

# **Impact of Dairies on Surface Water Quality in the Lower Yakima Valley, WA**

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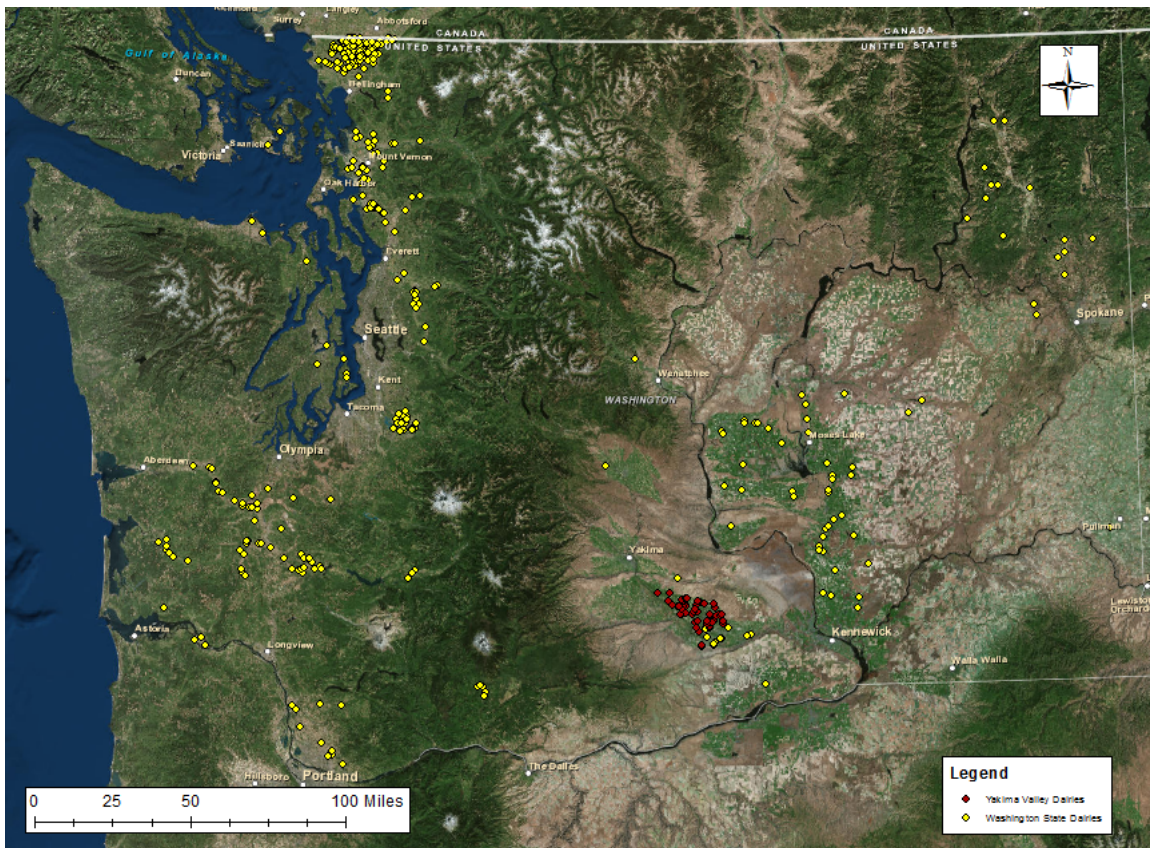
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## 1.0 Introduction

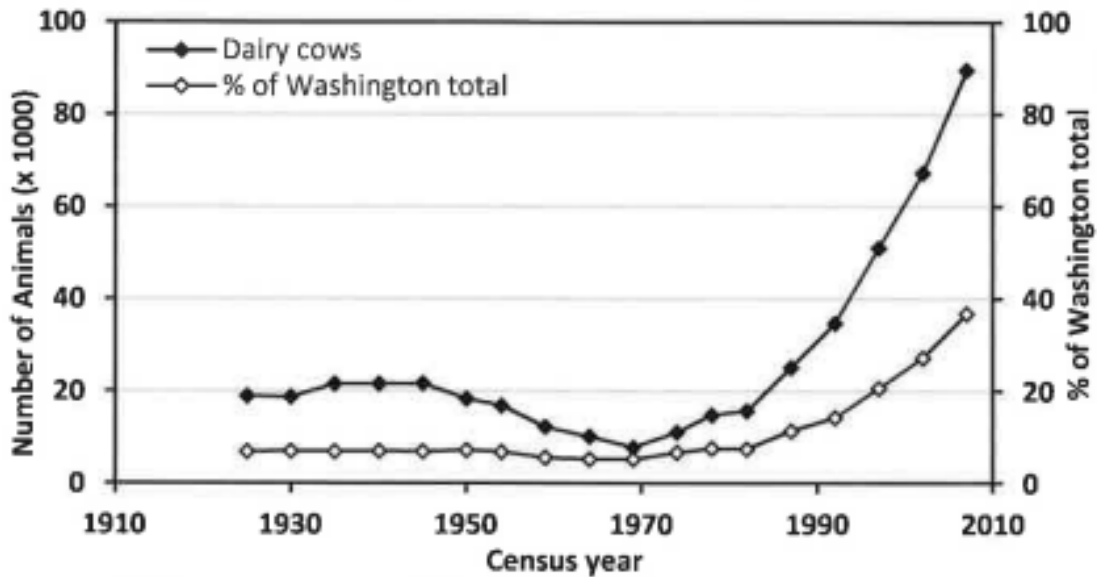
In recent decades there has been a shift within the United States from small, family owned dairies to large corporate dairies. These large-scale dairy farms are known as, “confined animal feeding operations,” CAFOs. This has considerably increased the efficiency of production. Since 1960 the milk production within the United States has doubled.<sup>8</sup> While this increase in production leads to cheaper and more readily available dairy products, there are also large-scale environmental repercussions. This is primarily due to the copious amounts of manure that CAFOs produce. Manure contains nitrogen, phosphorus, pathogens, hormones and antibiotics. Within the U.S. it is estimated that each year livestock animals produce between 3 and 20 times more manure than people. Additionally, there are no sewage treatment plants for livestock waste. Thus, where these operations lie, there is great potential for environmental contamination.

Washington State ranks tenth in dairy production within the United States. There are 423 dairies within Washington, 51 of which are in the Lower Yakima Valley. Dairies in Washington are shown in Figure 1; Lower Yakima Valley dairies are shown in red.



**Figure 1. Dairy Farms within Washington State.**

The Lower Yakima Valley is no exception to the shift from smaller dairies to CAFOs, as depicted in Figure 2.



