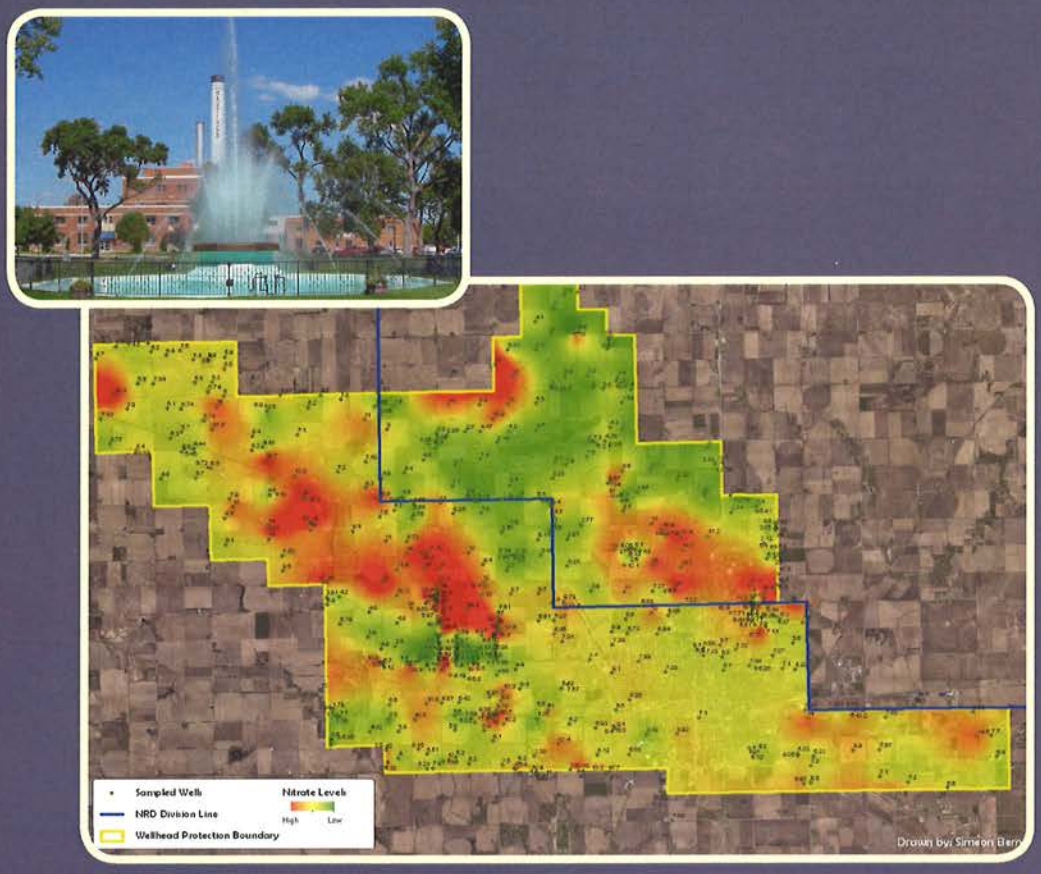
HASTINGS UTILITIES

Hastings Utilities



Hastings Utilities Water System Master Plan Phase II

Groundwater Modeling Study
2010-2011 Water Quality Summary
Well Based Nitrate Management Approach

February 2012

HDR | ONE COMPANY *Many Solutions®*

HASTINGS UTILITIES GROUNDWATER MODELING STUDY
TECHNICAL MEMORANDUM PHASE II

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STANDARD LIST - GLOSSARY OF TERMS AND ABBREVIATIONS

Alluvium: Unconsolidated terrestrial sediment composed of sorted or unsorted sand, gravel, and clay that has been deposited by water.

Aquifer: An underground geological formation, or group of formations, containing water. Are sources of groundwater for wells and springs.

bgs: Below Ground Surface

COHYST: Cooperative Hydrology Study. COHYST is a group of Nebraska interests that joined together as sponsors and partners to develop scientifically supportable hydrologic databases and models.

COHYST EMU: The Eastern Model Unit of the COHYST study.

Cretaceous: A geologic from circa 145.5 to 65.5 million years ago.

Drawdown: The drop in the water table or level of water in the ground when water is being pumped from a well.

Flood plain: The flat or nearly flat land along a river or stream or in a tidal area that is covered by water during a flood.

gpm: Gallons per minute

Hydraulic conductivity (K): The rate at which water can move through a permeable medium. (i.e. the coefficient of permeability.)

Hydrogeology: The geology of ground water, with particular emphasis on the chemistry and movement of water.

LBNRD: Little Blue North Natural Resources District

mgd: Million gallons per day

MODFLOW: Groundwater flow model developed by McDonald and Harbaugh (1988) with the USGS.

MODPATH: Groundwater particle tracking model developed by Pollock (1989) with the USGS.

MT3D: Solute transport modeling code developed by Zheng and Wang (1998)

Nitrate: Nitrate (NO_3) is a naturally occurring form of nitrogen found in soil. Nitrate can be expressed as either NO_3 (nitrate) or NO_3-N (nitrate as nitrogen). References to nitrate in this document are for nitrate as nitrogen.

Pleistocene: The Pleistocene is the epoch from 2.588 million to 12,000 years ago covering the world's recent period of repeated glaciations.

Potentiometric surface: The surface to which water in an aquifer can rise by hydrostatic pressure.

Tertiary: The Tertiary is a term for a geologic period 65 million to 1.8 million years ago.

TOT: Time of Travel

Unconfined aquifer: An aquifer containing water that is not under pressure; the water level in a well is the same as the water table outside the well.

UBBNRD: Upper Big Blue Natural Resources District

UNLCSD: University of Nebraska – Lincoln Conservation and Survey

Uranium: Uranium is a radioactive heavy metal. It occurs naturally in low concentrations in soil, rock and water.

WHPA: Well Head Protection Area, defined as the surface and subsurface area surrounding a water well or well field through which contaminants are reasonably likely to move toward and reach such water well or well fields.

EXECUTIVE SUMMARY

The following report presents the construction and application of a groundwater and solute transport model developed to help manage a groundwater well field operated by Hastings Utilities (HU). HU operates a water supply well field that consists of 32 production wells completed in the unconfined Pleistocene age sand and gravel aquifer that underlies the City of Hastings. These water wells are the only source of supply used to meet all of HU's water demands, which vary from an average daily demand of approximately 8 million gallons per day (mgd) to a maximum daily demand of approximately 22 mgd. The combined capacity of the 32 production wells is sufficient to meet the maximum day and peak hour demands including reasonable fire flow demands. Currently, the water supply wells pump directly into the distribution system with no system storage and no additional treatment. The level of nitrate present in most of the wells has increased throughout their operational history, and several wells have been removed from service as the nitrate concentration approached or exceeded the Maximum Contaminant Level (MCL) for nitrate as nitrogen of 10 milligrams per liter (mg/L). Nitrate (NO_3) is a naturally occurring form of nitrogen found in soil. Nitrate can be expressed as either NO_3 (nitrate) or NO_3-N (nitrate as nitrogen). References to nitrate in this document are for nitrate as nitrogen.

In 2010, Hastings Utilities (HU) hired HDR to develop a 20-Year Facility Implementation Plan (Plan) for potable water supply that included treatment options, residual waste stream treatment and disposal requirements, opinion of probable construction costs, and the best alternative for primary treatment and residual waste stream treatment and disposal. In November 2010, HDR presented the proposed Plan to the HU Board. Due to the high cost associated with full-scale nitrate treatment proposed in the Plan, the HU Board decided they would like to pursue other avenues aimed at delaying full-scale treatment as long as possible. As a result, HU requested that HDR perform additional analyses which focused on further evaluation of ground water quality and identification of additional water supply sources, was initiated in early 2011. An integral part of the Plan is the groundwater flow model, which is used to evaluate future nitrate concentrations in the HU water supply wells over the 20 year planning period.

This document presents the results of the Phase II groundwater modeling study, which is an update to the Phase I groundwater/solute transport model developed by HDR Engineering, Inc. (HDR) and was documented in the *Hastings Utilities Phase I Groundwater Modeling Study* (HDR, 2010). The Phase II model was developed to include the results of nitrate sampling conducted in 2011 and to also address several specific well field operational scenarios that could be beneficial in managing nitrates within the Hastings Utilities (HU) water supply well field. The update of the groundwater model, and the analysis and conclusions presented within this report, are based in part on the model constructed in Phase I.

TECHNICAL APPROACH AND MODELING OBJECTIVES

No significant changes to the construction or calibration of the Phase I groundwater model (HDR, 2010) were required to achieve the objectives of the Phase II model or the 20-Year Facility Implementation Plan update. The primary technical task for the Phase II groundwater model was to update the nitrate sample database to include the groundwater samples collected in the summer of 2011. These samples increased the number of samples within the dataset from approximately 500 samples to 770 samples. The results of the nitrate sampling effort were interpreted to develop an isoconcentration map for nitrate. The isoconcentration map represents a snapshot of the nitrate concentrations in the aquifer as measured in the summer of 2010 and 2011. These data were used to represent the initial conditions in the solute transport model. The solute transport model was constructed to reflect the conservative nature of nitrate transport in groundwater. A second change from the Phase I model is the inclusion of uranium as a transport parameter. Uranium concentrations were modeled in a similar manner as nitrate. A detailed description of the uranium transport model simulations is presented in Section 5 of the report.

The objectives for the Phase II groundwater modeling study were to evaluate several specific well field management alternatives, including:

1. *Pump, Treat, and Recharge option*. For this option, upgradient water supply wells are used to intercept areas of high nitrate concentrations. The pumped water would then be treated and returned to the aquifer through recharge/injection wells. The recharge/injected water forms a "bubble" of treated groundwater that travels downgradient at the speed of ambient groundwater flow and is later pumped out of the aquifer by existing HU wells that are located downgradient of the recharge/injection wells.
2. *Determine the feasibility of operating the existing wells near the Lochland Golf Course.* This analysis included a review of operation data of these wells, the geology near the Lochland golf course, estimating a maximum pumping rate for wells in this area, and estimating future nitrate concentrations in the wells.
3. *Provide future nitrate concentration data for each HU well, to be included in the 20-Year Facility Implementation Plan.* This involved updating the model predicted nitrate concentrations for all HU wells using the updated nitrate concentrations, which include the 2011 data.
4. *Evaluate the potential to develop new wells in areas with low nitrate concentrations.*
5. *Evaluate the impact on HU wells from other contaminants in the aquifer, including uranium*.

