

Investigating nitrogen levels in Hornsby Bend monitoring wells

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Abstract

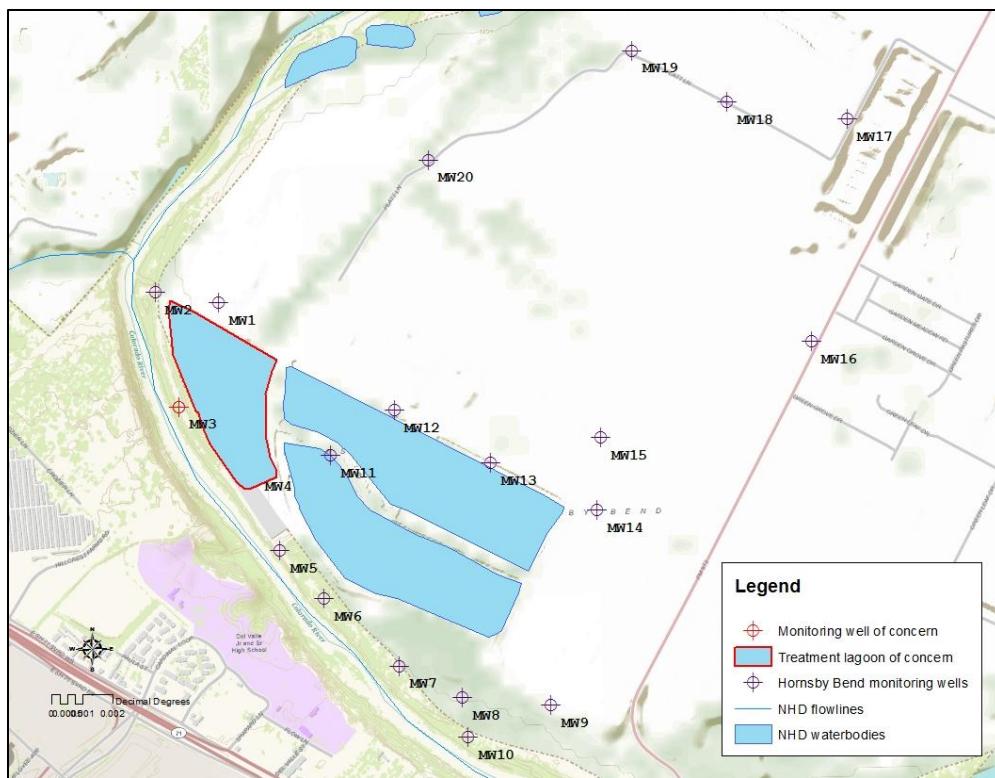
The objective of this investigation is to evaluate the distribution of ammonia and nitrogen concentrations throughout the aquifer layer underlying Hornsby Bend Biosolids Manufacturing Facility in Austin, Texas. Concentration distributions were analyzed using time-seriate and time-averaged techniques in ArcGIS, and these distributions were evaluated to determine whether the source of elevated ammonia levels is due to nearby lagoon leaching. In addition, groundwater depth was used as alternate indicator of leaching by determining the level of swelling around the lagoon. While the distribution of ammonia supports a lagoon leaching scenario, distribution of total nitrogen and groundwater depths do not support this theory. The report concludes that more transient environmental phenomena are likely dominating total nitrogen and groundwater levels of the plant, though more work needs to be done to rule out any contributions from the lagoon.

Introduction

Hornsby Bend Biosolids Management Facility in Austin, Texas processes municipal biosolids by reducing pathogenic content, decreasing biological oxygen demand and raising percent solids. The resultant material is then beneficially reused via direct land application or further composted and sold to local vendors. Water extracted in the process is diverted to a clarification unit before being channeled through a series of treatment lagoons. Concerned about the potential leaching of contaminants into proximal groundwater, Hornsby Bend constructed 21 monitoring wells on-site in the 1990s and began periodic sampling and analysis of several chemical parameters.

Since 2005, one such parameter — ammonia — has been detected in elevated levels in one particular well near a lagoon. There are a number of possible explanations for the observed concentrations, ranging from anoxic conditions to biologically mediated reaction; however, the main concern is that a breach may exist in the lagoon. The work contained herein characterizes 1) ammonia and total nitrogen composition and 2) groundwater depth in the underlying aquifer of the plant. These characterizations are made using time-seriate and time-averaged spatial analyses, which provide important insight into the potential source of elevated ammonia.

Figure 1 Monitoring well locations at Hornsby Bend Biosolids Management Facility. The monitoring well exhibiting elevated ammonia concentrations and proximal lagoon are outlined in red.



Methods

Feature basemap construction

A feature basemap was constructed by overlaying the ESRI topological basemap with flowline and waterbody features from the National Hydrography Dataset (NHD). NHD features were pared down to those contained within Travis County political boundaries in order to limit computational and rendering time. Monitoring well spatial data was originally obtained from a hardcopy report submitted at the time of their construction; however, no reference data frame was provided in the report. The data was imported as xy-coordinates and projected using a variety of reference coordinate systems including State Plane Central Texas (the current City of Austin standard), UTM Zone 14 and NAD83, but each reference failed to appropriately project the data. As a workaround, well pads were located and approximate geographic coordinates were obtained using Google Earth orthoimagery.

Chemical data and speciation concerns

Chemical data for each monitoring well was obtained from the City of Austin AWLIMS database; however, quantity and quality of the data is poor for several reasons. First, while groundwater monitoring was initiated for quality assurance purposes, regular sampling is not required by the facility's operating permit. As a result, sampling frequency is usually on a

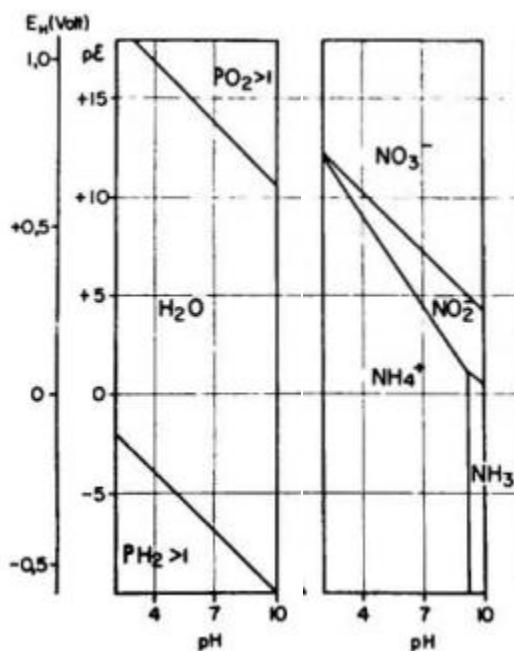
biennial basis, does not fall in regularly-spaced intervals and is not seasonally consistent. Further complicating matters are changes in instrumentation, method-detection-limits, and analytes of concern since sampling began. Such data limitations have constrained statistical analysis on sampling points and have obscured differences among elevated concentrations and anomalous data.

For instance, the consulting report detailing on-site monitoring well construction in the 1990s also recommended testing several chemical parameters including nitrates and nitrites; the report did not suggest testing ammonia levels as they are not a primary drinking water concern. However, this approach neglected oxidative/reductive reactions that readily convert nitrogen between ammonia-ammonium and nitrate-nitrite forms. Nitrogen speciation is dominated by ammonia-ammonium forms in electron deficient environments, such as when anoxic conditions are observed in a water column. In contrast, more oxidative conditions promote nitrate and nitrite speciation in the aqueous system. This concept is shown in terms of relevant reactions in Table 1 and graphically in Figure 2. As the figure demonstrates, nitrogen speciation is a function of both acidity and electron activity in the system. The portion of the figure on the left represents the natural bounds of electron activity in water. The line separating H_2O and $\text{PO}_2 > 1$ represents the most oxidative state achieved in water and the line separating H_2O and $\text{PH}_2 > 1$ represents the most reductive state. The areas of different sections on the right represent dominant species of nitrogen at the specified acidity and electron activity conditions. A superimposition of the left portion of the graph onto the right portion of the graph would show all the possible dominant forms of nitrogen in an aqueous environment. From this analysis, it is clear that ammonia (and by extension organic nitrogen) should have been tested concurrently with nitrate-nitrite to ascertain total nitrogen levels at the plant. The absence of ammonia data prior to 2005, the year ammonia analysis began and elevated levels first observed, precludes baseline establishment and makes data comparison very difficult.