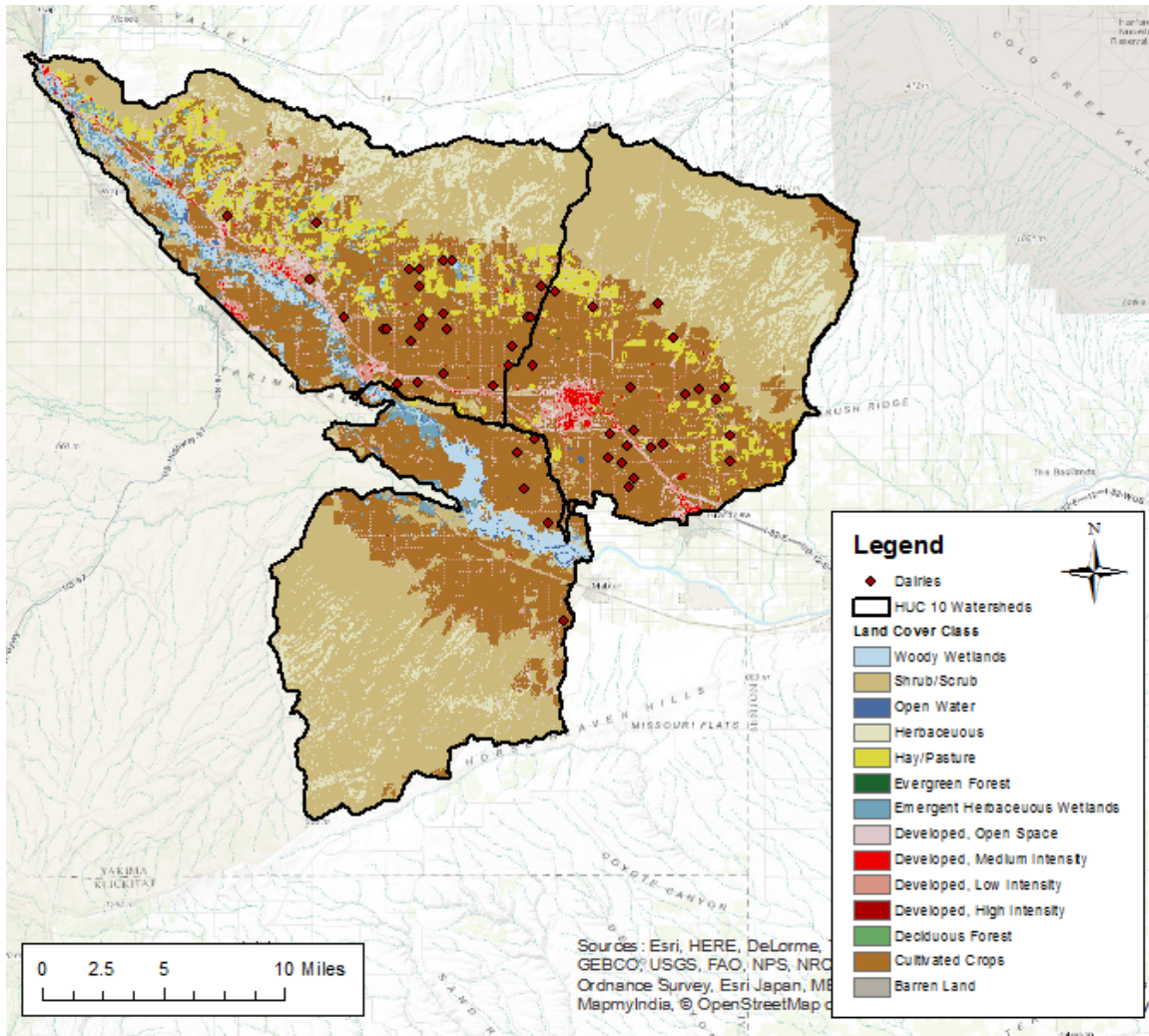
**Figure 2. Number of Dairy Cows in Yakima County.<sup>16</sup>**

Given this dramatic increase in dairy cows within the Lower Yakima Valley, there have been multiple documented cases of high nitrates within drinking water wells. This prompted the Environmental Protection Agency, EPA, in 2010 to sample wells throughout the region in an effort to locate the source of the nitrate contamination.<sup>5,7</sup> The results of this study, as well as a follow up study in 2013<sup>6</sup>, indicated that the nitrate contamination was primarily from the nearby dairies (as opposed to agriculture or residential septic systems). This led to an Administrative Order of Consent to the dairies by the EPA in an effort to improve drinking water quality.

These studies proved the impact dairies can have on groundwater quality, however, their effect on surface water was not assessed. The manure from dairies can enter surface waters through runoff, thereby increasing the water's concentration of nitrogen and phosphorus. Nitrogen and phosphorus are the limiting factors that control microbial growth. As a result, when the water's microorganisms are exposed to these nutrients their population blooms. These blooms block sunlight, produce toxins and when the microorganisms decompose, oxygen is depleted from the water<sup>15</sup>. This is known as eutrophication. The repercussions of eutrophication make the water uninhabitable for the plant and fish populations.

### 1.1 Area of Interest

The area of interest in this study is located in the Lower Yakima Valley of Central Washington in three HUC10 watersheds. The rivers and streams in these watersheds feed into the Yakima River. The Yakima River feeds into the Columbia River, the largest river in the Pacific Northwest. This area is predominately dedicated to agriculture, as seen in Figure 3 and quantified in Table 1.



**Figure 3. Land Use in the Lower Yakima Valley.**

**Table 1. Summary of Land Use in the Lower Yakima Valley.**

<i>Land Cover Class</i>	<i>Area (km<sup>2</sup>)</i>	<i>Fraction of Land</i>
Open Water	5665500	0.44
Developed, Open Space	63603000	4.91
Developed, Low Intensity	34375500	2.66
Developed, Medium Intensity	7414200	0.57
Developed, High Intensity	873900	0.07
Barren Land	4500	0.00
Deciduous Forest	24300	0.00
Evergreen Forest	118800	0.01
Shrub/Scrub	497852992	38.47
Herbaceous	100128600	7.74
Hay/Pasture	72551696	5.61
Cultivated Crops	446764512	34.52
Woody Wetlands	41585400	3.21
Emergent Herbaceous Wetlands	23217300	1.79

Only 8.21% of this region is developed, the rest of the land is primarily shrubs, pastures, and cultivated crops.

## **1.2 Project Objectives**

This term project investigates the impact of dairies on surface water quality in the Lower Yakima Valley. As dairies have previously proved to be the source of nitrate contamination in groundwater within the region, their impact on surface waters should be explored as well. Cow manure contains sizeable quantities of nitrogen and phosphorus, and therefore is expected to affect the ecology of nearby bodies of water. This study seeks to delineate which bodies of water in the region are at risk for contamination and to quantify the effect of the dairies on those waters by using dairies as point sources. This will provide a better understanding of the magnitude the dairy industry has on surface water contamination. Moreover, understanding the nutrient loading in the region could lead to implementation of better dairy management practices as well mitigation strategies.

## **2.0 Material and Methods**

### **2.1 Data Acquisition**

#### **2.1.1 Washington State Department of Ecology**

The Washington State Department of Ecology “maintains spatial datasets... in order to better describe the diverse natural and cultural environment that we live and work in.”<sup>13</sup> This data is made available to the public for viewing and downloading. From this database, the locations of the dairies, the HUC10 watersheds, 303(d) impaired waters and stream gages were extracted.

The dairy locations (supplied to the Washington State Department of Ecology from the Washington State Department of Agriculture) also gave the size of the dairy. Each dairy is classified as “small,” “medium” or “large.” Table 2 corresponds to these classifications.

**Table 2. Dairy Size Classification.**

<i>Size</i>	<i>Number of Cows</i>
Small	0-199
Medium	200-699
Large	700+

The most recent Dairy data is from 2012.

The most recent GIS dataset containing the 303(d) impaired waters within Washington are from 2012. All 303(d) impaired waters are waters the State of Washington does not consider “fishable and swimmable.”<sup>14</sup> The 303(d) listed waters are “Category 5,” meaning they require a “total daily maximum load,” TDML. This is the maximum amount of a pollutant a water body can receive and still safely meet water quality standards.<sup>3</sup>

All of the data from the Washington State Department of Ecology was within the Washington State Plane, South Zone, NAD 83 HARN in units of US feet.

### 2.1.2 NHDPlus V2 Flowlines

NHDPlus V2 is a geo-spatial, hydrologic framework dataset created by the U.S. Environmental Protection Agency.<sup>10</sup> The EPA Office of Water with the U.S. Geological Survey developed this dataset to enhance water quality monitoring, modeling and watershed assessment. Within the dataset there are flowlines, waterbodies, area features, as well as, five flow estimation models. The flow estimation model used for calculations within this study is “Flow E.”

### 2.1.3 Land Cover

The Land Cover Data was obtained from the National Land Cover Database (NLCD) created by the Multi-Resolution Land Characteristics Consortium (MRLC). Every five years new land cover data is published. The most recent of which is from 2011. This data covers a 16-class land cover classification scheme that is applied through the United States at a resolution of 30 meters.<sup>9</sup>

### 2.1.4 Nitrogen and Phosphorus Pollution Data Access Tool

In 2011 the EPA published a memorandum, “Working Effectively in Partnership with States to Address Phosphorus and Nitrogen Pollution through Use of a Framework for State Nutrient Reductions,” that stated the EPA would work with states to develop statewide strategies for



reducing nitrogen and phosphorus loadings.<sup>4</sup> From this, the EPA developed Data Access Tool with key information such as the nitrogen and phosphorus pollution in U.S. waters. From this tool the all the data from the monitoring stations within the HUC8 watershed that contained the study area was downloaded and processed.

## 2.2 Data Processing

### 2.2.1 Watershed Delineation

Three HUC10 watersheds were utilized in this study: Deep Canyon, Sunnyside and Spring Creek. Initially, a stream gage on the Yakima River downstream of the dairies was used to delineate a basin using the ArcGIS Spatial Analyst tool, “Watershed.” The basin was quite expansive, covering a large region of Central Washington. Three HUC10 watersheds located at the base of the basin contained the majority of the dairies in the Lower Yakima Valley. Only these three watersheds were used for data processing. The names and locations of the three watersheds are shown in Figure 4.