CONCLUSIONS AND RECOMMENDATIONS

The nitrate sample database used to interpret the concentration distribution within the aquifer consisted of approximately 770 water samples over the summer of 2010 and 2011 by HU, Little Blue Natural Resources District, or Upper Big Blue Natural Resources District staff. These samples were obtained primarily from irrigation wells, but domestic and municipal wells were also sampled. The sample results have shown that nitrate in groundwater is prevalent within and around the Hastings Well Head Protection Area (WHPA); and the average nitrate concentration detected was 7.7 mg/L. Approximately 25 percent of the 770 samples collected exceed the 10 mg/L MCL for nitrates and the maximum concentration detected was over 50 mg/L. This sample database was used update the nitrate levels in the groundwater model, which was then used to make predictions about future nitrate concentrations within the HU well field.

Other than modifying the initial nitrate concentrations in the model, no structural changes were made to the groundwater and solute transport model presented in the *Hastings Utilities Phase I Groundwater Modeling Study* (HDR, 2010). The conclusions of the Phase II modeling study are presented below, using the same numbering system as the previous objectives list.

1. *Pump, Treat, and Recharge option*. Based on the modeling performed, this option appears to be a viable long term option to manage the nitrate concentrations within the HU well field. This option has two primary benefits:
    a. Well 33 and a capture well (or wells) can be used to cut off a large portion of the high concentration nitrate groundwater that is moving south an east towards the HU wells. This water can be treated to a level below the nitrate MCL and then returned to the aquifer.
    b. Over years of active recharge, the water that is returned to the aquifer after treatment will form a hydraulic "bubble" of treated water, which will move downgradient at the speed of ambient groundwater flow until it is recovered by existing downgradient HU wells.

    Under the scenario modeled, the treated water would be recaptured by HU wells 8, 16, 21, 23, 25, 28, 29, 34, and 35 during the 20-year planning cycle. Over time, the wells that recover the treated

recharge water could be become the primary source of water for HU. This would ensure a reasonably constant long term water quality. Based on the modeled results, it appears that increasing the level of treatment of the effluent of the upgradient pumping wells from 5 mg/L to 2 mg/L offers only minimal benefit to the operation of the well field and treatment to a level of 5 mg/L will meet the project objective while also lowering the treatment cost.

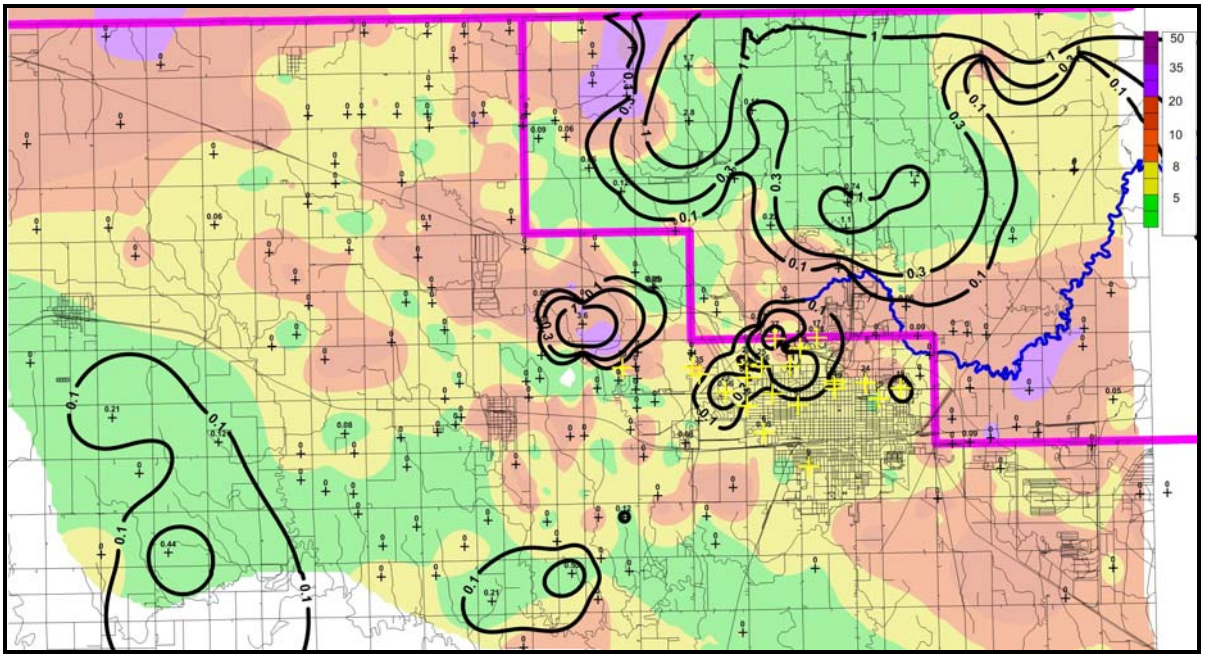
At this time, it is recommended that HU initiate meetings and discussions with regulatory agencies to discuss the pump treat recharge concept. If the regulatory community is agreeable towards this concept, it is recommended that a pilot scale demonstration project be initiated to demonstrate the feasibility of this concept. The project should include Well 33 as the pumping well and three new recharge wells. A modeling and monitoring program should be part of the demonstration phase project.

2. *Determine the feasibility of operating the existing wells near the Lochland Golf Course*. Based on our review of the hydrogeology in this area, development of production wells near the Lochland Golf Course is not recommended. The aquifer thickness in this area is significantly shallower than where the other HU wells are constructed. As a result, yields for municipal wells constructed near the golf course are anticipated to be much lower than the other HU wells. Additionally, the present day nitrate concentrations near the Lochland wells are above the nitrate MCL. Finally, the groundwater sample results indicate that iron, manganese, and uranium are all potential water treatment issues for wells near the golf course.
3. *Provide future nitrate concentration data for each HU well, to be included in the 20-Year Facility Implementation Plan*. These data were included in the 20-Year Facility Plan and were used to develop the recommendations presented within that document.
4. *Evaluate the potential to develop new wells in areas with low nitrate concentrations*. The nitrate sampling results from 2010 identified an area north and east of the HU 20 year time of travel WHPA that has low nitrates. HDR evaluated the potential to develop wells in this area and has concluded that it may be possible to develop low nitrate wells in this area. However, the aquifer in this area is thinner and has a lower transmissivity than in the area where the majority of the HU wells are constructed. Therefore, wells constructed in this area would likely produce at a lower flow rate than the current HU wells. Based on the analysis performed, it appears possible that up to six (6) wells, which would likely produce between 2,400 gpm to 3,000 gpm (3.5 to 4.3 mgd), could potentially be constructed in this area of low nitrates. However, test drilling in the areas of the potential wells is should be performed to evaluate site specific geologic conditions before this option is further explored.

   Iron has been detected in this portion of the aquifer at concentrations that exceed the EPA secondary MCL standard of 0.3 mg/L (as shown below on Figure 5-9a). Therefore, if wells are constructed in this portion of the aquifer, a centralized treatment plant to remove iron may be required. Finally, the groundwater sample results indicate that manganese and uranium are also potential water treatment issues for wells near this area.
5. *Evaluate the impact on HU wells from other contaminants*. Several groundwater contaminants, in addition to nitrates, were discovered during the summer 2011 sampling event, including: uranium, total dissolved solids, iron and manganese. Each of these contaminants impacts the ability to locate "pristine" areas of the aquifer. In the report, Figures 5-9a through 5-9c and Figure 5-10 illustrate the areas within the aquifer that are impacted by iron, manganese, and uranium. Figure 5-9a has been included in the Executive Summary for ease of reference. The quantitative evaluation of the impact of these compounds on the HU well field is beyond the scope of this investigation; however several model runs were performed to evaluate the potential future concentrations of uranium. The model simulations performed to evaluate uranium show

that the HU wells located in the north central portion of the HU well field (Wells 22, 24, 25, 26, 28, and others) intercept the highest concentration of uranium and that the model predicted concentrations in many these wells rise during the 20 year planning period. Based on the distribution of uranium observed in the aquifer, and the model simulations performed, it appears as though the HU wells are acting as a hydraulic containment system that is capturing much of the uranium and limiting the potential for uranium to move downgradient, beyond the HU wells. At this time, it is recommended that sampling for these compounds be expanded if possible. Additionally, these compounds should be included in any pre-design investigation of a future water supply well.

Figure 5-9a – Iron (black contours) and Nitrate (filled color contours) Concentrations near Hastings



Note: Figure shows contours of interpreted iron concentrations (mg/L). Groundwater sample locations for iron are shown as a black cross hatch. Nitrate color scale is the same as in the previous figures. Existing HU wells are shown in yellow.

FUTURE MODEL USES AND LIMITATIONS

The HU groundwater model continues to serve as a powerful well field management tool that can be used to complete future evaluations of how changes well field pumping can impact nitrate concentrations in wells. To maintain the usefulness of the model will require continued groundwater sample collection and analysis, and maintenance of those data in a GIS database.

Groundwater and solute transport modeling are state of the practice tools applied by groundwater hydrologists to solve complex problems. Given the complexity of the problems solved through groundwater modeling, it is unreasonable to expect that model results will represent the absolute aquifer response to future stresses. Rather, when applied by an experienced practitioner, the results of a groundwater and solute modeling study should represent a reasonable approximation of future aquifer behavior under the modeled conditions.