Table 1 Relevant redox and acid-base reactions for nitrogen speciation in aqueous systems

$\frac{1}{2}\text{NO}_3^- + \text{H}^+ + e^- \rightleftharpoons \frac{1}{2}\text{NO}_2^- + \frac{1}{2}\text{H}_2\text{O}$	(1)
$\frac{1}{8}\text{NO}_3^- + \frac{5}{4}\text{H}^+ + e^- \rightleftharpoons \frac{1}{8}\text{NH}_4^+ + \frac{3}{8}\text{H}_2\text{O}$	(2)
$\frac{1}{6}\text{NO}_2^- + \frac{4}{3}\text{H}^+ + e^- \rightleftharpoons \frac{1}{6}\text{NH}_4^+ + \frac{1}{3}\text{H}_2\text{O}$	(3)
$\text{NH}_4^+ \rightleftharpoons \text{NH}_3 + \text{H}^+$	(4)

Figure 2 Nitrogen speciation as a function of acidity and electron activity in water. Figure taken and modified from Stumm and Morgan (1996)



Groundwater depth data

Groundwater depth data was even sparser than chemical data, mostly owing to the fact that the data was not contained within a City electronic database but was rather obtained by examining hand-written notes made at the time of sampling. Many of these notes have been misfiled or lost over time, and these holes compound the problem of an already limited dataset. However, most of the notes were recovered for the time period of interest (post-2005).

Time-series analysis

Chemical and groundwater depth data were imported as xy-data and converted into time-enabled feature class layers in ArcGIS. The following chemical parameters were used in the time-series analysis

- 1) Ammonium ion-ammonia ($\text{NH}_4^+ - \text{NH}_3$)
- 2) Total nitrogen (TOT-N), which is an aggregate of $\text{NH}_4^+ - \text{NH}_3$, organic nitrogen and nitrate-nitrite ($\text{NO}_3^- - \text{NO}_2^-$). Note the sum of $\text{NH}_4^+ - \text{NH}_3$ and organic nitrogen is measured as the parameter total Kjeldahl nitrogen (TKN).

By using the TOT-N parameter, any variations in nitrogen speciation within the aquifer were accounted for and any potential nitrogen sources could be more easily identified. Time-series were constructed for both parameters using graduated symbology to represent relative

concentrations at the plant. In addition, two $\text{NH}_4^+ - \text{NH}_3$ time-series were constructed depicting two distinct sampling time-scales. The first series represented $\text{NH}_4^+ - \text{NH}_3$ concentrations since institution as a regular analyte in 2005, and the other represented a series of monthly sampling recently undertaken to gain better insight into in-situ conditions. This purpose of this approach was to evaluate potential error as a source of sampling frequency. Note that monthly sampled wells only consist of MW1, MW2 and MW3. Thus, any comparisons made between the two time-series focused on these three wells only.

A similar time-series was developed for groundwater depth from 2003 to present. This time-series established a record of water table levels at the plant over that time. The purpose of this time-series was to illuminate any sustained swelling near the monitoring well in question. Such an event would help support the theory that elevated ammonia levels are a result of lagoon breach.

Time-averaged analysis

Groundwater chemical and depth data were also examined on a time-averaged basis. This was accomplished by using all of the recorded data in the time-frame of interest (post-2005) to generate spline-interpolated surface rasters depicting relative spatial concentrations at the plant. Surface rasters were developed for $\text{NH}_4^+ - \text{NH}_3$, TOT-N, and depth and subsequently compared for overlapping trends. The results of this comparison and time-series analyses are explicated in the following section.

Results

$\text{NH}_4^+ - \text{NH}_3$ Time-series

Results of the $\text{NH}_4^+ - \text{NH}_3$ time-series are shown in Figure 3. As can be seen from figure, the data is relatively consistent over time for each monitoring well, especially for wells in the upgradient in the plant. Fluctuations tend to be larger for the wells nearest the lagoons. In addition, monitoring wells downgradient of the treatment lagoons tend to have higher ammonia concentrations, with MW3 having extremely high concentrations relative to all other sampled wells. In contrast, the wells upgradient in the aquifer have very little ammonia concentrations. These results tend to support the scenario in which the lagoons are leaching and ammonia is accumulating in the wells downgradient.

Comparison of the time-series analyses at different time-scales indicates biennial data, despite such large sampling intervals, is fairly consistent with recent data obtained on a monthly basis. An important result of this analysis was that the data is representative of actual conditions and are not being affected by transient phenomena. A graphical comparison of these two time-scales is shown in Figure 4. Monthly time-series for $\text{NH}_4^+ - \text{NH}_3$ is shown in Figure 5.