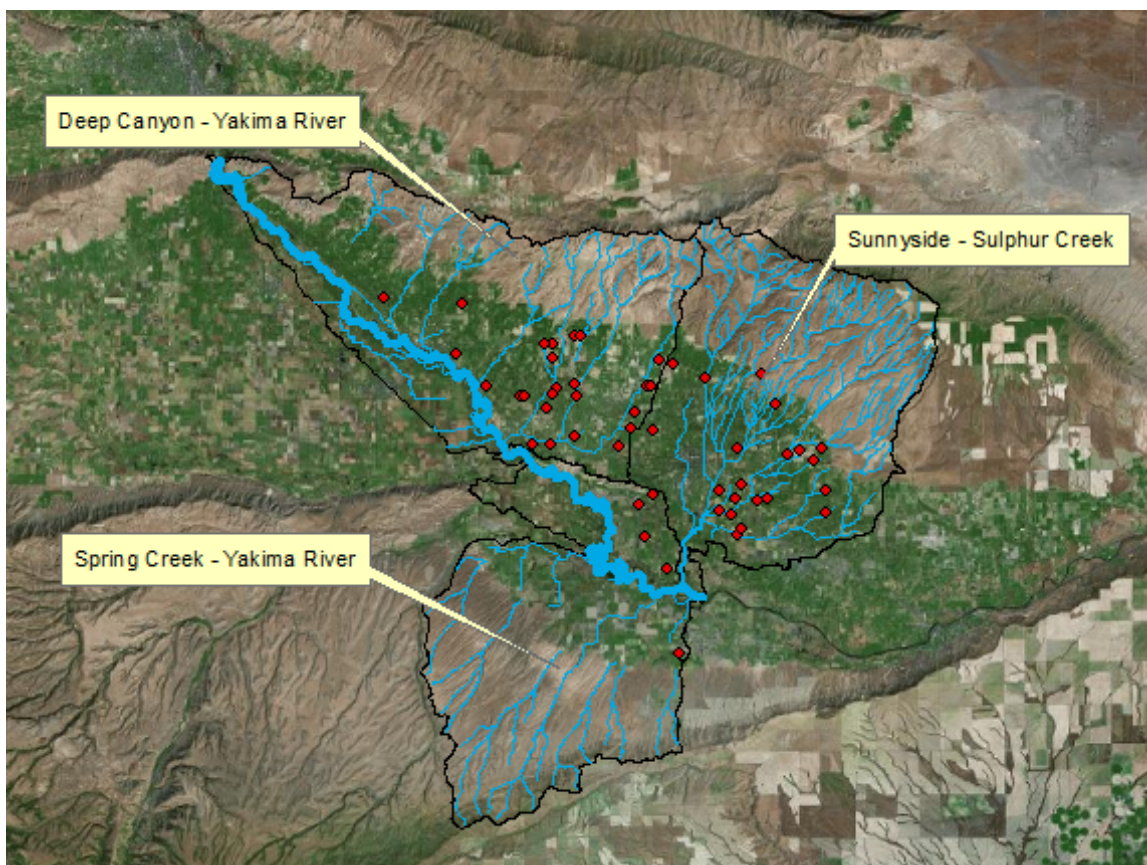


Figure 4. HUC10 watersheds in the Lower Yakima Valley.

### 2.2.2 Nutrient Loading Estimates

The nutrient loading was estimated from the number of cows at each dairy and the total nitrogen and phosphorus produced per cow per day. Table 3 summarizes the average load of nitrogen and phosphorus produced by various livestock.

**Table 3. Nutrient Loading for Various Livestock.<sup>11</sup>**

<i>Livestock Type</i>	<i>Total Manure</i>	<i>Nitrogen</i>	<i>Phosphorus</i>
	<i>- lbs/day/1000-lb animal unit -</i>		
Beef	59.1	.31	.11
Dairy	80.0	.45	.07
Hogs and pigs	63.1	.42	.16
Chickens (layers)	60.5	.83	.31
Chickens (broilers)	80.0	1.10	.34
Turkeys	43.6	.74	.28

Dairy cows contribute .45 and .07 pounds of nitrogen and phosphorus respectively, per 1000-pound animal. According to Dairy Moos, the average dairy cow is approximately 1,500 pounds.<sup>2</sup> Thus, the average cow excretes .675 and .105 pounds of nitrogen and phosphorus per day. Additionally, the Natural Resource Conservation Service within the United States Department of Agriculture notes that within the Pacific Northwest 80% of the manure is recoverable. Therefore, 20% of the manure is not recoverable and contributes to the total nutrient loading. The final calculations for nutrient loading per dairy are as follows.

$$\text{Nitrogen Load} = .675 \times \text{Dairy Size} \times .2 \tag{1}$$

$$\text{Phosphorus Load} = .105 \times \text{Dairy Size} \times .2 \tag{2}$$

As previously noted, the dairy size supplied by the WSDE is a range, not a specific number per dairy. Therefore a low, medium and high estimate for the number of cows within a dairy was made for each small, medium and large dairy. Table 4 summarizes these estimates.

**Table 4. Dairy Size Estimate Matrix.**

<b>Dairy Size:</b>	<b>Estimate</b>		
	Low	Medium	High
Small	50	100	150
Medium	300	450	600
Large	750	900	1050

By combining Equations (1) and (2) with the dairy size estimates in Table 4, the nutrient loading estimates were calculated (Table 5). These values were incorporated into the Dairy shapefile.

**Table 5. Nutrient Loading per Day per Dairy Size Estimate.**

Size	Nitrogen Loading Estimate			Phosphorus Loading Estimate		
	Low	Medium	High	Low	Medium	High
Small	6.75	13.5	20.25	1.05	2.1	3.15
Medium	40.5	60.75	67.5	6.3	9.45	12.6
Large	101.25	121.5	141.74	15.75	18.9	22.05

### 2.2.3 Nutrient Loading within the Watersheds

The nutrient loading estimate per dairy was used to estimate the nutrient loading per watershed. This was accomplished by spatially joining the Dairy shapefile with the HUC10 shapefile. This created a new shapefile that summed the total loading of the dairies and differentiated them by watershed. The nutrient loading estimates were then used to spatially interpolate the nutrient loading throughout the three HUC10 watersheds by Natural Neighbor and Kriging.

### 2.2.4 Government Sample Stations

The data obtained from the Nitrogen and Phosphorus Pollution Data Access Tool was uploaded from an Excel file to ArcGIS. Once all the stations were mapped onto Washington State the Excel file with the results of the sampling sites were uploaded to ArcGIS as well. The station locations were then joined with the sampling results into one shapefile.

### 2.2.5 Individual Assessment of Nitrogen and Phosphorus Loading from Dairies

To assess a dairy's nutrient loading upon a body of water the data stored in the NHDPlus V2 dataset was utilized. First, five dairies were chosen that were within 155m of a stream or river. This minimized nutrient losses to the soil. The distance, the velocity and the flow were recorded for each segment of stream/river from the dairy of interest to the Yakima River. For each segment the retention time that water is in a segment was calculated as follows,

$$\text{Retention Time of Stream Segment} = \frac{\text{Length of Stream Segment}}{\text{Velocity of Stream Segment}} \quad (3)$$

Multiplying Equation (3) by the flow rate of the stream segment yields the volume of water in the stream segment (Equation 4).

$$\text{Volume of Stream Segment} = \text{Flow Rate of Stream Segment} \times \text{Retention Time of Stream Segment} \quad (4)$$

The total time for a particle travel to the Yakima River from a dairy is the summation of the Retention Time calculated for each segment. The total volume of water between the dairy and the Yakima River is the summation of the volume of each segment. The number of volumes that reach the Yakima River within one day is the shown in Equation 5.

$$\text{Volume of Water Entering the Yakima River per day} = \sum \text{Volume of Segment} \times \frac{24 \text{ hours}}{\sum \text{Retention Times}/3600 \text{ seconds}} \quad (5)$$

The medium estimate (Table 5) of nitrogen and phosphorus loading (converted to g/day) was used to calculate concentration. By combining the nutrient load and Equation 5 the concentration of nitrogen and phosphorus in a river when entering the Yakima River is calculated (Equation 6).

$$\text{Concentration of Nutrient} = \frac{\text{Nutrient Load per day}}{\text{Volume of Water Entering the Yakima River per day}} \quad (6)$$

### 3.0 Results and Discussion

#### 3.1 Dairy Cows in the Region

Within the study area there are 51 dairies. These include 4 small, 11 medium and 36 large dairies. Table 6 summarizes the dairy sizes by HUC10 watershed.