Specific to the study presented within this document, the largest source of uncertainty is the interpretation of nitrate concentrations in the aquifer (Figure 4-2b). This interpretation was based on 770 water samples collected from irrigation, domestic, and municipal water supply wells. Concentrations obtained from

each well were assumed to be representative of the average nitrate concentration for the entire aquifer thickness, which may not always be an accurate assumption. However, this simplifying assumption was necessary given the compressed project schedule. It is possible that if additional data are collected, the interpretation of the nitrate concentrations will change which could impact the predicted concentrations presented in this report. **An additional simplification was the assumption of no continuous nitrate or uranium sources with the model domain. If nitrates or uranium are present in the unsaturated zone of the soil profile, it is possible that the observed future nitrate concentrations could be higher than the model predicted concentrations presented within this report.** As the understanding of the nitrate plume migration and source(s) is improved through future data collection, the limitations of the model can be further reduced. This concept is a key driver for continued groundwater sampling and modeling.

Uncertainty in the flow model was decreased by using the COHYST EMU regional groundwater modeling study as a building block for groundwater model. Uncertainties in the flow model input parameters are reasonably well controlled, when considering the modeling objectives, given that the groundwater model parameters were obtained from a regional study which includes physical aquifer boundaries and aquifer heterogeneity. Uncertainty in the solute transport model is limited, as the only transport processes simulated were advection and dispersion. The greatest source of uncertainty in the solute transport model is the input values used for the dispersion parameters.

FUTURE DATA COLLECTION

The groundwater sampling that was performed to support the Phase I and Phase II models has shown that the aquifer is impacted by contaminants other than nitrate. Continuing to collect samples from portions of the aquifer that have not been sampled before and maintaining a sampling program that rotates sample collection from wells would be an invaluable source of data for the management of the HU well field and for any future model updates. It is recommended that the migration of the nitrate plume near Well 33 be monitored by collection of semi-annual or annual water quality samples from select wells. Additionally, it would be beneficial to collect groundwater samples for phosphorous in order to better understand the relationship of nitrates and phosphorous in groundwater. Groundwater samples collected for phosphorous could potentially give an indication as to the source(s) of uranium and whether it is man made or naturally occurring.

1 INTRODUCTION

HU operates a water supply well field that consists of 32 production wells completed in the unconfined Pleistocene age sand and gravel aquifer that underlies the City of Hastings. These water wells are the only source of supply used to meet all of HU's water demands, which vary from an average daily demand of approximately 8 million gallons per day (mgd) to a maximum daily demand of approximately 22 mgd. The combined capacity of the 32 production wells is sufficient to meet the maximum day and peak hour demands including reasonable fire flow demands. Currently, the water supply wells pump directly into the distribution system with no system storage and no additional treatment. The level of nitrate present in most of the wells has increased throughout their operational history, and several wells have been removed from service as the nitrate concentration approached or exceeded the Maximum Contaminant Level (MCL) for nitrate as nitrogen of 10 milligrams per liter (mg/L). Nitrate (NO_3) is a naturally occurring form of nitrogen found in soil. Nitrate can be expressed as either NO_3 (nitrate) or NO_3-N (nitrate as nitrogen). References to nitrate in this document are for nitrate as nitrogen.

In 2010, Hastings Utilities (HU) hired HDR to develop a 20-Year Facility Implementation Plan (Plan) for potable water supply that included treatment options, residual waste stream treatment and disposal requirements, opinion of probable construction costs, and the best alternative for primary treatment and residual waste stream treatment and disposal. In November 2010, HDR presented the proposed Plan to the HU Board. Due to the high cost associated with full-scale nitrate treatment proposed in the Plan, the HU Board decided they would like to pursue other avenues aimed at delaying full-scale treatment as long as possible. As a result, HU requested that HDR perform additional analyses which focused on further evaluation of ground water quality and identification of additional water supply sources, was initiated in early 2011. An integral part of the Plan is the groundwater flow model, which is used to evaluate future nitrate concentrations in the HU water supply wells over the 20 year planning period.

This document presents the results of the Phase II groundwater modeling study, which is an update to the Phase I groundwater/solute transport model developed by HDR Engineering, Inc. (HDR) and was documented in the *Hastings Utilities Phase I Groundwater Modeling Study* (HDR, 2010). The Phase II model was developed to include the results of nitrate sampling conducted in 2011 and to also address several specific well field operational scenarios that could be beneficial in managing nitrates within the Hastings Utilities (HU) water supply well field. The update of the groundwater model, and the analysis and conclusions presented within this report, are based in part on the model constructed in Phase I. Therefore, a copy of the *Hastings Utilities Phase I Groundwater Modeling Study* has been included as Appendix 1-1 for ease of reference.

1.1 PROJECT PURPOSE

The primary purpose of the Phase II groundwater model update was to update the interpreted nitrate concentrations in the aquifer to include data collected during 2011. This increased the total number of samples used to quantify the distribution of nitrates in the aquifer from approximately 500 samples to 770 samples. These data are the basis for the nitrate concentrations the are imported into the solute transport model and were used to project future nitrate concentrations in the HU wells. Once the nitrate concentrations were updated in the model, the Phase II model was used to evaluate the following specific well field management alternatives:

1. Pump, Treat, and Recharge option. For this option, upgradient water supply wells are used to intercept areas of high nitrate concentrations. The pumped water would then be treated and returned to the aquifer through recharge/injection wells. The recharge/injected water forms a "bubble" of treated groundwater that travels downgradient at the speed of ambient groundwater flow and is later pumped out of the aquifer by existing HU wells that are located downgradient of the recharge/injection wells.

- For this option, treatment standards of 5 milligrams per liter (mg/L) and 2 mg/L were used for the water that is returned to the aquifer. The model predicted concentrations were used by HDR water treatment engineers to evaluate the potential benefits of treatment to lower discharge values.

2. Determine the feasibility of operating the existing wells near the Lochland Golf Course. This analysis included a review of operation data of these wells, the geology near the Lochland golf course, estimating a maximum pumping rate for wells in this area, and estimating future nitrate concentrations in the wells.
3. Updating the model predicted nitrate concentrations for all HU wells using the updated nitrate concentrations, which include the 2011 data.
4. Evaluate the potential to develop new wells in areas with low nitrate concentrations. Consideration of other water quality concerns such as iron and manganese was included in the evaluation.
5. Evaluate the impact on HU wells from other contaminants in the aquifer, including uranium.

The model predicted future nitrate concentrations for many of the above scenarios were used to evaluate well field management alternatives and are also presented in the Hastings Utilities Well Based Nitrate Management Approach Technical Memorandum, also developed by HDR (HDR, 2011). When appropriate, the data and results previously presented in that report will also be presented within the Phase II modeling report.

1.2 TECHNICAL APPROACH

No significant changes to the construction or calibration of the Phase I groundwater model (HDR, 2010) were required to achieve the objectives of the Phase II model or the 20-Year Facility Implementation Plan update. The primary technical task for the Phase II groundwater model was to update the nitrate sample database to include the groundwater samples collected in the summer of 2011. These samples increased the number of samples within the dataset from approximately 500 samples to 770 samples. The results of the nitrate sampling effort were interpreted to develop an isoconcentration map for nitrate. The isoconcentration map represents a snapshot of the nitrate concentrations in the aquifer as measured in the summer of 2010 and 2011. These data were used to represent the initial conditions in the solute transport model. The solute transport model was constructed to reflect the conservative nature of nitrate transport in groundwater. A second change from the Phase I model is the inclusion of uranium as a transport parameter. Uranium concentrations were modeled in a similar manner as nitrate. Additional information on the uranium transport model simulations is presented in Section 5.

1.3 REPORT ORGANIZATION

The remainder of the report presents the methods used to construct the groundwater and solute transport models, and the results of the model simulations. The report is organized as follows:

- **Section 1** – Introduction
- **Section 2** – Hydrogeologic Conceptual Model
- **Section 3** – Groundwater Flow Model Construction
- **Section 4** – Distribution of Nitrates in Groundwater
- **Section 5** – Model Simulations
- **Section 6** – Summary and Conclusions

2 HYDROGEOLOGIC CONCEPTUAL MODEL

The hydrogeologic conceptual model was discussed in the Phase I model and has not changed for this update for Phase II. Any questions related to the hydrogeologic framework of the groundwater model are referred to Section Two of the *Hastings Utilities Phase I Groundwater Modeling Study*, which has been included as Appendix 1-1

3 GROUNDWATER FLOW MODEL CONSTRUCTION

The construction of the groundwater model was discussed in the Phase I model and has not changed for this update for Phase II. Any questions related to the groundwater model are referred to Section Three of the *Hastings Utilities Phase I Groundwater Modeling Study*, which has been included as Appendix 1-1

4 DISTIBUTION OF NITRATES IN GROUNDWATER

The most critical component of the modeling process involved the interpretation of 770 groundwater samples collected during the summer of 2010 or 2011 for analysis of nitrate in groundwater. The majority of the groundwater samples were collected from irrigation, domestic, and municipal wells located within HU's WHPA. However, some of the samples were collected well outside of the WHPA to evaluate nitrate concentrations in these areas. The results of the sampling effort were interpreted by HDR to develop an isoconcentration map for nitrate. The following section details the process involved in collecting the groundwater samples and interpreting nitrate concentration data.

4.1 HU/NRD SAMPLING PROGRAM

In 2009 the Hastings Wellhead Protection Committee represented by various stakeholders recommended that all domestic, irrigation, municipal and industrial wells located within the Hastings WHPA be sampled for nitrates along with other related constituents. This recommendation was adopted as part of the Hastings Wellhead Protection Plan (WHPP). To accomplish the requested water sampling an inter-local agreement was executed between the UBBNRD, LBNRD, and HU. This inter-local agreement allowed for each entity to collect and analyze water samples in the Hastings WHPA. The results of the water analysis are to be shared with each entity. As recommended by the Hastings WHPA Committee these data are to be used to assess the fate and transport of the nitrate contamination within the Hastings WHPA. This was accomplished through the groundwater modeling process presented within this document.