Figure 3 Biennial NH₄-NH₃ time-series (a) 2005

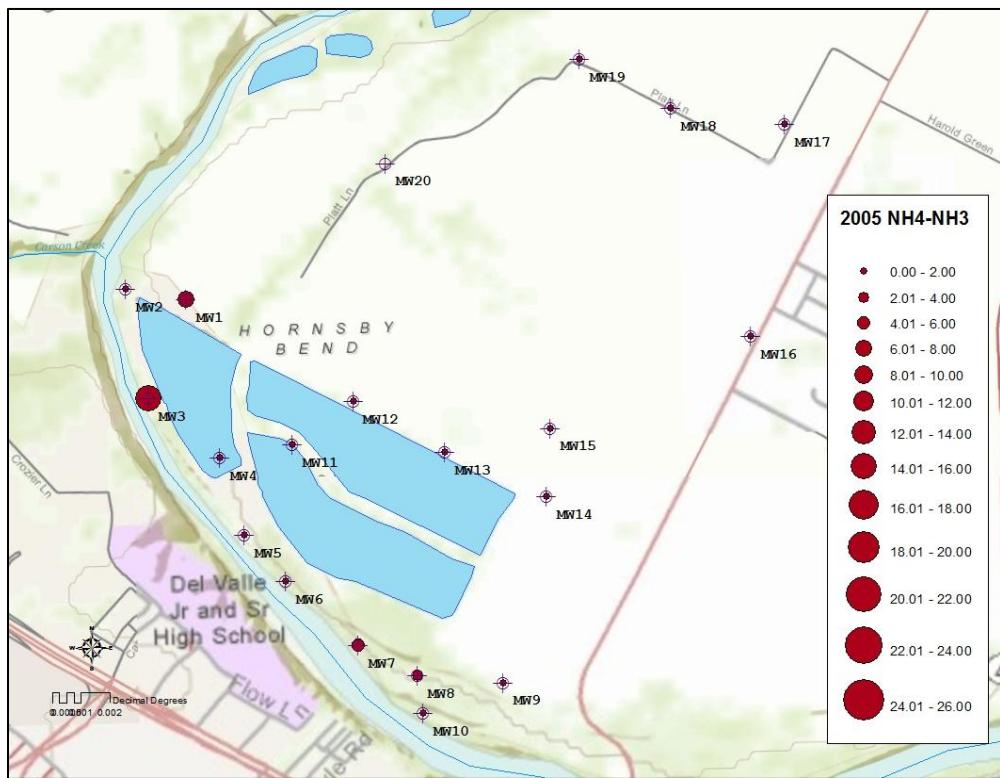


Figure 3 Biennial NH₄-NH₃ time-series (b) 2007

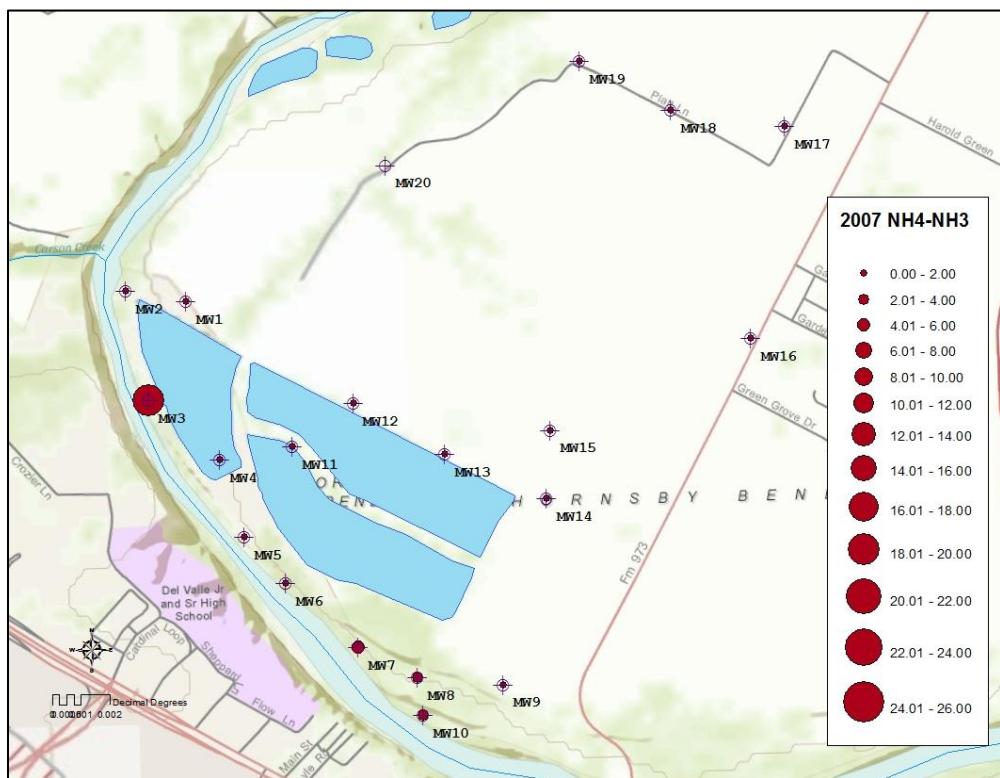


Figure 3 Biennial NH₄-NH₃ time-series (c) 2009

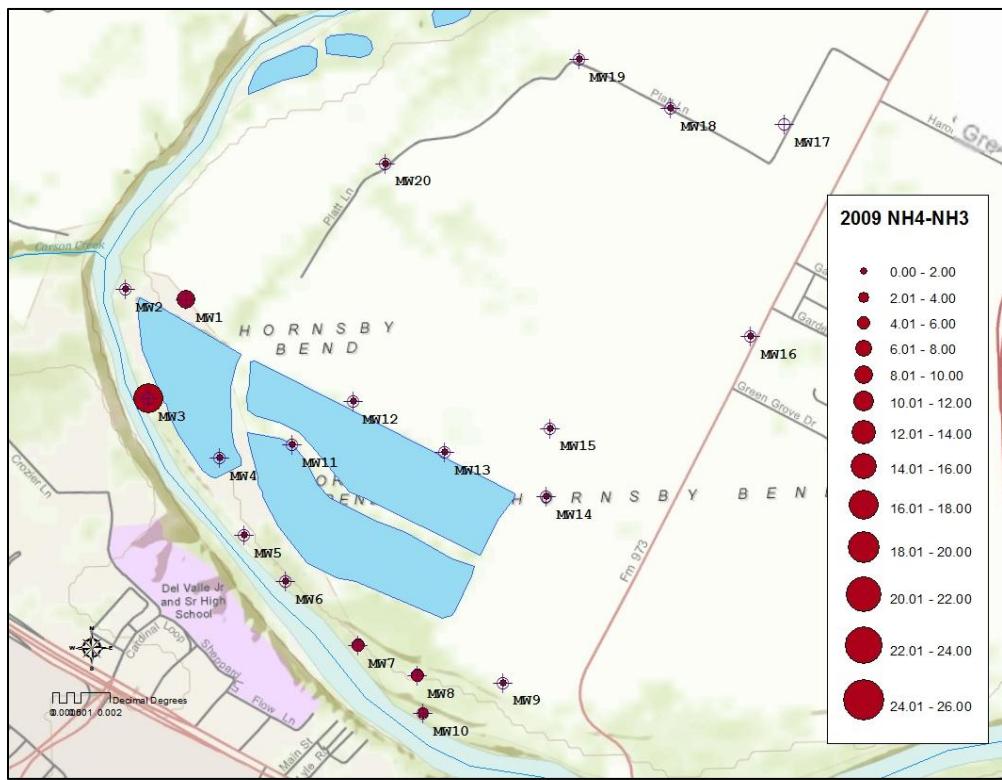


Figure 3 Biennial NH₄-NH₃ time-series (d) 2011

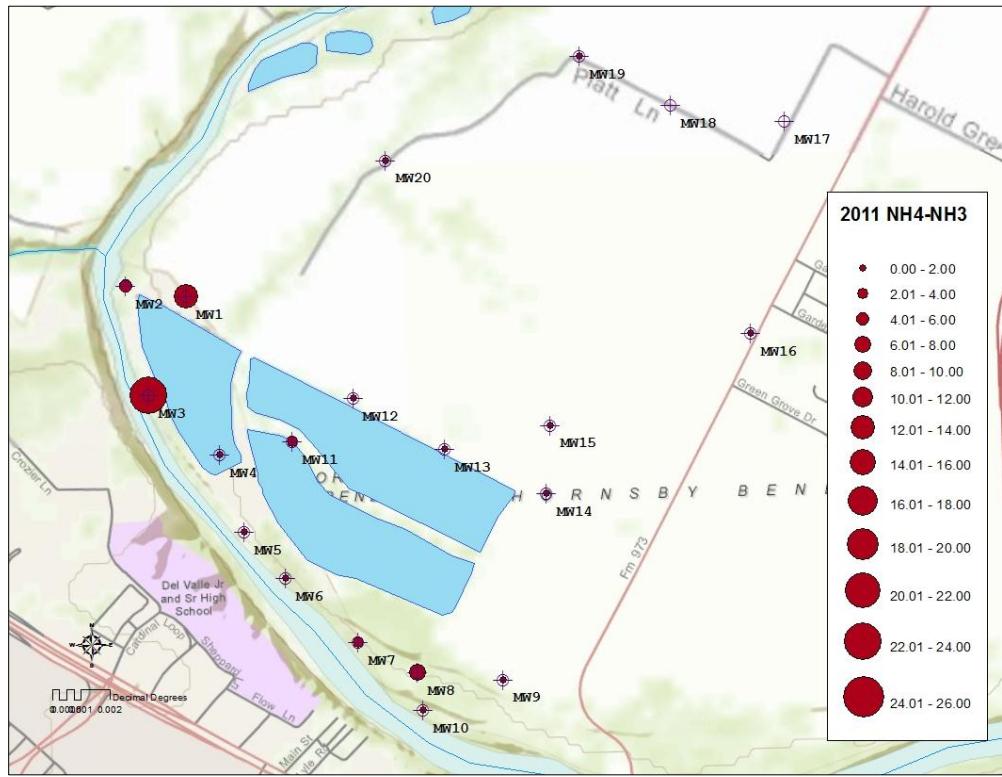


Figure 4 Comparison of average biennial and monthly sampled NH₄-NH₃ concentrations including 5% error bars