**Table 6. Dairy Size Distribution by Watershed.**

<i>Size</i>	<i>Deep Canyon</i>	<i>Sunnyside</i>	<i>Spring Creek</i>	<i>Total</i>
Small	3	1	0	4
Medium	6	4	1	11
Large	16	16	4	36
Total	25	21	5	51

As seen, Deep Canyon watershed contains the most dairies in the region. Although Sunnyside contains fewer dairies it is important to note that it still contains the same number of large dairies as Deep Canyon. Spring Creek watershed contains the fewest number of dairies. From this distribution of dairies the majority of the nutrient loading would be north of the Yakima River.

#### 3.2 Nutrient Loading

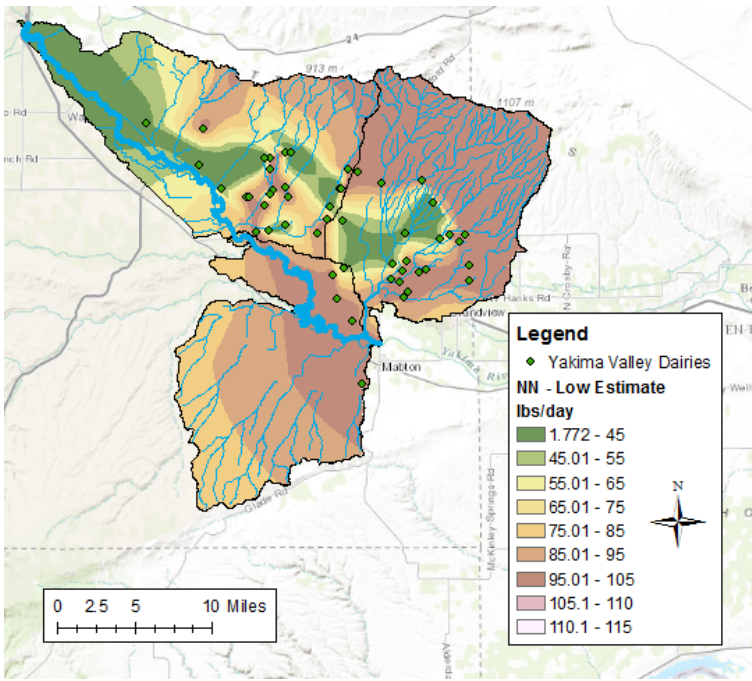
Initially, Thiessen polygons were utilized to calculate the load per watershed. However, this method overestimated the load per watershed by counting the load of one dairy in two watersheds adjacent to each other. By joining the dairy data with the HUC10 regions accurate nitrogen and phosphorus loadings could be calculated, as summarized in Table 7.

**Table 7. Daily Nutrient Loading per Watershed.**

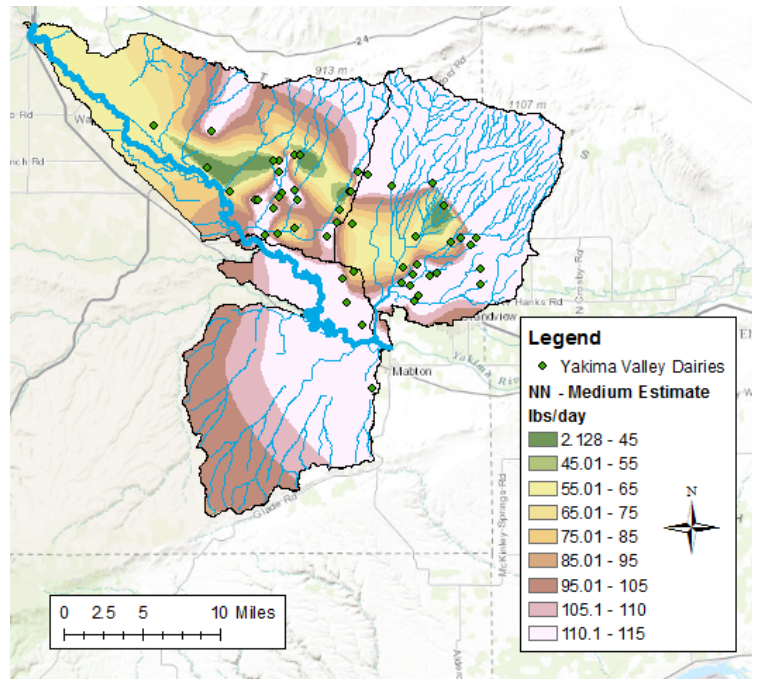
<i>Watershed</i>	<i>Total Nitrogen Load (lbs)</i>			<i>Total Phosphorus Load (lbs)</i>		
	<i>Low</i>	<i>Medium</i>	<i>High</i>	<i>Low</i>	<i>Medium</i>	<i>High</i>
Spring Creek	445.5	546.75	648	69.3	85.05	100.8
Sunnyside	1782	2200.5	2612.25	278.25	342.3	406.35
Deep Canyon	1789	2227.5	2673	277.2	346.5	415.8
Total	4016.5	4974.75	5933.25	624.75	773.85	922.95

Given that Spring Creek has far fewer dairies than Deep Canyon and Sunnyside, it is reasonable that it would have the smallest loading per day of the three watersheds. Sunnyside and Deep Canyon are comparable in loading magnitude.

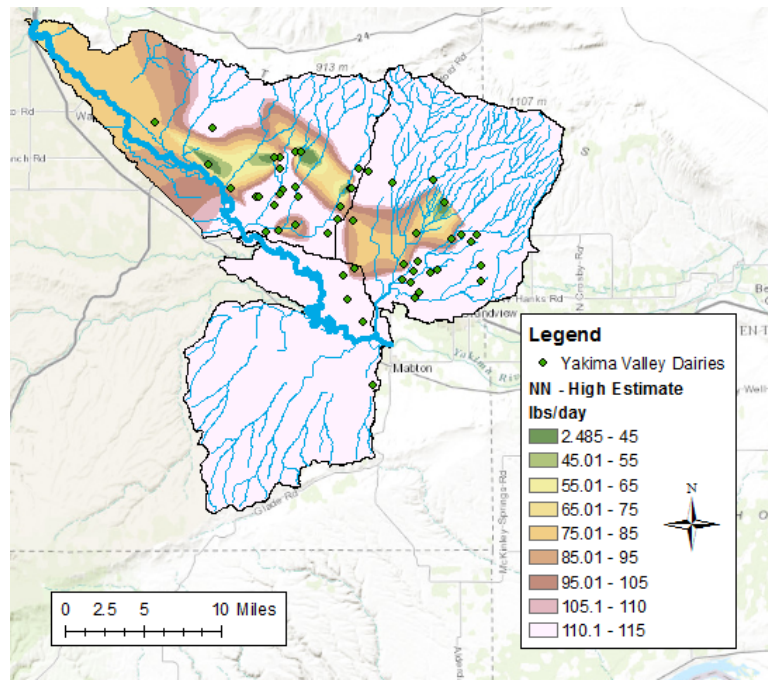
To understand nutrient loading distribution throughout the watershed the spatial interpolation techniques, Natural Neighbor and Kriging, were employed. Initially, Spline was utilized as an interpolation technique, however, Spline produced drastic values (such as negative loading), thus, the results were discarded. IDW was considered as another form of interpolation, but as the basic equation used for interpolation is the same as Natural Neighbor<sup>1</sup>, only Natural Neighbor was utilized. Figure 5 illustrates the results of Natural Neighbor interpolation from the nitrogen load. Figure 6 illustrates the results of the Kriging interpolation from the nitrogen load. The loading ranges associated with each color were kept constant throughout the figures for the purpose of comparison.