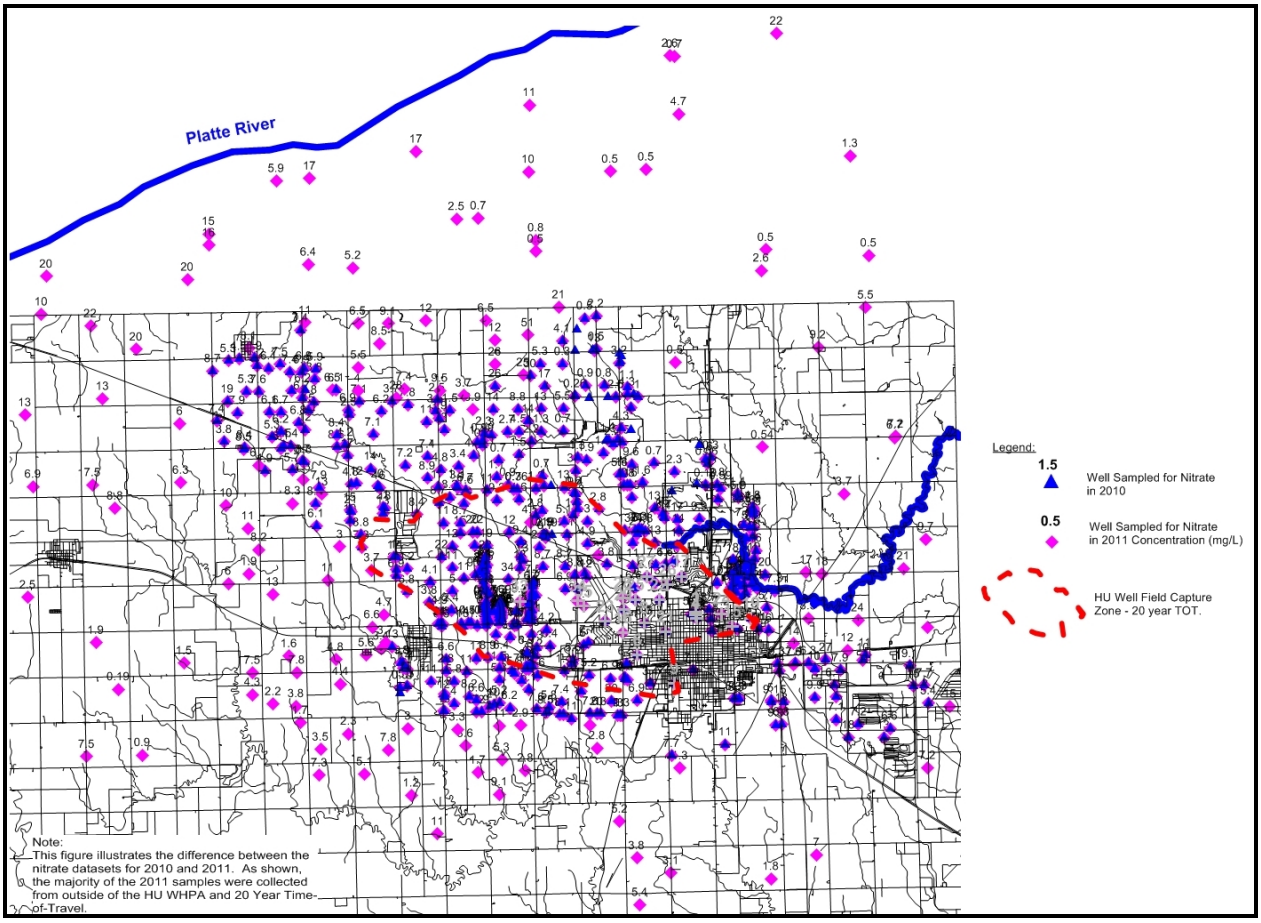
4.2 INTERPRETATION OF NITRATE CONCENTRATIONS

Constructing a groundwater and solute transport model is a data intensive process. The most critical input parameter necessary to generate meaningful predictions of future nitrate concentrations in water supply wells is the initial nitrate concentration field. To characterize the distribution of nitrates in the aquifer, HU/LBNRD/UBBNRD collected approximately 770 water samples over the summer of 2010 and 2011. The samples were obtained primarily from irrigation wells, however domestic and municipal wells were also sampled.

The samples collected in 2010 were mostly collected within the HU well field's WHPA, and many of these were collected within the 20 year time of travel zone. Conversely, the majority of the samples collected in 2011 were collected from outside the HU well field WHPA and well outside of the 20 year time of travel of the well field. Each of these samples was analyzed by a chemical laboratory to determine the concentration of nitrate as nitrogen in the water sample. The sampling results were provided to HDR via a GIS database for interpretation. HDR did not evaluate the sampling protocol, analytical laboratory data, or data quality reports from the analytical lab.

The location of samples collected during the 2010 and 2011 sampling events is shown on Figure 4-1. In this figure, the samples collected in 2010 are shown in blue while the samples collected in 2011 are shown in pink. As shown on this figure, very few new locations were sampled in 2011 within the 20 year time of travel of the HU. Therefore, the interpreted nitrate concentrations within the 20-year time of travel of the HU well field did not change from what was presented in the Phase I model (HDR, 2010).

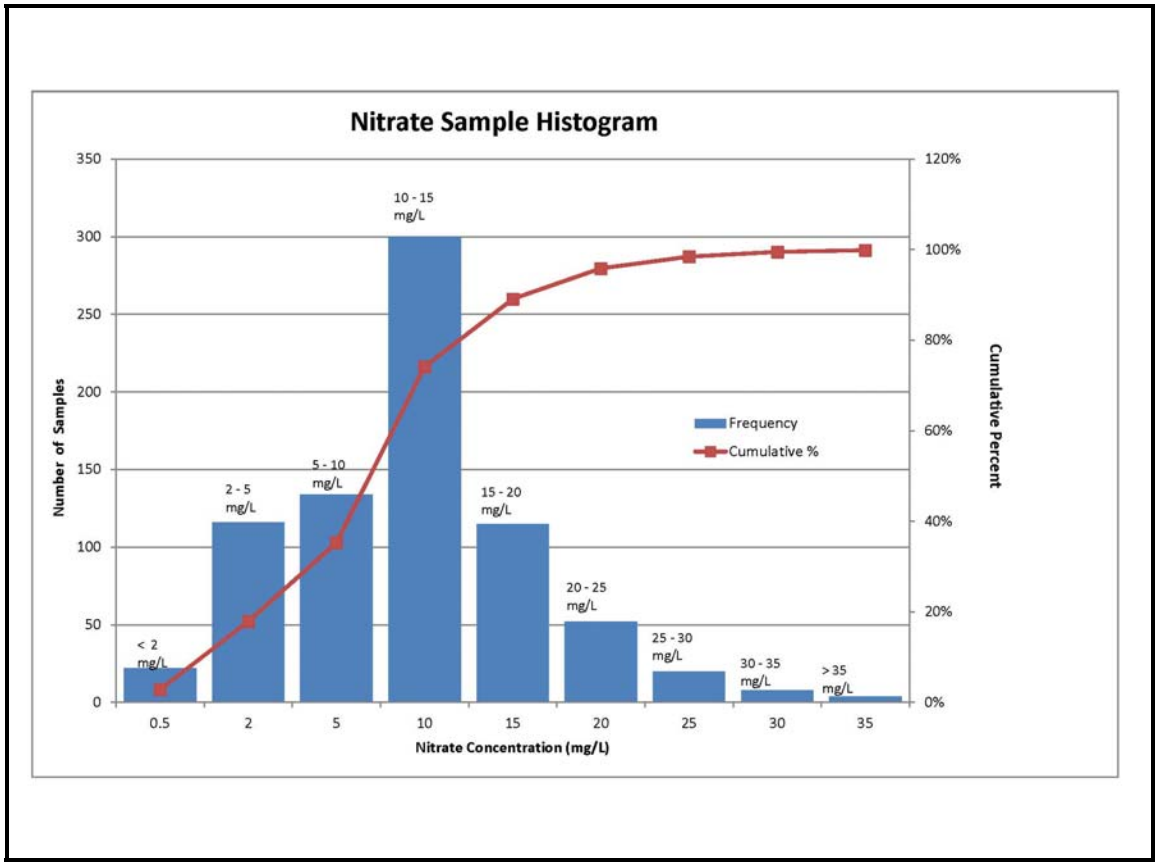
Figure 4-1 Comparison of 2010 and 2011 Nitrate Groundwater Sample Locations



All samples collected were included in the interpretation of nitrate concentrations in the aquifer regardless of type of well (irrigation well, domestic well etc). Concentrations obtained from each well were assumed to be representative of the average nitrate concentration for the entire aquifer thickness. This simplifying assumption was necessary because many of the samples were collected from pumping irrigation wells or municipal well, which are screened over large intervals within the aquifer.