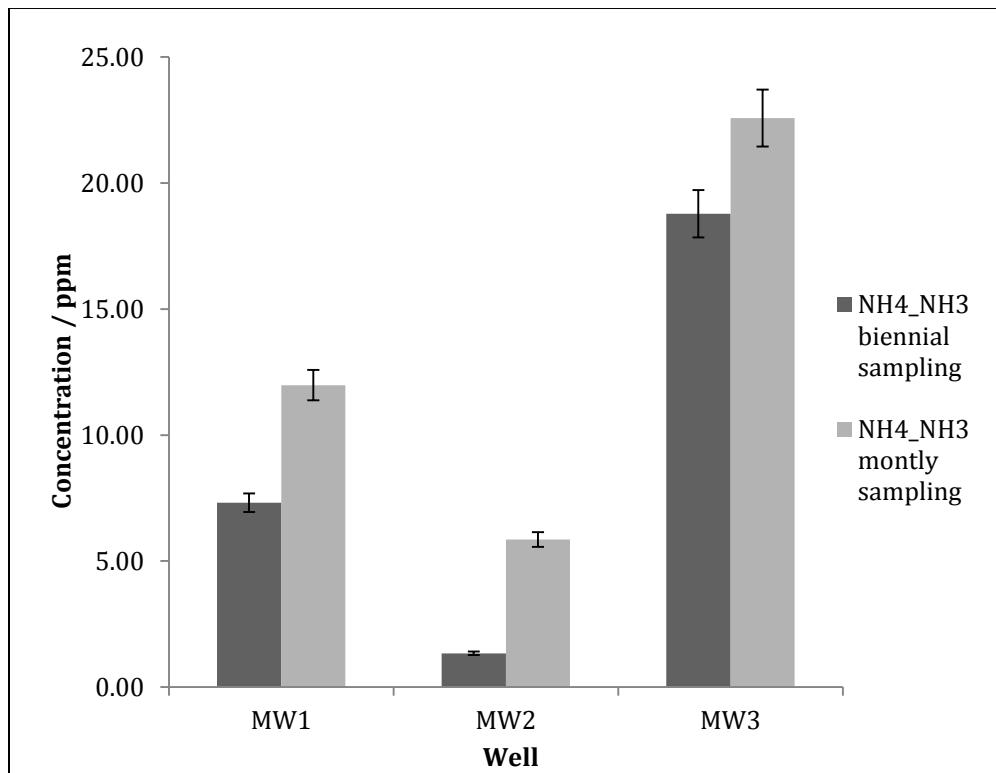


Figure 5 Monthly NH₄-NH₃ time-series (a) Jun 2011

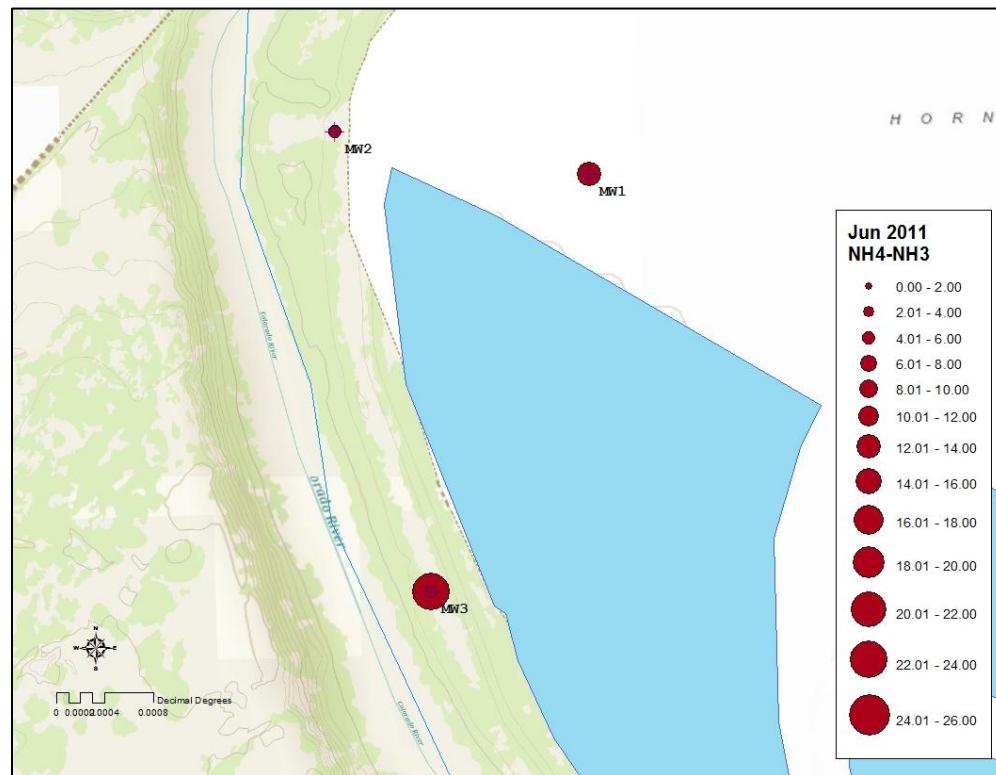


Figure 5 Monthly NH₄-NH₃ time-series (b) Jul 2011

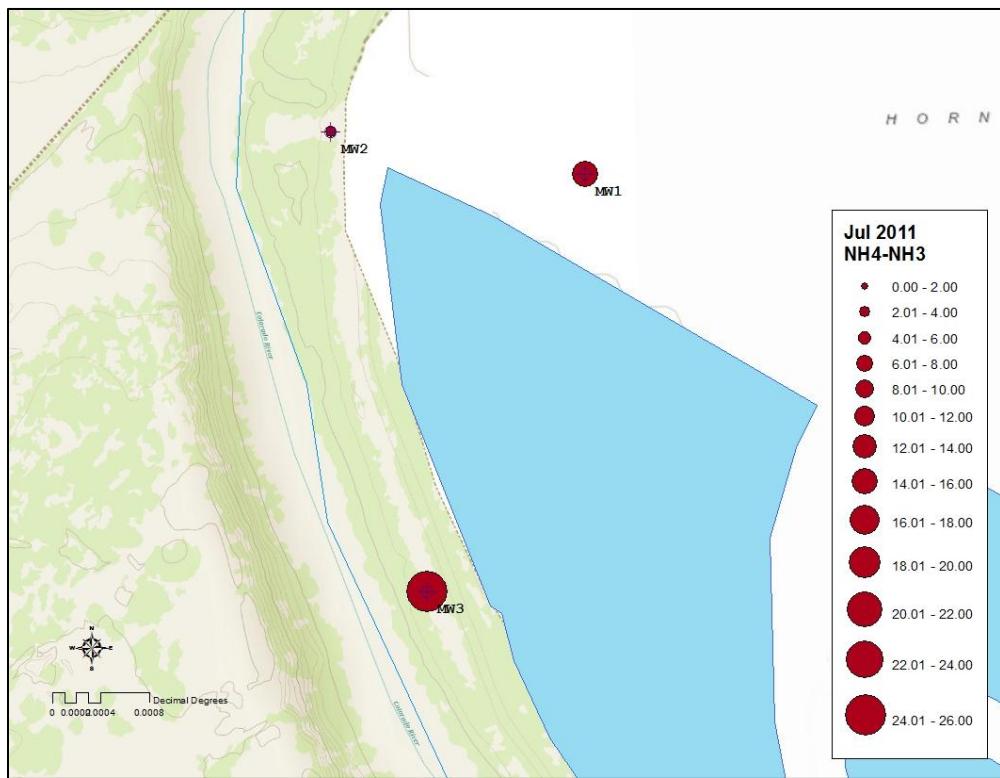


Figure 5 Monthly NH₄-NH₃ time-series (c) Aug 2011

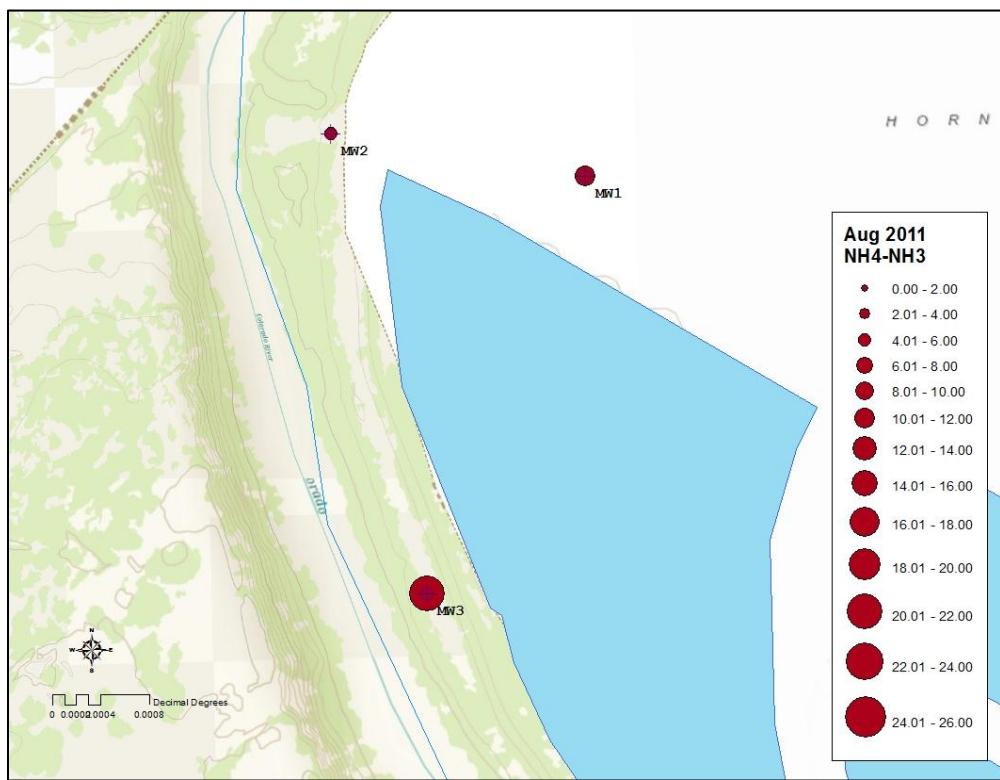


Figure 5 Monthly NH₄-NH₃ time-series (d) Sep 2011

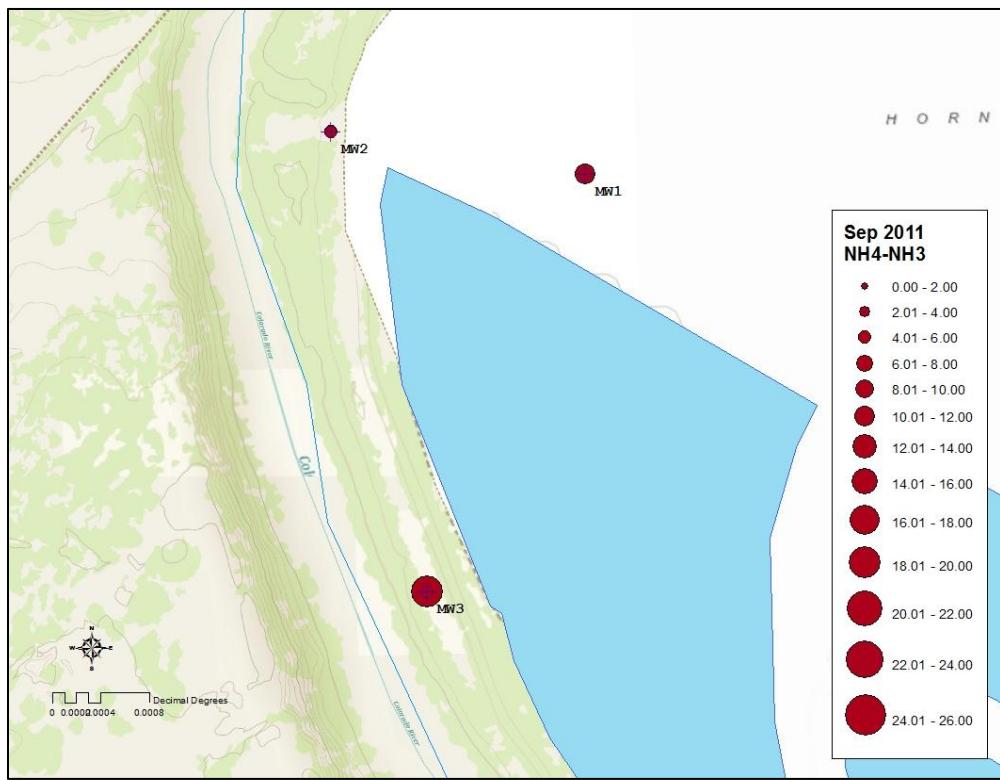
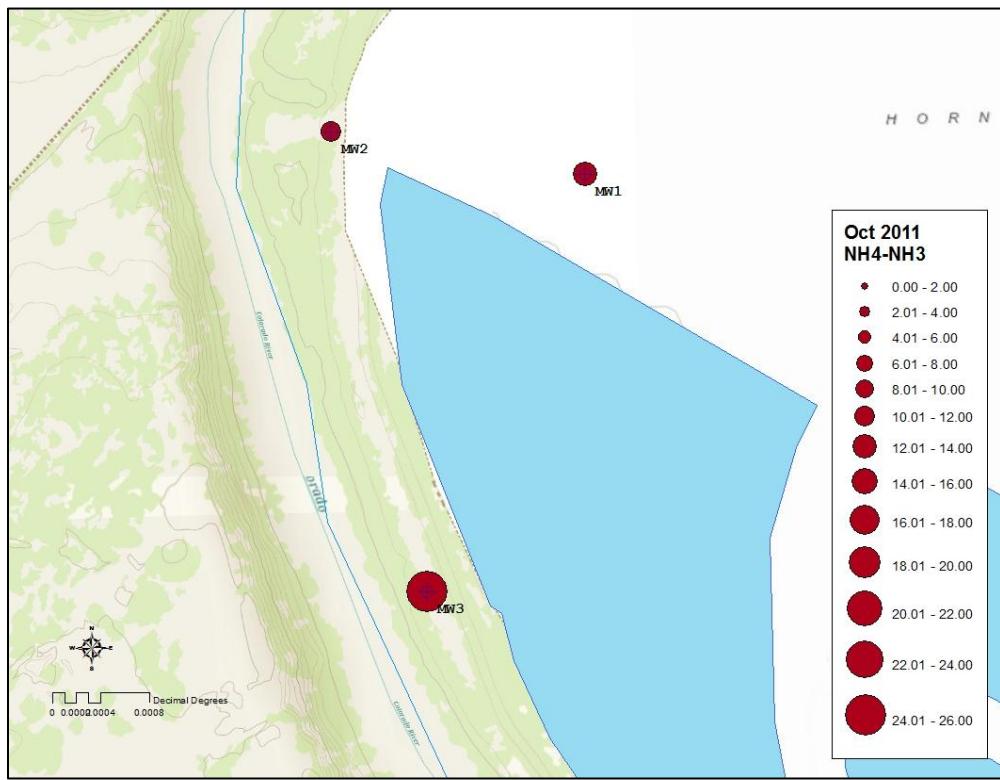


Figure 5 Monthly NH₄-NH₃ time-series (e) Oct 2011



TOT-N Time-series

While the preceding analysis supports the theory of lagoon leaching, it is not, by any means conclusive. Many factors could be at play including relatively anoxic zones closer near the lagoons which are converting all nitrogen forms to $\text{NH}_4^+ - \text{NH}_3$. Therefore, a Tot-N time-series analysis was performed to account for all nitrogen species present in Hornsby Bend aquifer layers. This time-series is displayed in Figure 6 and demonstrates two important results: 1) The data are much more varied for total nitrogen than that of $\text{NH}_4^+ - \text{NH}_3$, indicating a stronger influence of more transient environmental features and 2) There are much higher total nitrogen concentrations spread throughout the plant, not just in the wells by the lagoons. In fact, there are several elevated levels observed in the uppermost region of the site, which are stations far removed from the treatment lagoons and are below fields that only receive a small portion of land applied biosolids. Therefore, the TOT-N time-series indicates the prevalence of nitrogen regardless of Hornsby Bend operations. Much of this influx of nitrogen concentration into Hornsby Bend groundwaters is probably from surrounding agricultural facilities. In sharp contrast with the $\text{NH}_4^+ - \text{NH}_3$ time-series analysis, the TOT-N series does not point to lagoon leaching as being the primary source of nitrogen aquifer composition, though it still does not rule out the possibility that the lagoons are contributing to overall nitrogen levels.