(A)

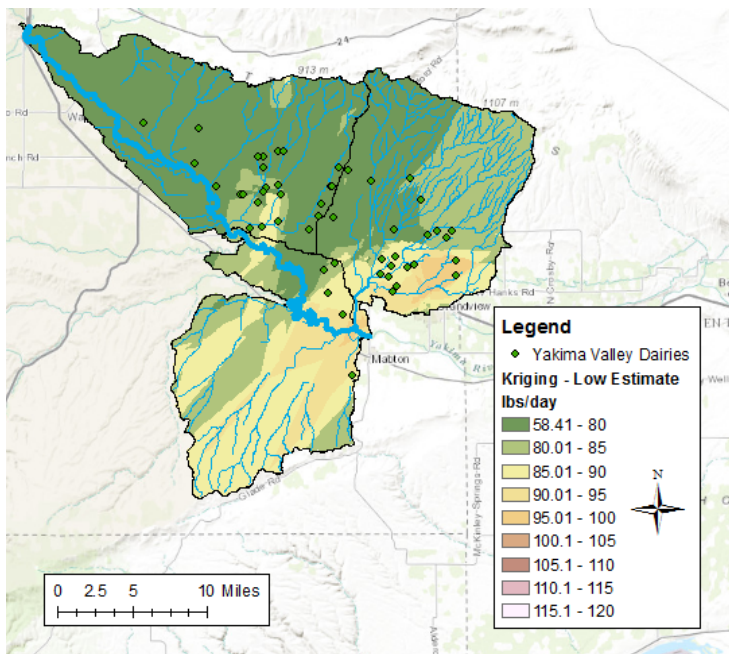


(B)

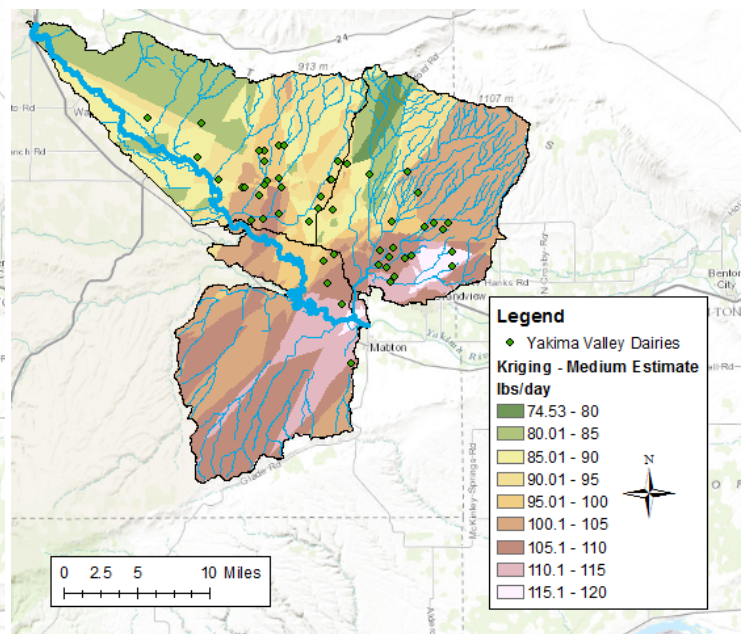


(C)

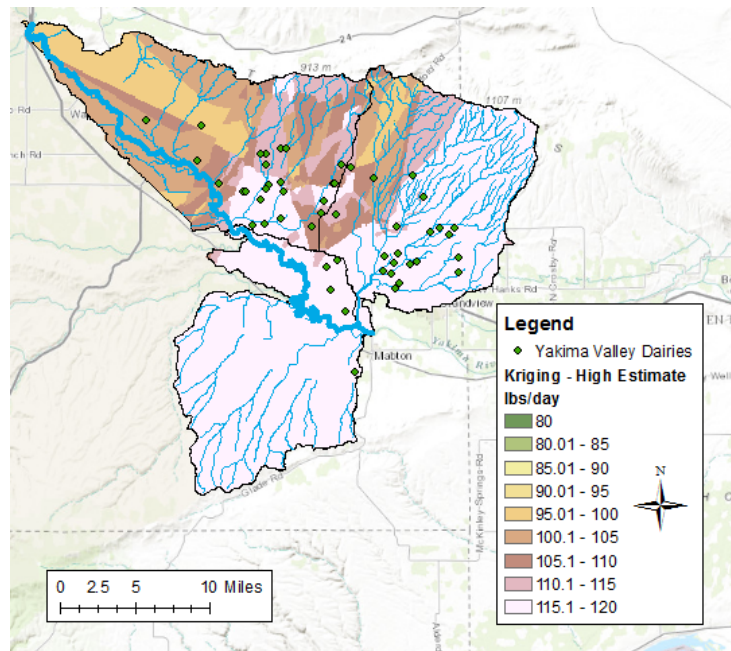
**Figure 5. Natural Neighbor Interpolation of Nitrogen Loading (lbs/day).  
A.) Low Estimate. B.) Medium Estimate. C.) High Estimate.**



(A)



(B)

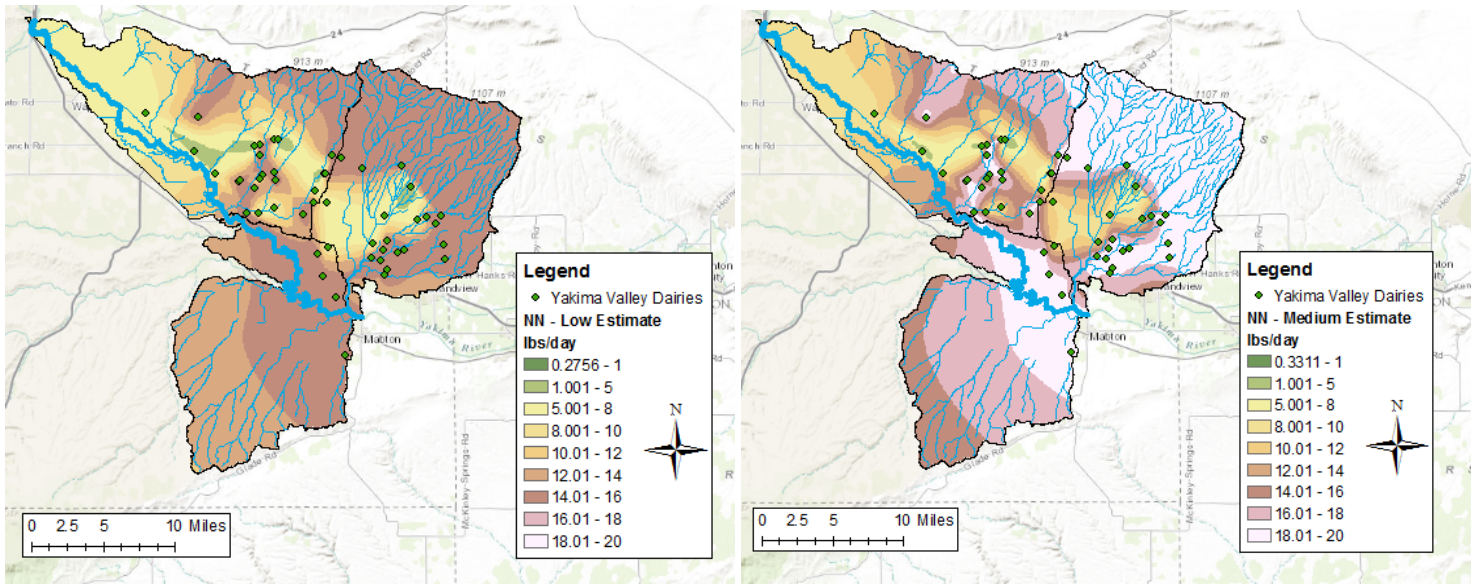


(C)

**Figure 6. Kriging Interpolation of Nitrogen Loading (lbs/day).  
A.) Low Estimate B.) Medium Estimate. C.) High Estimate.**

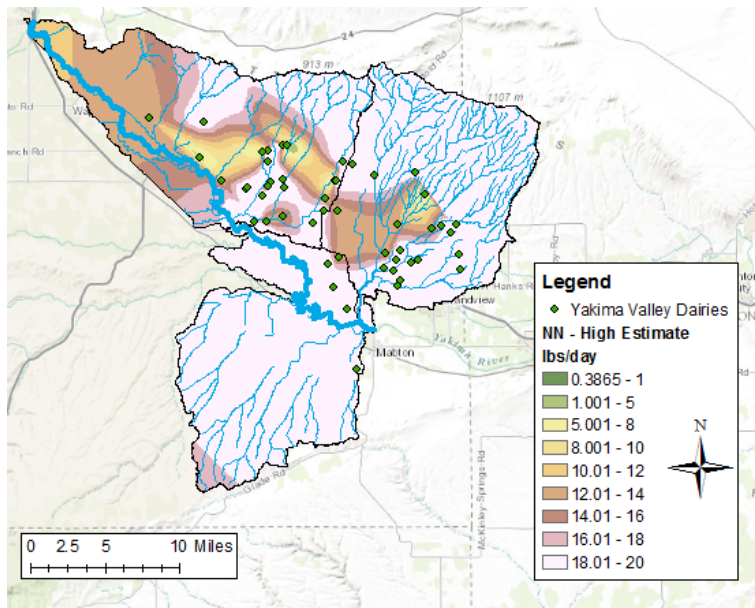
These figures illustrate that the smaller dairies are located throughout the middle of the Sunnyside and Deep Canyon watersheds. The larger dairies are located closer to the Yakima River and the southeastern portion of the Sunnyside watershed. Overall, Kriging produced results that were generally lower than those of Natural Neighbor, despite the same inputs. The distribution throughout the watershed was also more irregular by the Kriging method.