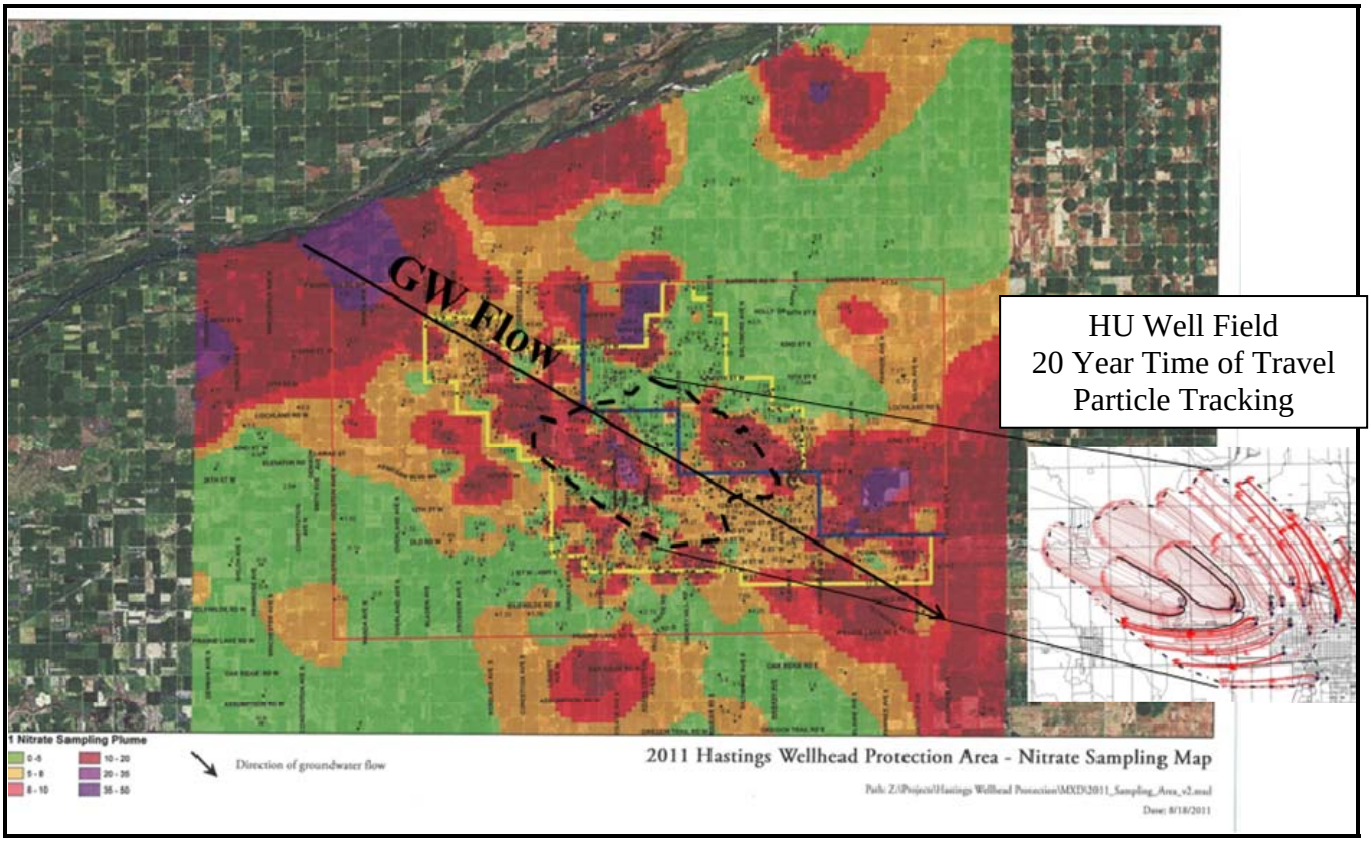
The database of samples used to interpret the nitrate concentration distribution in the aquifer reflects all samples collected in 2010, and the samples collected in 2011 up to the end of September. HDR received the final sampling database on September 19, 2011. Standard statistical methods were applied to the dataset, which consisted of 770 samples collected in the summer of 2010 and 2011. The results of a histogram plot of the nitrate samples are presented as Figure 4-2a. Measured nitrate concentrations ranged from not detected to 50.8 mg/L. As shown of Figure 4-2a, approximately 25 percent of the 770 samples collected exceed the 10 mg/L MCL for nitrates. The average nitrate concentration detected within the aquifer is 7.7 mg/L. The standard deviation of the samples within the dataset is 6.1 mg/L, meaning the concentration range within one standard deviation of the mean is between 1.6 to 13.8 mg/L. This analysis indicates that nitrate are above the MCL of 10 mg/L in less than one standard deviation of the mean of the dataset sampled.

Figure 4-2a Interpreted Nitrate Concentrations from Full 2010 and 2011 Database



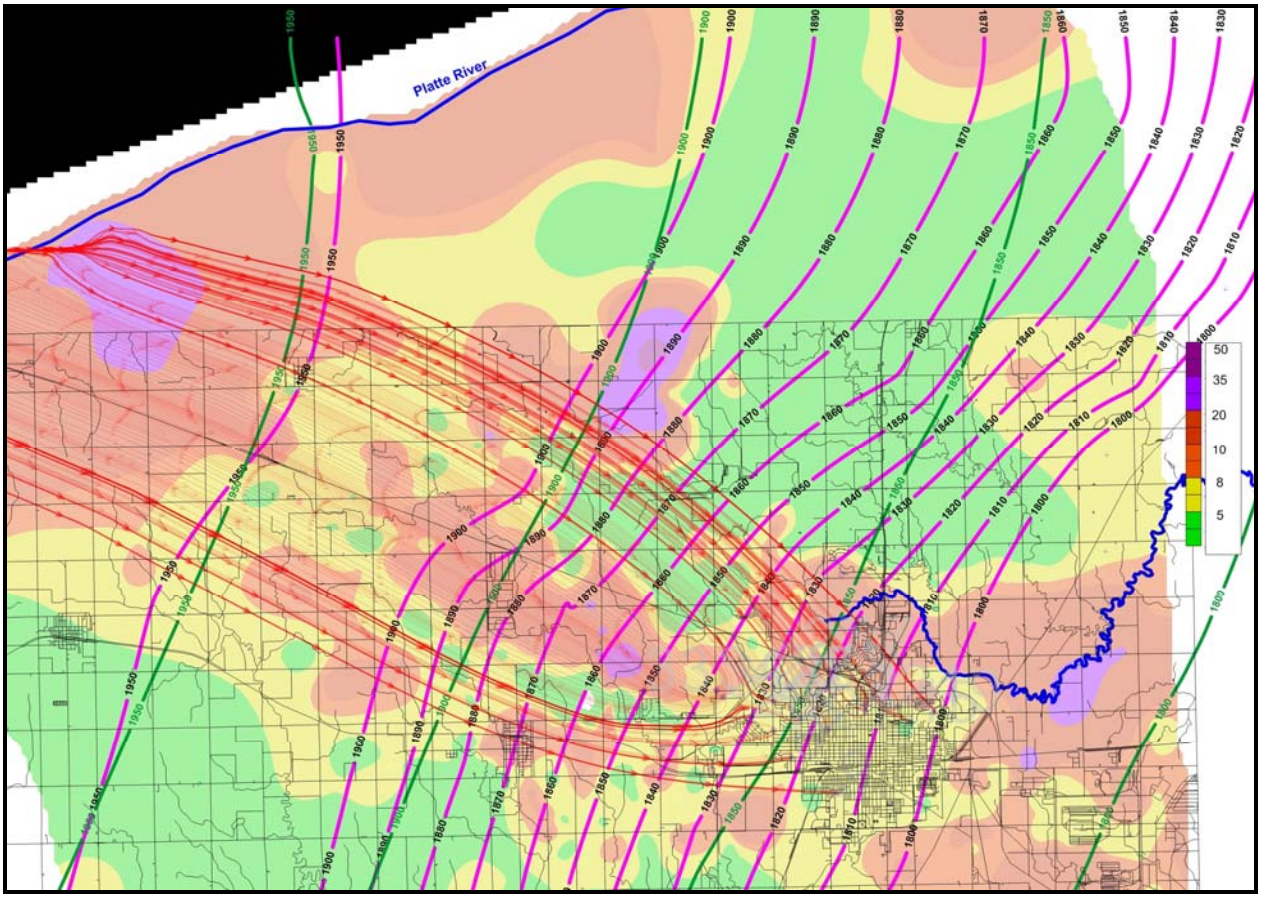
The interpretation of the spatial distribution of nitrates within the aquifer is shown on Figure 4-2b. This interpretation developed by HU staff using a contouring function in the Spatial Analyst extension of ArcView™. The interpretation of nitrates presented on Figure 4-2b was reviewed manually by HDR staff and appears reasonable. The figure includes an overlay of the 20 year time of travel of the well field to illustrate the extent of the sampling completed, which includes samples collected from wells that are located many miles outside of the HU WHPA and/or the 20 year time of travel of the HU well field. The nitrate concentrations shown on Figure 4-2b illustrate that nitrates are much more than a 20 year concern for HU.

Figure 4-2b Interpreted Nitrate Concentrations from Full 2010 and 2011 Database



The final interpretation of nitrate concentrations imported into the model is presented on Figure 4-3. These concentrations represent the model concentrations at time zero of the twenty year model simulations. The interpretation was developed using a Kriging algorithm in Surfer™. Kriging is typically used to evaluate irregularly spaced data and attempts to express trends suggested evident in the spatial distribution of the data, so that high points might be connected along a ridge rather than isolated by bull's-eye type contours. The interpreted nitrate concentrations resulting from the Kriging algorithm were checked manually by a hydrogeologist and re-interpreted as necessary. Manual reinterpretation of the Kriging algorithm's contours was minimal because of the large quantity of data points available, which generally improves the output of contouring programs.