Figure 6 Biennial TOT-N time-series. (a) 2005

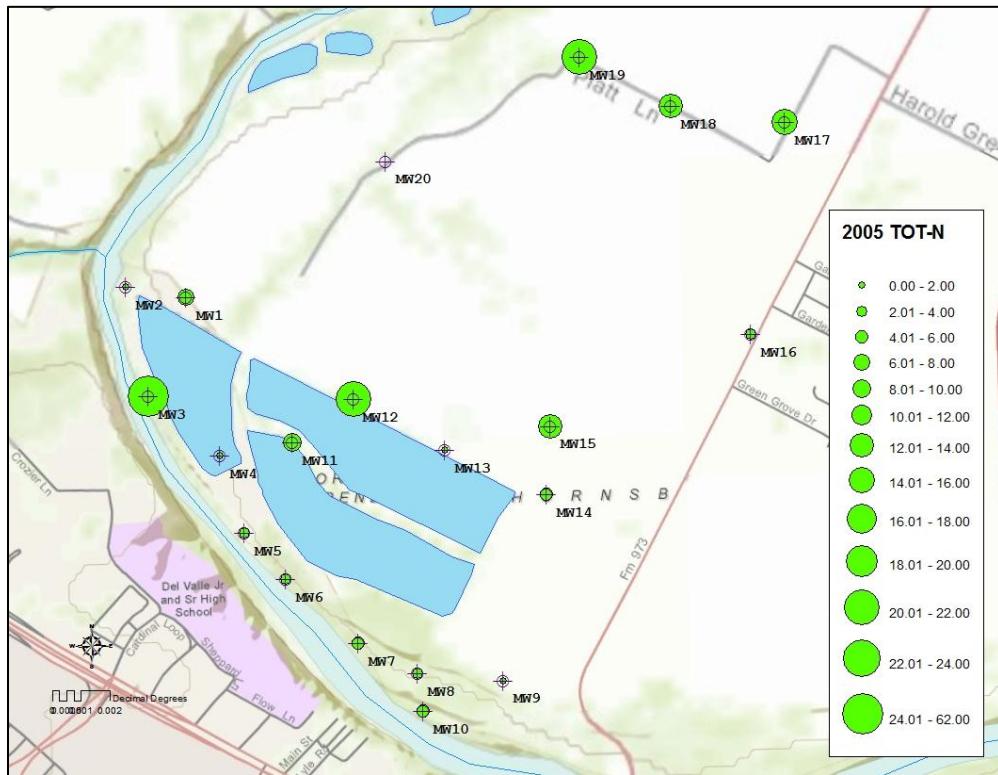


Figure 6 Biennial TOT-N time-series. (b) 2007

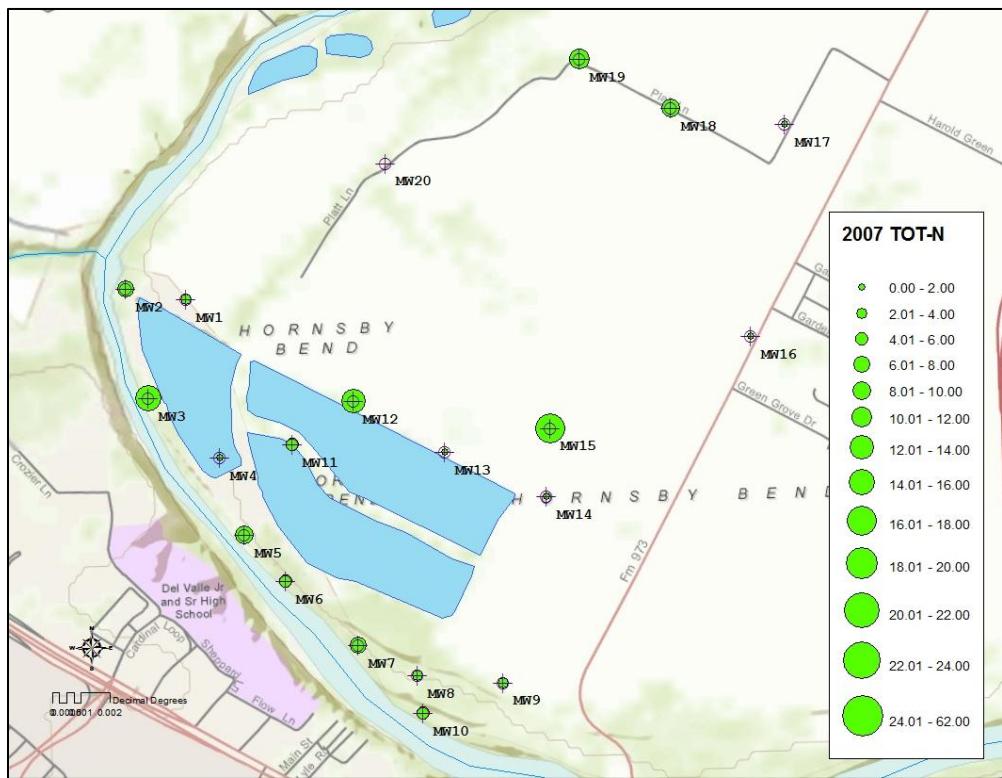


Figure 6 Biennial TOT-N time-series. (c) 2009

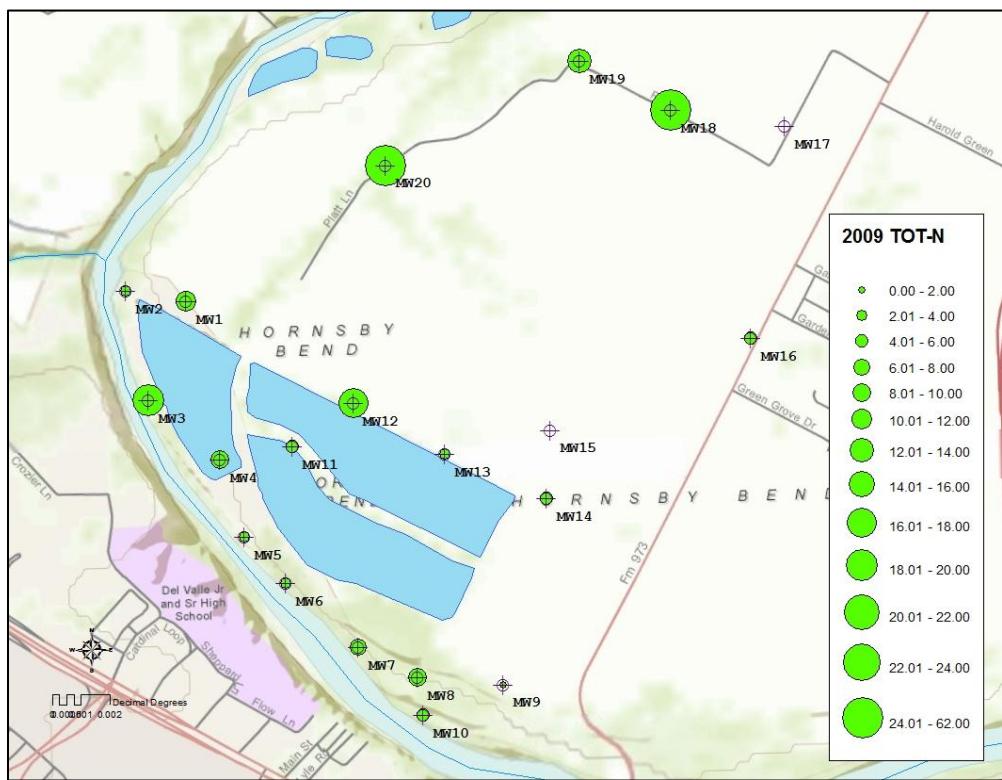
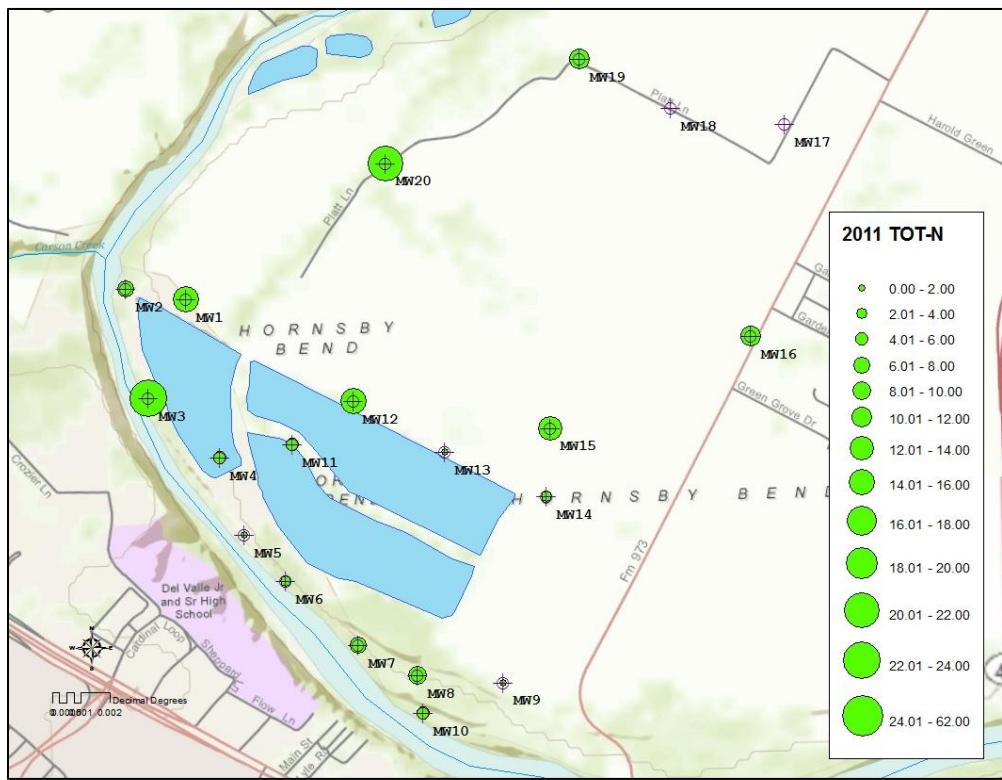


Figure 6 Biennial TOT-N time-series. (d) 2011



Groundwater depth time-series

A time-series evaluating groundwater depth was also conducted, and the results are reported in Figure 7. Upon inspection of the figure, it is obvious that there was no sustained swelling over the time range in the vicinity of MW3 or the potentially breached lagoon. Furthermore, the data was highly variable throughout the lower region of the plant, including for wells upgradient of the lagoons. The limited and highly variable nature of the data did not lend itself well to drawing conclusions, though the data do not support a lagoon leaching scenario. Any elevated depth values are likely subject to transient environmental conditions such as precipitation levels preceding sampling. Therefore, further investigation needs to be made in order to normalize these values to annual rainfall numbers.