When analyzing these spatial interpolations, the inaccuracies at the perimeter of the watersheds need to be taken into consideration. In these areas the spatial analyst tool is predicting a value from the nearest dairy despite that the nitrogen load would not travel upstream. Therefore, the interpolations along the perimeter are irrelevant. These areas should be discounted when estimating nitrogen loading. When viewing Figures 5 and 6 only the area that contains the concentrated dairies should be considered. Furthermore, since there is great variability in the values of nitrogen loading (due to the low, medium and high estimates), the exact nitrogen loading “values” should not be considered so much so as the distribution of the nitrogen loading. These figures provide a visual of the areas and bodies of water in the Lower Yakima Valley that are more likely to be impacted by nitrogen loading from the dairies. The same should be applied to the phosphorus loading interpolation (Figures 7 and 8).



(A)

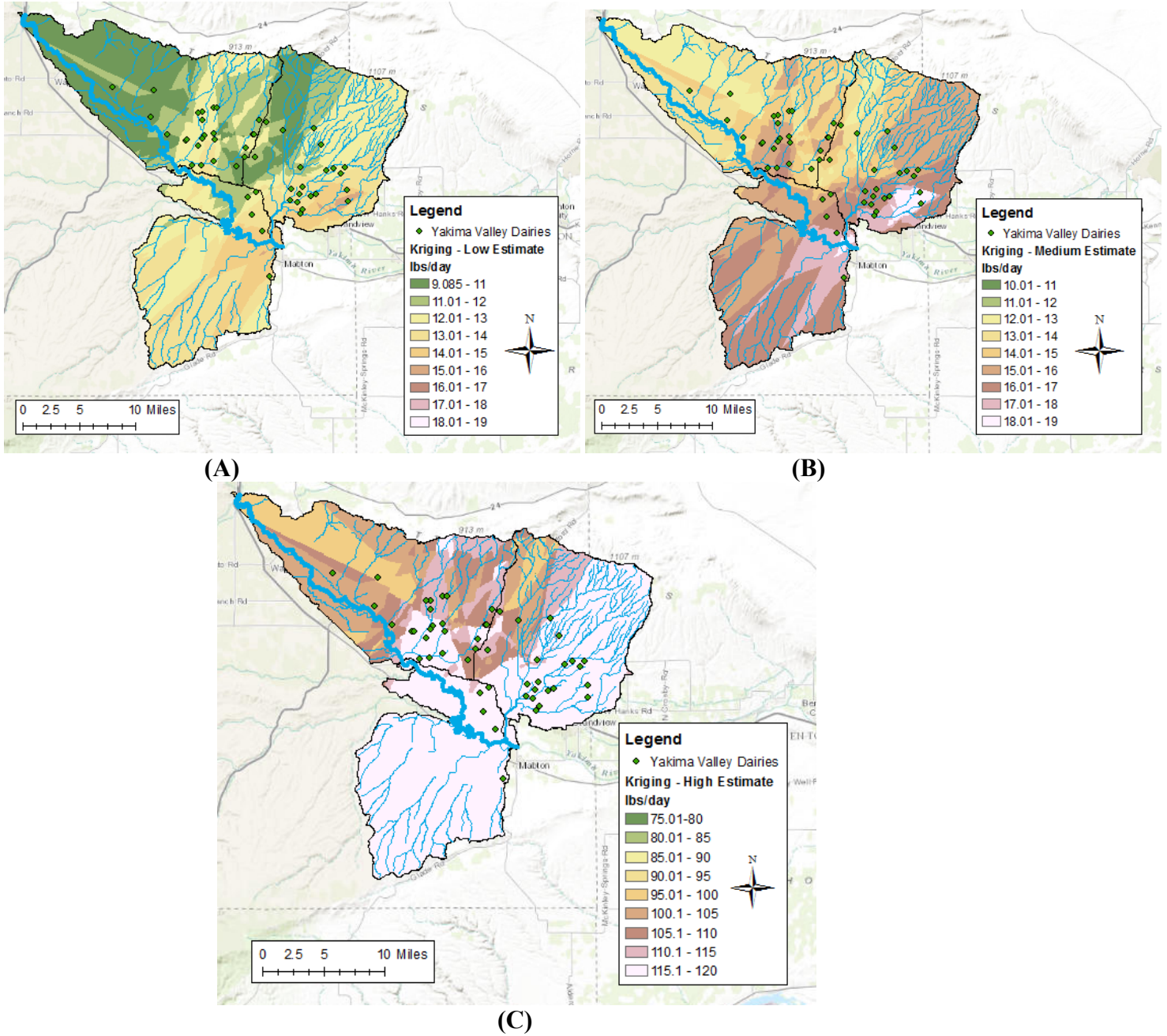
(B)



(C)

**Figure 7. Natural Neighbor Interpolation of Phosphorus Loading (lbs/day)  
A.) Low Estimate. B.) Medium Estimate. C.) High Estimate.**

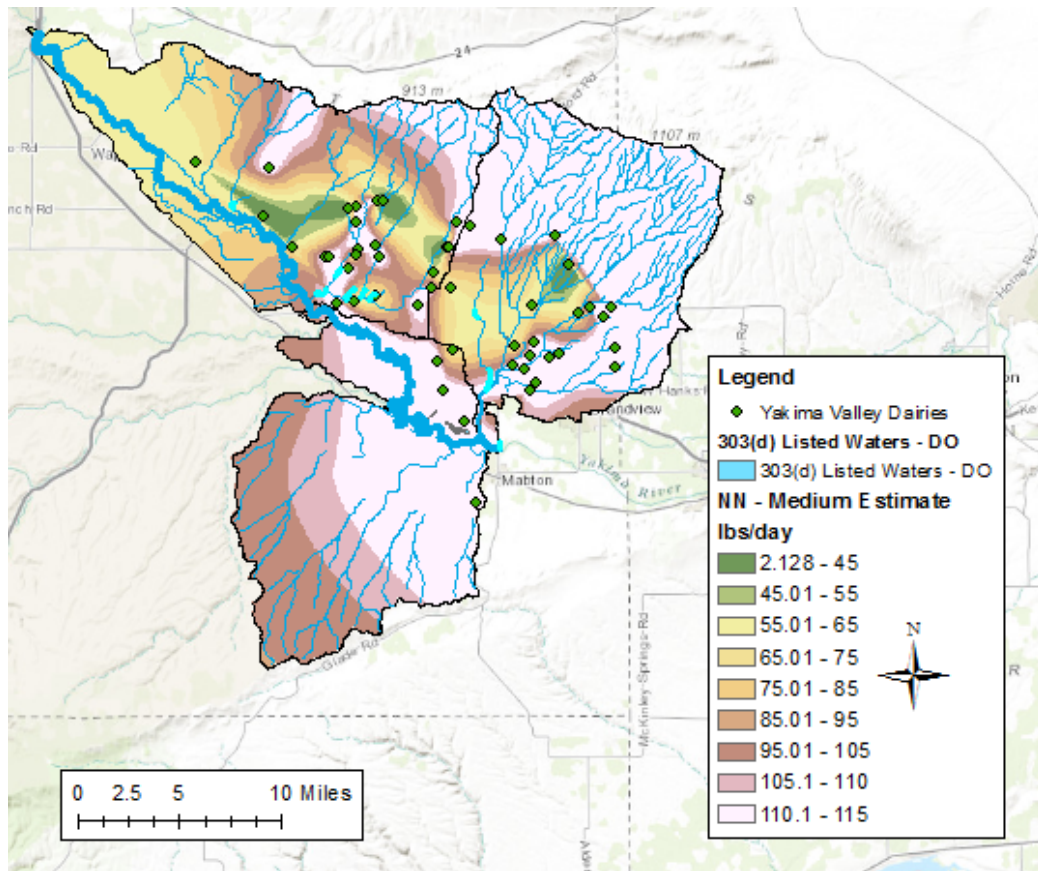




**Figure 8. Kriging Interpolation of Phosphorus Loading (lbs/day). A.) Low Estimate B.) Medium Estimate. C.) High Estimate.**