Figure 4-3 Comparison between Pre-Development and Spring 2010 Groundwater Elevations

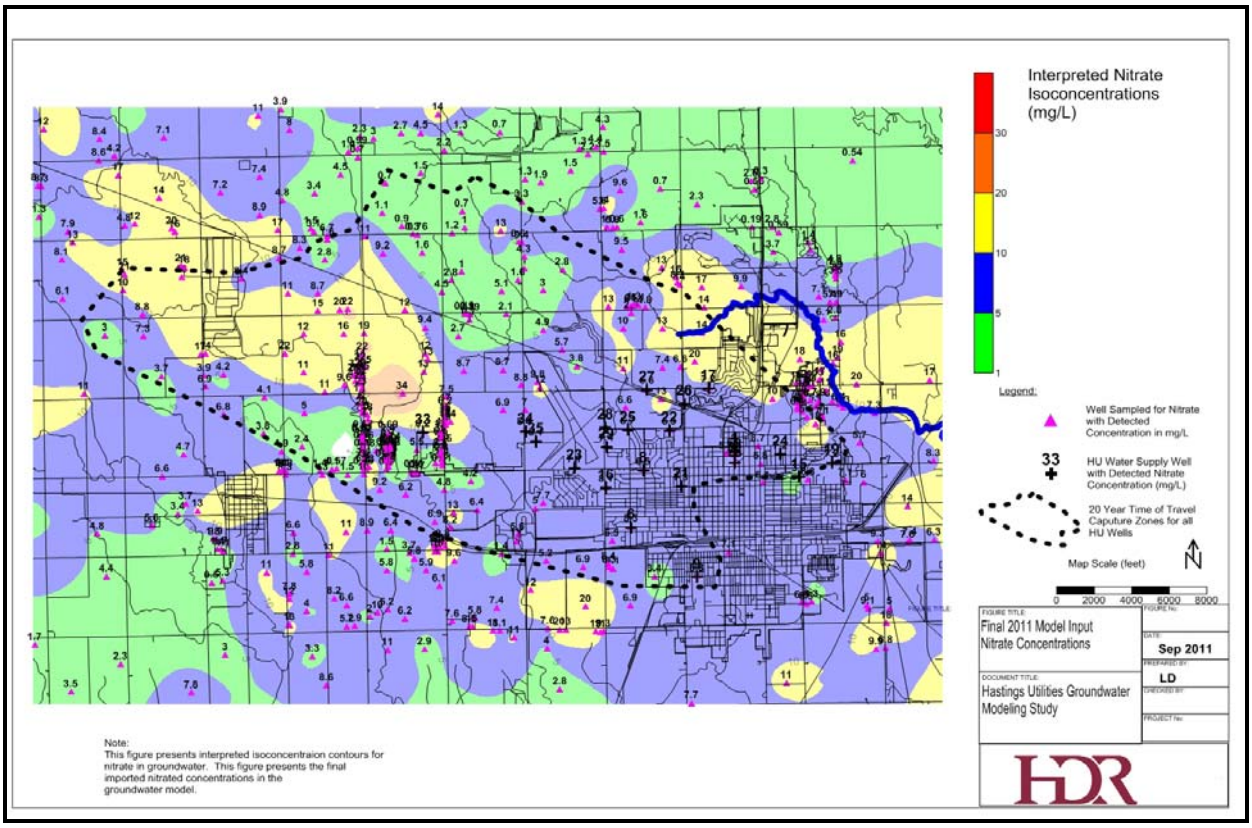


Note: Pre-development groundwater elevation contours (COHYST, 2007) shown in green and Spring 2010(HDR, 2010) groundwater contour elevations shown in pink. Nitrate concentrations are shown in the background of the figure. The nitrate color scale is included for nitrate concentrations in mg/L. Simulation assumes steady state pumping at 8 mgd for HU wells. Particle tracking results are shown for steady state conditions.

Figure 4-3 illustrates the difference between pre-development groundwater elevations and the groundwater elevations measured in Spring 2010. The Spring 2010 groundwater elevation contours show a distinct bend when compared to the pre-development groundwater elevation contours. This bend in the groundwater elevation contours is a result of the long term pumping that has occurred within Hastings, beginning with the water withdrawn for the NDS Power Plant and continuing up to the present day municipal withdrawals. Because groundwater (and contaminant) flow is perpendicular to the groundwater elevation contours, it is apparent that much of the nitrate contamination which originates upgradient of Hastings, including the Platte River Valley, will migrate towards the Hastings Utility wells over time.

The interpreted nitrate concentrations within the HU 20 year time of travel presented on Figure 4-4 are not significantly different than those presented on Figure 4-1 of the Phase I modeling report (HDR, 2010). Because the starting nitrate concentrations are similar to those used in the Phase I model, there were no significant changes in the model predicted concentrations in the HU wells over the 20 year planning period.

Figure 4-4 Final Nitrate Concentrations Imported into the Groundwater Model - Full 2010 and 2011 Database



5 MODEL SIMULATIONS

Other than modifying the initial nitrate concentrations in the model, no changes were made to the solute transport model presented in the *Hastings Utilities Phase I Groundwater Modeling Study* (HDR, 2010). The following section presents a summary of the groundwater and solute transport modeling predictive scenarios.

5.1 MODELING OBJECTIVES

The objective for the HU groundwater modeling study was to expand upon the well field management alternatives identified in the Phase I model and evaluate several specific well field management alternatives, including:

- Pump, Treat, and Recharge. For this option, upgradient water supply wells are used to intercept areas of high nitrate concentrations. The pumped water is then treated and returned to the aquifer through recharge/injection wells. The recharge/injected water forms a "bubble" of treated groundwater that travels downgradient at the speed of ambient groundwater flow and is later pumped out of the aquifer by existing HU wells that are located downgradient of the recharge/injection wells.
    - For this option, a treatment standard of 5 mg/L and 2 mg/L were used for the water that is returned to the aquifer. The model predicted concentrations were used by HDR water treatment engineers to evaluate the potential benefits of treatment to lower discharge values.
- Determine the feasibility of operating the existing wells near the Lochland Golf Course. This analysis included a review of operation data of these wells, the geology near the Lochland golf course, estimating a maximum pumping rate for wells in this area, and estimating future nitrate concentrations in the wells.
- Develop model concentration for the Phase II model or the 20-Year Facility Implementation Plan. This involved updating the model predicted nitrate concentrations for all HU wells using the updated nitrate concentrations, which include the 2011 data.
- Evaluate the potential to develop new wells in areas with low nitrate concentrations.
- Evaluate the impact on HU wells from other contaminants in the aquifer, including uranium.

The model predicted future nitrate concentrations for many of the above scenarios were used to evaluate well field management alternatives and are also presented in the Hastings Utilities Well Based Nitrate Management Approach Technical Memorandum, developed by HDR (HDR, 2011). When appropriate, the data and results previously presented in that report will also be presented within the Phase II modeling report.

5.2 MT3D INITIAL CONDITIONS

The interpretation of nitrate concentrations presented on Figure 4-3 were imported into the modeling software program (Groundwater Vistas) and selected as the initial concentration conditions for the MT3D model runs. This concentration distribution represents the model concentrations at time zero of the 20 year planning simulations. Model runs were completed assuming no continuous sources of nitrates are present within the model domain. This assumption is optimistic as it appears that additional nitrate is being added to the aquifer, as evidenced in the vadose zone sampling completed by Roy Spalding of the University of Nebraska-Lincoln in 2010. The assumption of no additional nitrate sources is necessary

given the absence of information on the location of additional source and the contribution of these additional sources to concentrations in groundwater.

5.3 MODEL SCENARIOS

The objective of the modeling scenarios was to evaluate the changes in nitrate concentrations in specific water supply wells for various pumping distributions. The model simulations were performed assuming transient conditions with annual stress periods, which allows the modeler to adjust individual well flow rates once per year. Most simulations were performed assuming a total annual average well pumping rate of between 8.3 and 9.5 mgd. Table 5-1 summarizes the base case pumping scenario used for all simulations presented within this report. A summary of the simulations performed is presented in the following sections.

Table 5-1 – Pumping Rates Used for Model Simulations

HU Water Supply Well Number	HU Reported Pumping 2004 - 2008 Average Rate (gpm)	Base Pumping Rate (gpm) for Modeling Scenarios (Scenario 2 in HDR Water Treatment Study)
1	140	**140**
2	85	**125**
4	103	**103**
5	Not Pumped	
6	45	
7	Not Pumped	
8	267	**267**
9	170	
10	Not Pumped	
11	Not Pumped	
12	Not Pumped	
13	Not Pumped	
14	Not Pumped	
15	6	**125**
16	374	**374**
17	58	
19	134	**134**
20	Not Pumped	
21	574	**574**
22	76	**76**
23	167	
24	156	**156**
25	144	
26	18	
27	378	
28	505	**505**
29	517	
31	Not Pumped	
32	Not Pumped	
33	1,207	**1,200**
34	Not Installed	**1,000**
35	Not Installed	**1,000**
	Well Field Total (gpm)	5,779
	Well Field Total(mgd)	8.3

5.3.1 PUMP-TREAT-RECHARGE

The general concepts associated with the pump-treat-recharge well field management alternative are:

1. Select wells located along the upgradient (ground water) side of Hastings would be used to intercept large quantities of nitrate-impacted water. The upgradient wells would consist of Well 33 and a new well or capture well, which would be strategically located to intercept an area of high nitrate concentration ground water.
2. The raw ground water would be treated to reduce the nitrate concentrations to 2 or 5 mg/L.

3. Most or all of the treated water would be returned to the aquifer downgradient of the two pumping wells through several recharge wells. The recharged water would migrate downgradient towards the other HU water supply wells, at the natural rate of ground water flow. The recharged water would be recaptured by several HU water supply wells.

The primary benefit of the pump-treat recharge concept is the development of a zone of treated water in the aquifer (recharge bubble) that forms over the first few years of system operation. With this concept, the aquifer acts as a near infinite volume storage source for treated water. The treated water is then removed by existing HU water supply wells during the 20-year planning period.

With this well management option, water would need to be pumped from Well 33 and the capture well 365 days per year, 24 hours per day. As such, this water would then need to be treated and injected continuously as well. This has the further benefit of treating for average day demands, using the aquifer for storage and operating wells in the summer months as required to meet maximum day conditions.

5.3.1.1 METHODOLOGY

The purpose of the pump-treat-recharge model simulations was to evaluate the feasibility of this well field management strategy to protect and improve the water quality of existing HU wells. The model simulations were developed to conceptually demonstrate viability only and do not represent system final design. If adopted, a final pump-treat-recharge system could be a scaled up or scaled down version of what is presented below.

The pump-treat-recharge option was developed assuming Well 33 and a new well (Capture Well) would be used to intercept the high nitrate ground water. Model simulations were performed using a 1,500 gpm flow rate for Well 33 and a 2,000 gpm flow rate for the Capture Well. As the purpose of these two wells would be to intercept as much nitrate impacted water as possible, the wells were assumed to operate 24 hours per day, 7 days per week, at a high well yield.