Figure 7 Groundwater depth time-series (a) 2003

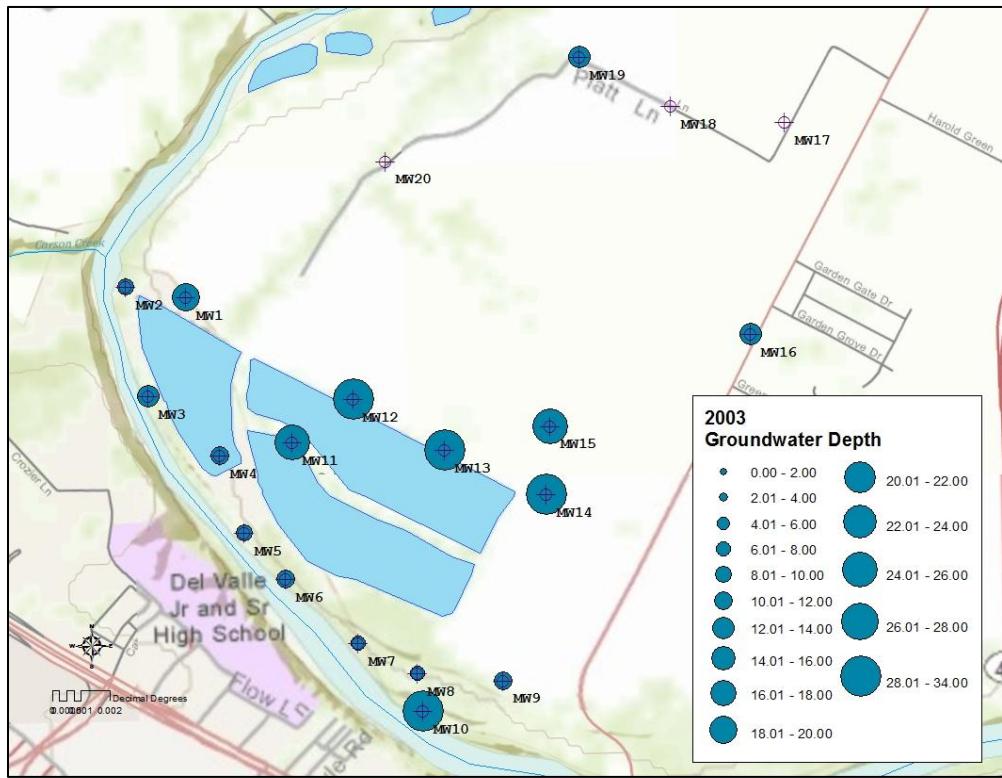


Figure 7 Groundwater depth time-series (a) 2009

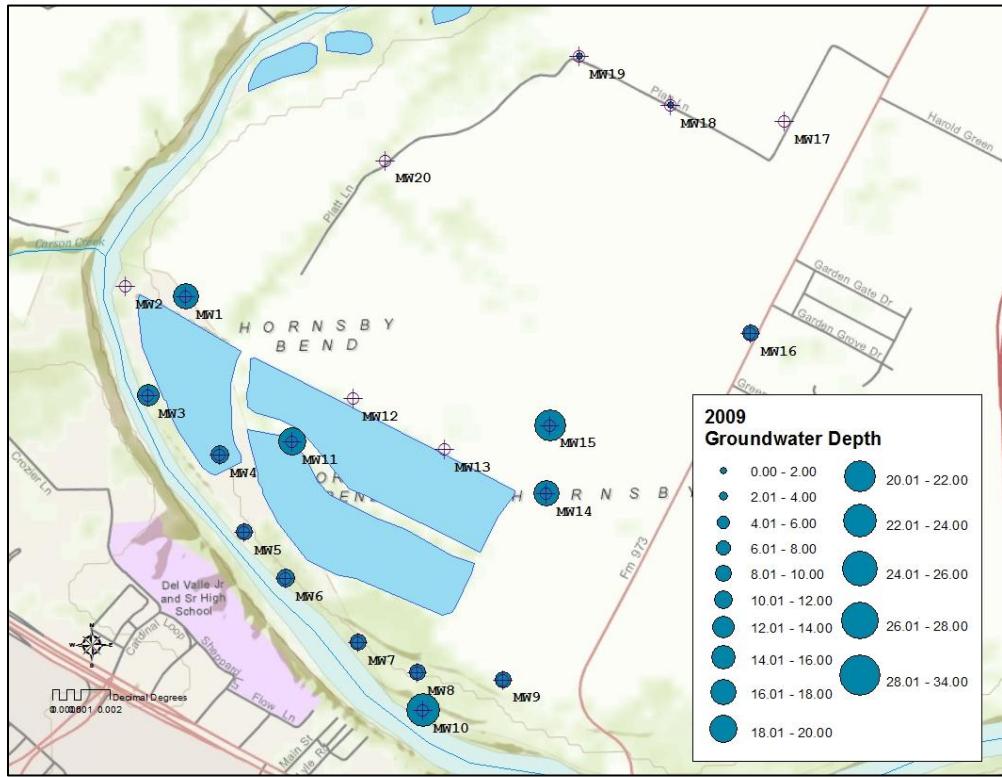
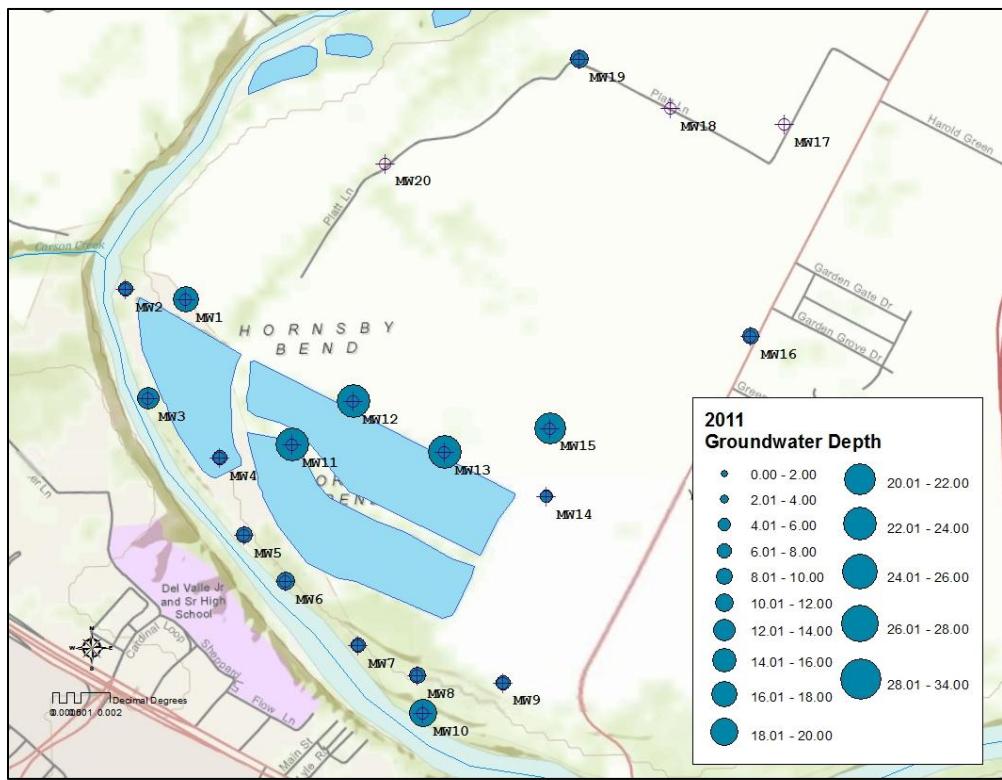


Figure 7 Groundwater depth time-series (c) 2011



Spline-interpolated continuous surfaces

Time-averaged continuous surfaces were made for NH_4^+ - NH_3 , TOT-N, and groundwater depth data using spline interpolation methods. The resulting raster images are presented in Figures 8-10. The results are consistent with conclusions drawn from time-seriate analyses. The NH_4^+ - NH_3 surface indicates a conglomeration of ammonia concentration in the southeast corner of the plant, indicating a potential breach in the nearby lagoon. However, comparisons with the TOT-N and groundwater depth images show that there is greater variance and wider distribution across the plant site.