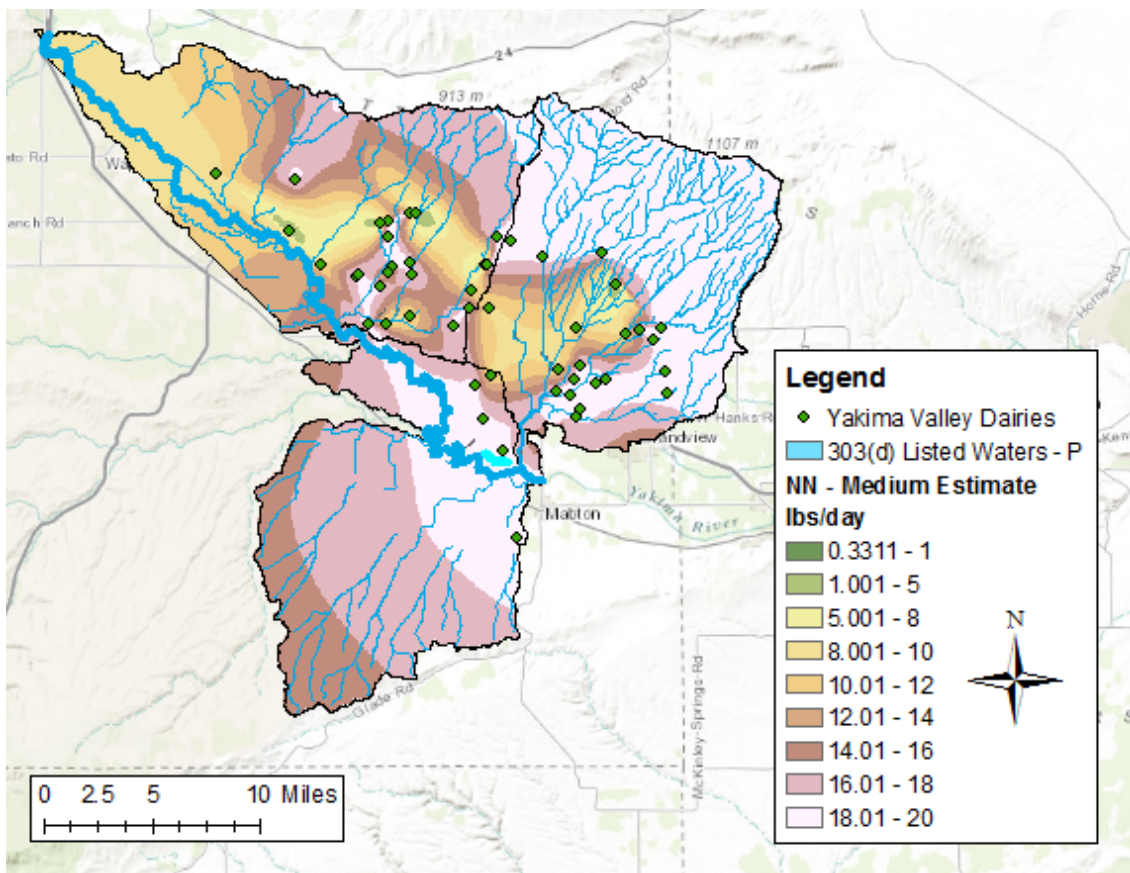
To further explore whether the spatial interpolations provide insight on nutrient loading in the region, the 303(d) listed waters for dissolved oxygen within the region were overlaid with the nitrogen Natural Neighbor interpolation map. As aforementioned, a flux of high nitrogen loading into a body of water leads to rapid microbial growth. The decay of these microorganisms depletes the water body's dissolved oxygen levels. As seen in Figure 9, there is some correlation between regions of high nitrogen loading and the 303(d) listed waters. The impaired waters are in regions classified by high nitrogen loading. Nevertheless, there are some 303(d) listed waters

for dissolved oxygen that lie within regions of moderate nitrogen loading, so this correlation is may not be strong enough to assert that the nitrogen loading is solely from the dairies.



**Figure 9. Nitrogen Loading Interpolation and 303(d) Dissolved Oxygen Listed Waters.**

The phosphorus Natural Neighbor interpolation overlaid with the 303(d) listed waters for Total Phosphorus show a stronger correlation. Within the three HUC10 watersheds there is one lake that is considered a 303(d) listed water for Total Phosphorus and it is located in the region with the highest phosphorus loading from the Kriging and Natural Neighbor interpolations.

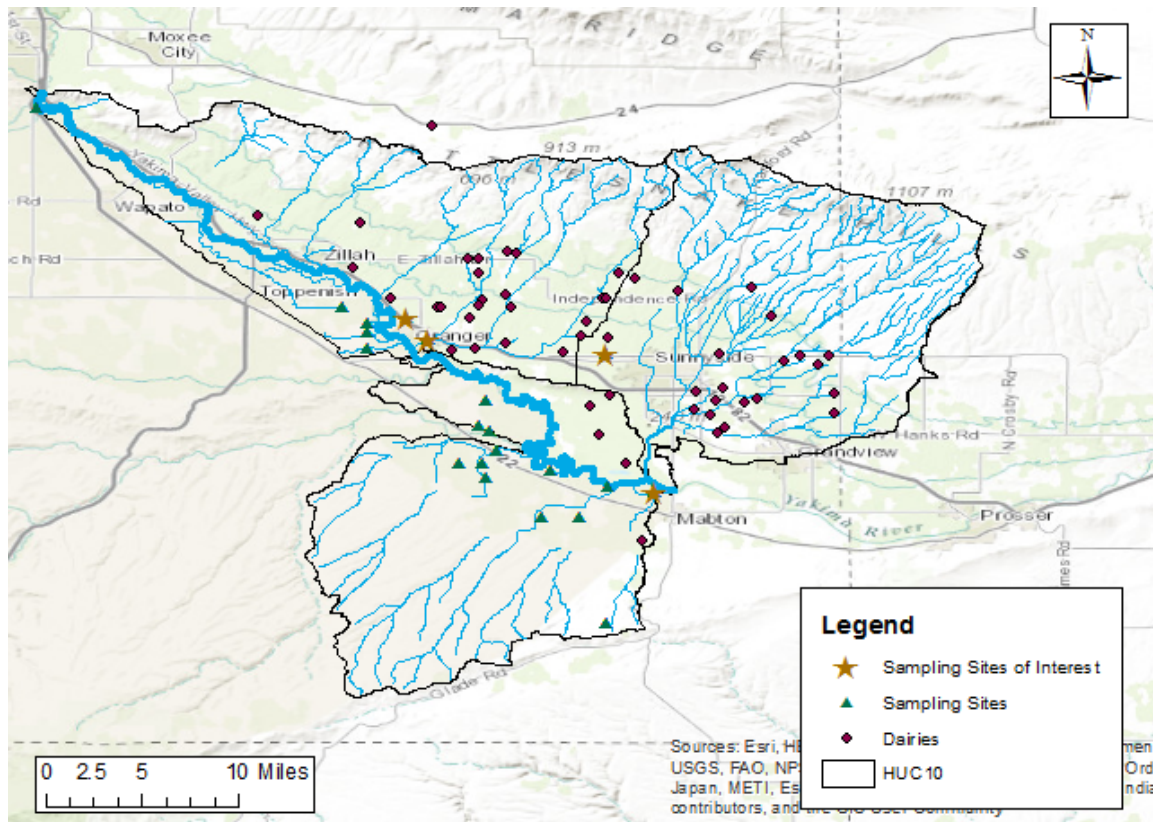


**Figure 10. Phosphorus Loading Interpolation and 303(d) Phosphorus Listed Waters.**

Additionally, it should be noted that this body of water has minimal flow. Minimal flow and elevated daily phosphorus loadings would cause the phosphorus to accumulate within the lake. Thus, the spatial interpolations may be better at predicting an impaired water if the water body has low flow. This could also explain why some of the dissolved oxygen impaired waters are located in regions of moderate loading (Figure 9). It is possible that despite the moderate nitrogen loading there is low flow within the streams; this would cause nitrogen accumulation and consequently low dissolved oxygen.

### 3.3 Government Sampling Sites

To further assess the correlation between the dairies, nutrient loading and water quality, results of government water sampling sites were taken into consideration. Within the three HUC10 watersheds there were several sampling stations, but only four stations that are located downstream of the dairies, and thus, relevant to this study. Figure 11 shows the locations of these sampling sites.