Model simulations were performed assuming treated effluent levels of 2 and 5 mg/L. The treated water was recharged into the aquifer using seven (7) wells, each with a recharge rate of 500 gpm. The seven (7) recharge wells to two (2) pumping wells ratio was selected for the model simulations based on established aquifer storage and recovery (ASR) rules of thumb that indicate the recharge capacity of a well is typically between three (3) to four (4) times less than the pumping capacity of a well (Pyne, 1995).

The Capture Well is located downgradient of the highest nitrate concentrations. Operation of both the Capture Well and Well 33 effectively protects the other existing HU wells from the zone of high nitrate concentration ground water that is located upgradient of these two wells (Figure 5-1). The location of the recharge wells, and the results of the recharge particle tracking simulations are shown on Figure 5-2.

Figure 5-1 - Capture Zones for Well 33 and Capture Well

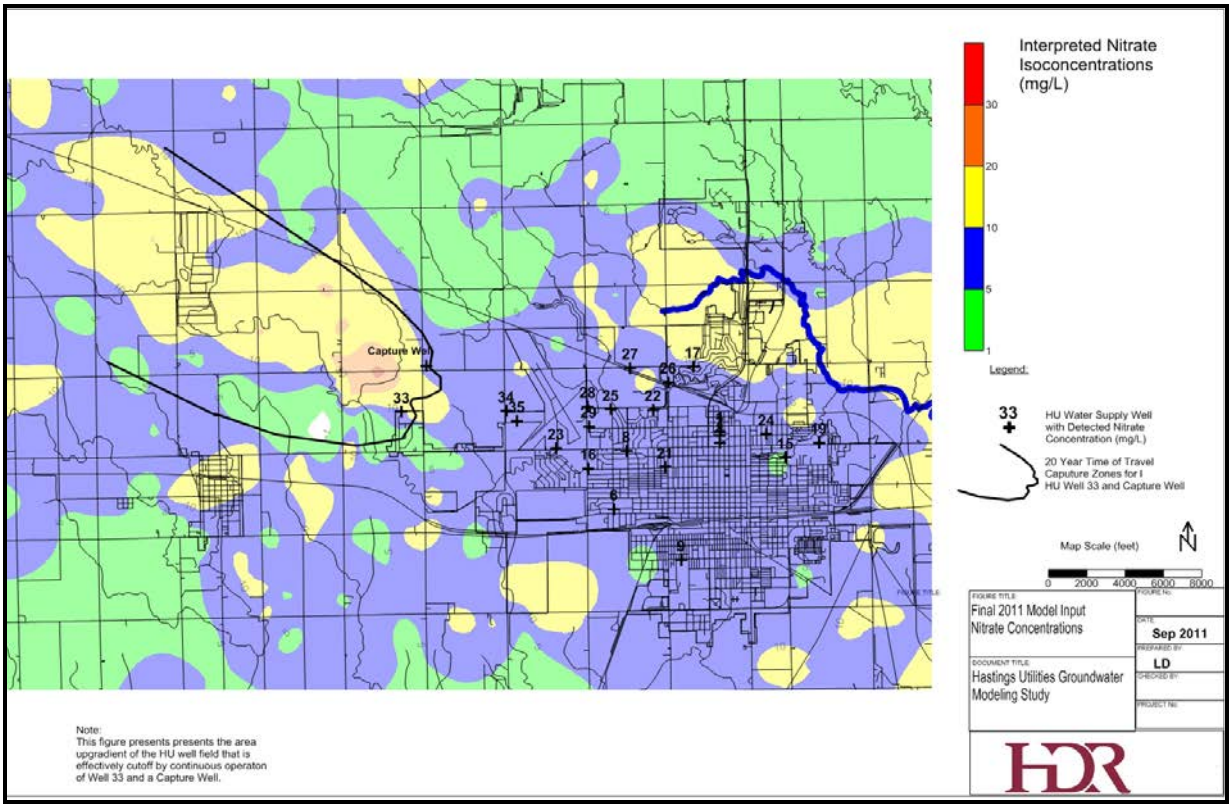
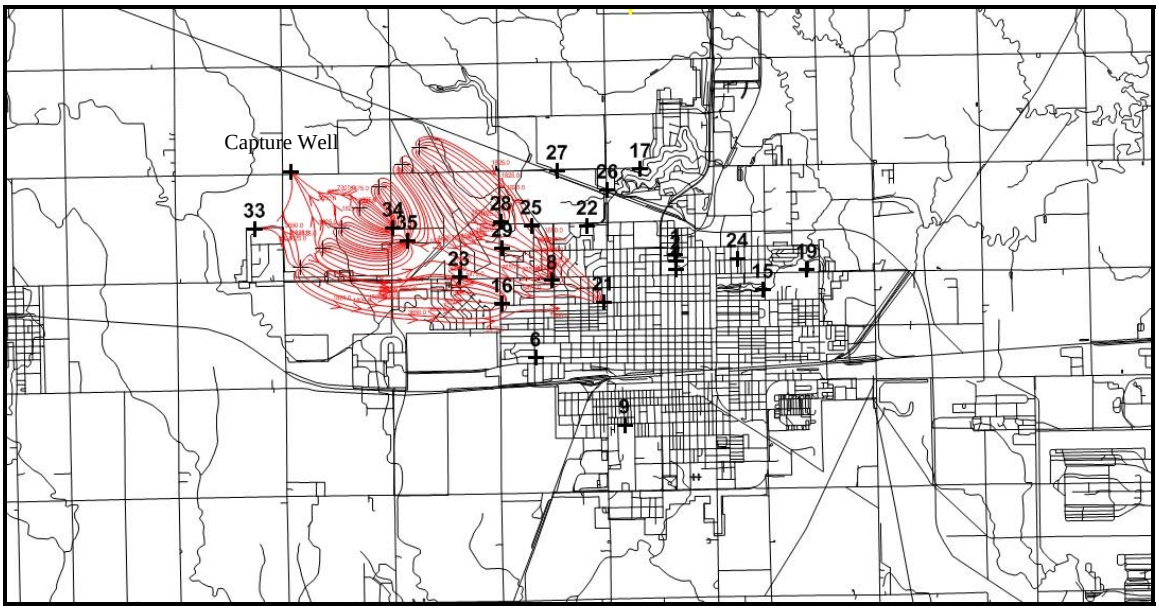


Figure 5-2 - Model Predicted Recharge Particle Tracking Results - 20-Year Time



The recharge wells, shown on Figure 5-2 were located to achieve the maximum benefit for existing HU wells, which are located downgradient of two pumping wells. Under the modeled scenario, the treated water would be recaptured by HU wells 8, 16, 21, 23, 25, 28, 29, 34, and 35 during the 20-year planning cycle. The model predicted time for treated water to first reach the downgradient HU wells is summarized in Table 5-2.

Table 5-2 – Time for Treated Recharge Water to Reach Downgradient Well

Well Number	Time for Treated Recharge Water to Reach Well
8	9 years
16	11 years
21	13 years
23	9 years
25	7 years
28	4 years
29	6 years
34	1 year
35	2 years

The model predicted future nitrate concentrations at each HU well were tracked by the ground water model for both the 2 mg/L and 5 mg/L treatment-recharge scenarios. The results of these analyses are shown on Figures 5-3 and 5-4, respectively. Although it would take several years for the treated water to reach the downgradient HU water supply wells, the benefit of the pump-treat-recharge option is predicted to occur very quickly due to the addition of the Capture Well.

Figure 5-3 - Model Predicted Nitrate Concentrations in Downgradient Recovery Wells for 2 mg/L Recharge Simulation

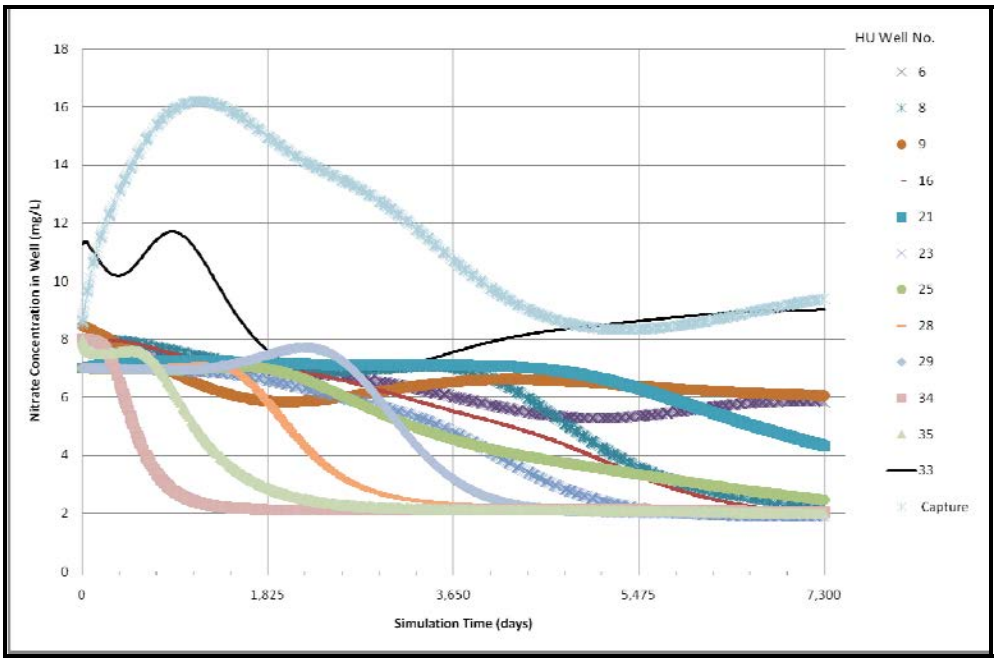
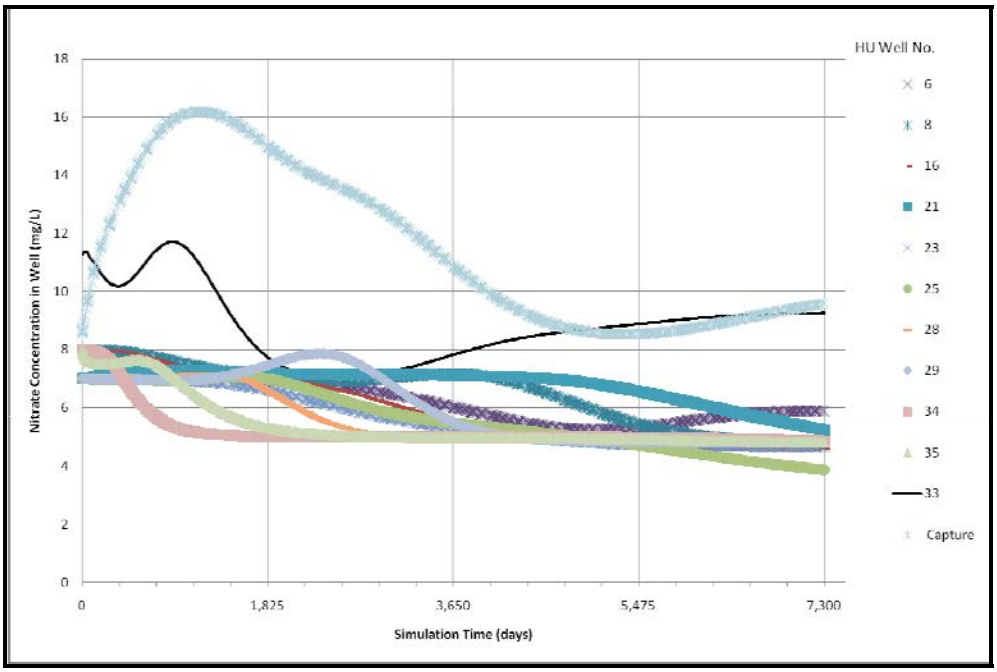


