1	1.2	1.2	2
NB09	16N/31E-31Q01	DW	390	0.36	0.44	0.42	2
NM1	19N/29E-14G01	IW	400	5.1	5.1	5.1	1
NM3	19N/29E-14J01	IW	713	2.3	2.3	2.3	1
NM4	19N/29E-14Q01	IW	700	0.2	0.2	0.2	1
NM8	19N/29E-15A01	IW	945	0.3	0.3	0.3	1
NM9	19N/29E-15B01	IW	658	0.4	0.4	0.4	1
NM10	19N/29E-15G01	IW	620	1.5	1.5	1.5	1
NM11	19N/29E-15R01	DW	70	2.3	2.3	2.3	1
NM12	19N/29E-16E01	DW	290	3.5	3.5	3.5	1
NM13	19N/29E-16N01	IW	495	1.4	1.4	1.4	1
NM7	19N/29E-22C01	MW07-UG	50	0.1	4.4	1.3	15
NM6	19N/29E-22E01	MW06-DG	55	0.1	5	0.53	15
NM16	19N/29E-22J01	IW	560	0.4	0.4	0.4	1
NM5	19N/29E-22N01	MW05-DG	65	10	25	14.9	14
NM17	19N/29E-23G01	DW	202	1.1	1.1	1.1	1
NM2	19N/29E-22P01	MW02-DG	47	5	9.9	7.8	15
NM19	19N/29E-25N02	DW	121	0.7	0.7	0.7	1
NM21	19N/29E-28A02	DW	222	2.5	2.5	2.5	1
NM22	19N/29E-28H01	DW	220	0.5	0.5	0.5	1
NM23	19N/29E-28L01	DW	200	0.5	0.5	0.5	1
NM24	19N/29E-33E01	DW	232	3.6	3.6	3.6	1

Appendix Two
Ground Water Nitrate Data for Wells Within One Mile of Facility Sprayfield Areas (1985-1994)

Map #	Well Location	Well Type	Well Depth	Nitrate Levels Detected (mg/l) Min.	Max.	Avg.	Sample #
NM25	19N/29E-34A01	DW	322	1.3	1.3	1.3	1
NM26	19N/30E-17E01	IW	500	2.4	2.4	2.4	1
NM27	19N/30E-20D01	IW	450	8.4	8.4	8.4	1
NM28	19N/30E-30B01	IW	410	3.4	3.4	3.4	1
NM29	19N/30E-30L01	DW	675	2.4	2.4	2.4	1
NM30	19N/30E-30L02	DW	692	0.8	0.8	0.8	1

DW	Domestic Drinking Water Supply Well
IW	Irrigation Well
I	Industrial Well
MW-UG	Facility Monitoring Well - Upgradient
MW-DW	Facility Monitoring Well - Downgradient
PWS	Public Water Supply Well

Shaded values indicate averages at/or exceeding the Maximum Contaminant Level of 10 mg/l for nitrate as nitrogen.

Appendix Three
Blaney-Criddle Equation for the Calculation of Crop Irrigation Requirements

$$E_t\ (\text{cm}) = K \sum_{i=1}^{n} (1.8T_{ai} + 32)d_i$$

K = crop coefficient for the whole growing season (from U.S. Soil Conservation Service 1970)

n = number of month in the growing season

i = individual month in the growing season so T_{ai} and d_i are respectively the air temperature and the fraction of annual hours of daylight for each month

Seasonal Coefficients (K) for Irrigated Crops

Crop	K
Alfalfa	2.3 - 2.5
Beans	1.8 - 2.0
Corn	2.2 - 2.3
Grains	2.2 - 2.4
Grass, pasture	2.1 - 2.3
Peas	1.8 - 2.1
Potatoes	1.8 - 2.0

Monthly Fraction of Annual Daylight

Lat.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
50°N	.060	.063	.082	.092	.107	.109	.110	.100	.085	.075	.061	.056
40°N	.067	.066	.082	.089	.099	.100	.101	.094	.083	.077	.067	.075
30°N	.073	.070	.084	.087	.095	.095	.097	.092	.083	.080	.072	.072