**Figure 11. Government Sampling Sites.**

The stations of interest are denoted with a star. The inorganic nutrient testing was conducted by the United States Bureau of Reclamation and the EPA National Aquatic Resource Survey. The stations provided data on the concentration of orthophosphate, phosphorus, ammonia, Kjeldahl nitrogen and inorganic nitrogen (nitrite and nitrate). This data also spanned a broad range of dates, from 1999 to 2011. The majority of the inorganic nitrogen results are considered higher than the normal inorganic nitrogen concentration for Washington surface waters (between 0.1 mg/L to 0.6 mg/L<sup>12</sup>) but were below the EPA maximum contaminant level for nitrogen, 10 mg/L. As shown in the interpolations for nitrogen in Figure 5 and Figure 6 the sampling location within the Sunnyside watershed would be expected to contain the least amount of nitrogen of the four sampling stations. This station has an inorganic nitrogen concentration of 0.3 mg/L whereas the other three stations have loadings of at least an order of magnitude larger. The station with the largest nitrogen loading, 11.5 mg/L, greater than the EPA MCL, is located the furthest downstream. This is also a region predicted to have high nitrogen loading, indicating a relationship between the nutrient loading from dairies and the actual nitrogen concentration within streams.

On the other hand, the results pertaining to phosphorus were less conclusive. Phosphorus remains higher at the stations located in high phosphorus zones, but only by minute margins. Given that there are only four sampling stations, this is not enough data to conclude the correlation between the predicted regions of high phosphorus loadings and actual field samples.

### 3.4 Evaluation of Individual Dairies' Nutrient Loading on the Yakima River

Five dairies that were located within 155 meters of a stream or river were analyzed individually for their nutrient loading on the Yakima River. The dairies were chosen due to their proximity to a nearby stream to minimize nutrient losses to the soil. The dairies studied are shown in Figure 12. Table 8 summarizes the results of the analysis.

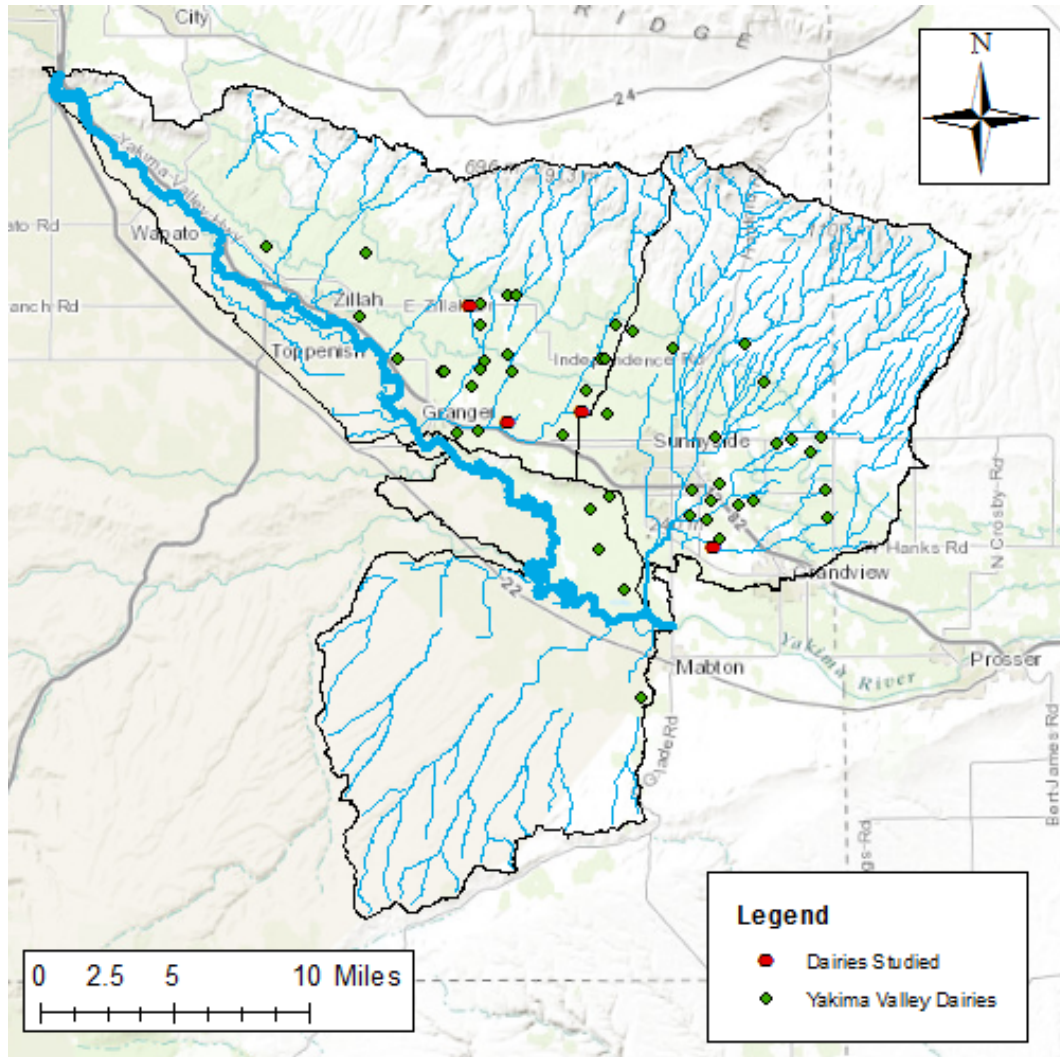


Figure 12. Dairies studied for individual nutrient loading on the Yakima River.

**Table 8. Nutrient Loading on the Yakima River by Individual Dairies.**

<b>Dairy</b>	<b>Size</b>	<b>Number of Cows</b>	<b>Distance to River/Stream [m]</b>	<b>N concentration [µg/L]</b>	<b>P concentration [µg/L]</b>
Frieslandia Dairies LLC	Large	900	137.27	0.0105	0.0016
Deruyter Bros Dairy	Large	900	15.86	0.0357	0.0056
Harrison Dairy	Medium	450	154.76	0.0066	0.0010
Liberty Dairy	Small	100	82.9	0.0086	0.0013
Suncrest Dairy	Medium	450	121.26	0.0155	0.0024

The nitrogen and phosphorus concentrations calculated for all the dairies are very low when entering the Yakima River. The concentration is strongly dependent on the distance the dairy is from the Yakima River (thus, the volume of water available to dilute the nutrients). Even the large dairies, Frieslandia Dairies LLC and Deruyter Bros Dairy, are far below a concentration of concern. According to Yang *et al.*<sup>15</sup>, for a river to be considered “Eutrophic” the concentration of nitrogen must be above 2000 µg/L and the concentration of phosphorus above 100 µg/L. As all the calculated concentrations are well below this, it is improbable a single dairy is the sole contributor to surface water contamination. The flow of the stream plays a large role in the dilution of the waste from dairies.

## **4.0 Conclusions and Future Work**

The Lower Yakima Valley contains 51 dairies, which comprises only 12% of the total dairies in Washington but over 40% of the cows. While these dairies have previously been shown as the source of groundwater pollution within the region, one cannot definitively assert from this data they are the sole source of surface water pollution. The concentration of nitrogen and phosphorus within a water body is dependent on the nutrient load that reaches the river and the flow of the river. The constant flow of rivers and streams dilutes the nutrients as they enter larger bodies of water, thus, it is difficult by spatial interpolation to differentiate which dairies are at risk. For bodies of water with minimal flow, spatial interpolation may provide the basis of a tool for determining which bodies of water are at risk.

Future work to assess the impact of these dairies on surface water should focus on integrating the nutrient loading and the flow within the rivers. This could be accomplished by combining the data within NHDPlus V2 dataset, the direction of flow accumulation and the dairy nutrient loading. Additionally, the amount of nutrients that percolate into the soil versus the runoff into the streams should be analyzed. This analysis could be completed by obtaining the soil data for the region and calculating its permeability. This data combined with the direction of flow on the Lower Yakima Valley landscape would predict which direction the nutrients are travelling and the portion lost to the soils. Moreover, more field samples should be taken in regions that are downstream of dairies. Finally, obtaining data on the exact number of cows in a dairy would increase the accuracy of this study. While the estimates may provide a general idea of the nutrient loading, the values still could be vastly under- or over-estimated. With additional

specific and complete data a more comprehensive study of the impact of dairies in the Lower Yakima Valley can be conducted.

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