Figure 8 NH₄-NH₃ spline-interpolated continuous surface raster

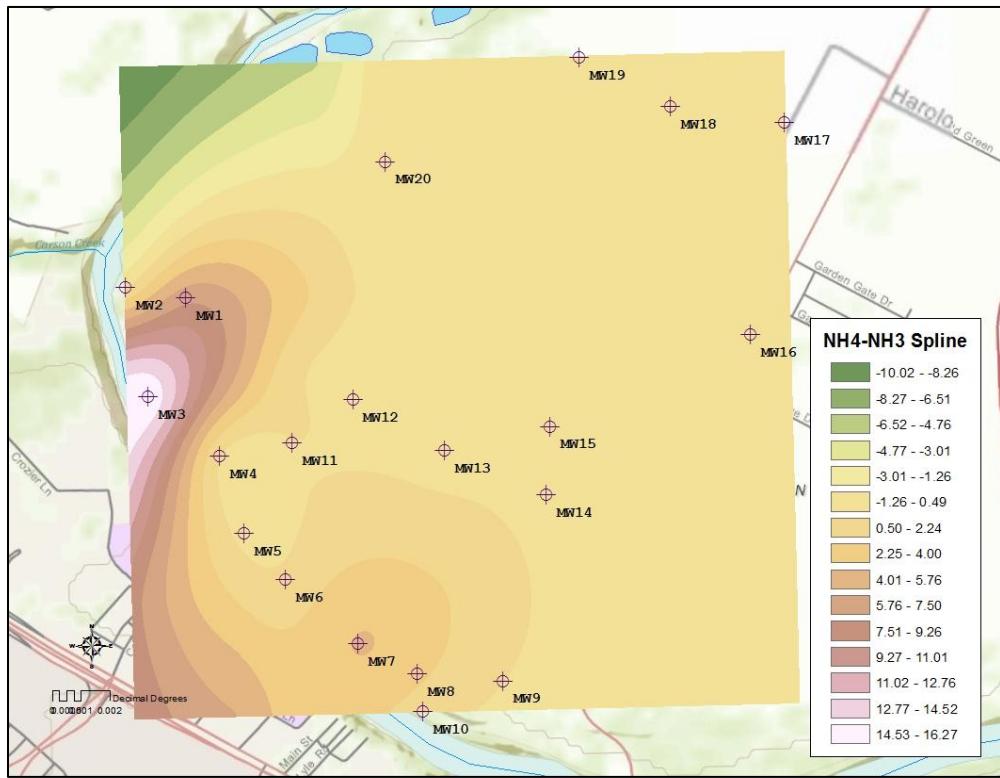


Figure 9 TOT-N spline-interpolated continuous surface raster

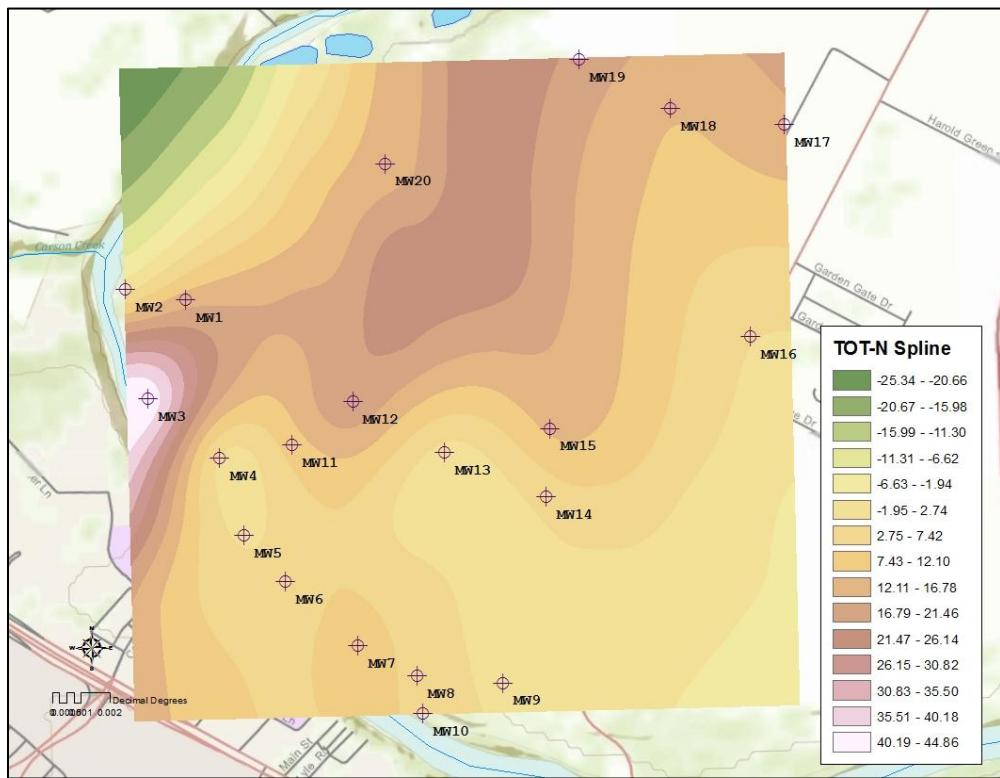
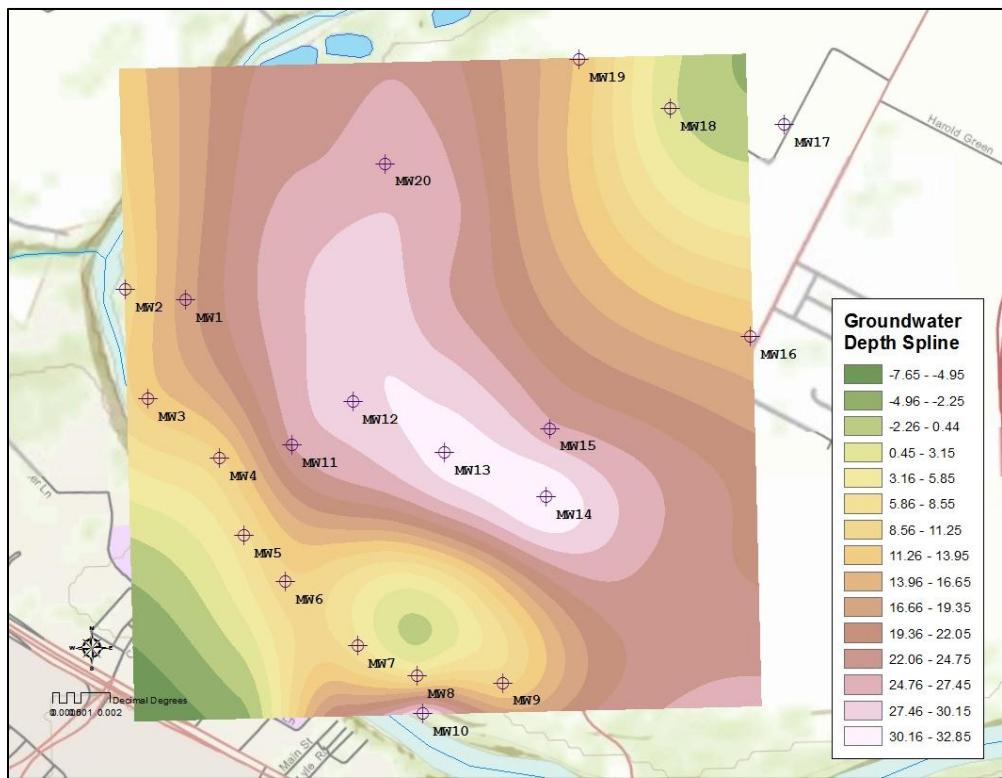


Figure 10 Groundwater depth spline-interpolated continuous surface raster



Conclusions

While data constraints made it difficult to isolate and determine the source of elevated ammonia in MW3, processing the observational data using GIS facilitated simultaneous analysis in both spatial and temporal contexts. This approach illuminated some important concepts and results that may help influence decision making going forward. The first important take-away is that speciation matters when testing and analyzing in-situ chemical composition. Evaluating spatial $\text{NH}_4^+ \text{-NH}_3$ and TOT-N concentrations together demonstrated that neglecting speciation effects can lead to dramatically different conclusions. Analysis of $\text{NH}_4^+ \text{-NH}_3$ concentrations from both a time-seriate and time-averaged perspective very much supported the idea that the source of elevated levels was likely the nearby lagoon; conversely, the same analyses for total aqueous nitrogen showed concentrations widely distributed throughout the plant. If the flow pattern of the aquifer can be characterized, it could be compared to the TOT-N surface raster to see if the bulk of the flow coincides with the region of higher concentrated nitrogen. This type of analysis has been reserved for future work.

A second important principle is that results are only as good as the observational data put into the modeling. The surface rasters have little data points and lack the spacing needed to get much more reliable interpolation results. On the other hand, GIS provides powerful tools to

investigate limited data and derive information from the dataset. In this case, the distribution and variation of TOT-N and groundwater depth suggests transient environmental conditions dominate TOT-N concentration and groundwater depth at the plant; however, contributions made from lagoon leaching were not ruled out in the analysis. Despite prevailing uncertainties, the information contained herein can help prioritize future tasks at the utility, though ultimately a more rigorous study such as a tracer test will need to be performed in order to resolutely rule out considerable contributions from lagoon leaching.

References

Stumm, W., & Morgan, J. J. (1996). Aquatic Chemistry : Chemical Equilibria and Rates in Natural Waters. John Wiley & Sons, Inc. (US).