Figure 5-4 - Model Predicted Nitrate Concentrations in Downgradient Recovery Wells for 5 mg/L Recharge Simulation



From the results of the model simulations presented above, it can be seen that over time the downgradient pumping wells eventually produce water with nitrate concentrations well below the MCL of 10 mg/L.

Based on these results, it appears that increasing the level of treatment of the effluent of the upgradient pumping wells from 5 mg/L to 2 mg/L offers only minimal benefit to the operation of the well field.

5.3.2 LOCHLAND WELLS

A review of the historical well performance data, hydrogeologic setting, and nitrate conditions near the wells was conducted to evaluate the potential of developing wells located near the Lochland golf course. HU maintains two wells (Well 31 and 32) near the Lochland golf course. Well 31 was constructed in 1984 and Well 32 was constructed in 1971. Available well records indicate that these wells were capable of achieving flow rates between 450 and 700 gpm when first constructed. HU maintains the infrastructure associated with these wells and water rights associated with the wells, but does not actively pump the wells into distribution.

The hydrogeology near the Lochland golf course is significantly different from the hydrogeology on the west side of Hastings, near Wells 33, 34, and 35. The depth to the static water level in the aquifer in this area ranges from 110 to 120 ft bgs, while the depth to bedrock near the wells ranges from 162 and 166 ft bgs. These facts limit the saturated thickness of the aquifer near the Lochland wells to 40 to 50 feet, which is much less than the saturated thickness in the area of Wells 33, 34, and 35, which is approximately 120 feet. The saturated thickness of an aquifer impacts the potential yield of a well in two ways:

1. Less saturated thickness reduces the transmissivity of the aquifer. The transmissivity of the aquifer near the Lochland wells is between 50,000 to 100,000 gallons per day per square foot (gpd/ft^2) while the transmissivity near Well 33 is between 100,000 to 150,000 gpd/ ft^2.
2. Less saturated thickness reduces the available drawdown in the pumping well.

The yield of a new Lochland well was estimated to evaluate the value of re-drilling these wells using current municipal well drilling practices. For the purposes of this calculation, it was assumed that a new well would be constructed using a 20-foot screen, which would provide 20 to 30 feet of available drawdown to the top of the well screen. Given the low transmissivity values and the limited available drawdown, it was estimated that the maximum pumping rate for a municipal well constructed in this area would be between 400 and 500 gpm.

5.3.2.1 NITRATES NEAR THE LOCHLAND WELLS

The 20-year time of travel capture zone of the Lochland wells was calculated using the particle tracking code MODPATH. The model simulation was performed assuming the two Lochland wells would operate at a flow rate of 400 gpm each. Figure 5-5 illustrates the model predicted particle tracking results for this simulation. During the development of this report, 2011 sampling data revealed that nitrate levels near Lochland area were higher than those obtained during 2010 sampling. In fact, the nitrate concentrations near the southernmost Lochland well are presently between 10 and 15 mg/L. The model predicted future nitrate concentrations at the Lochland wells for this model simulation are presented on Figure 5-6.

Figure 5-5 – 20-Year Time of Travel for Lochland Wells

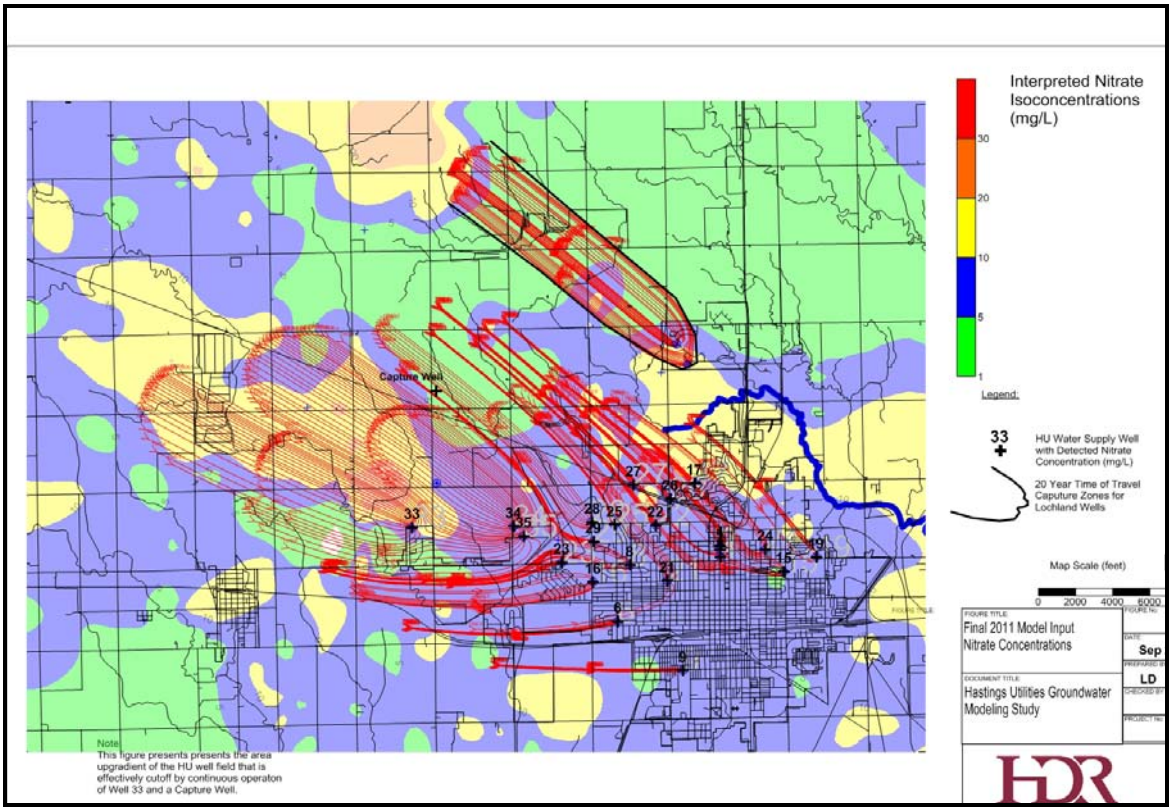
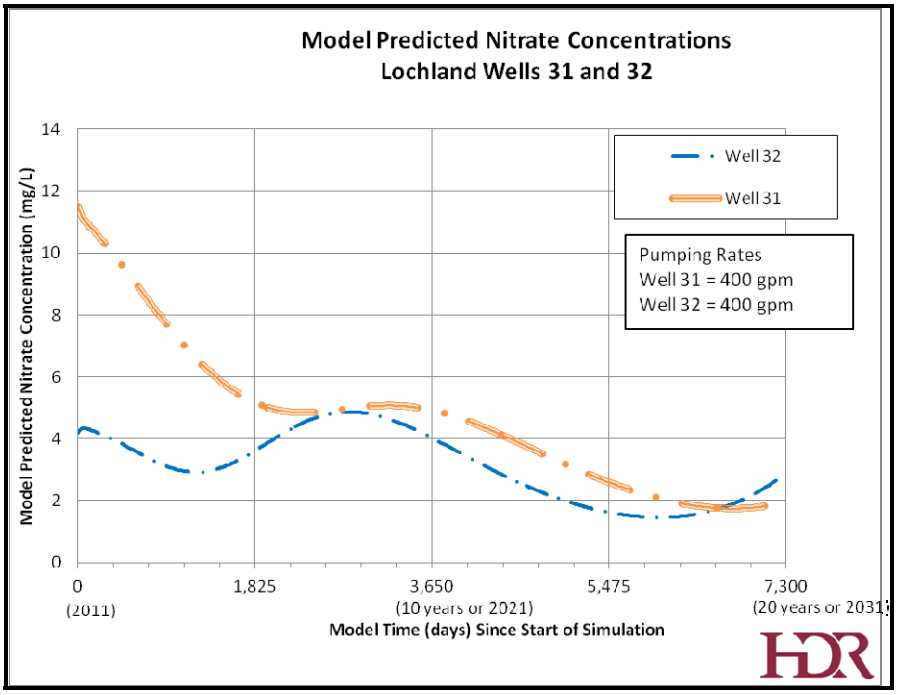


Figure 5-6 – Model Predicted Nitrate Concentrations for Lochland Wells



The results of the Lochland Well model simulation show that the model predicted nitrate concentration for Well 31 is currently above the MCL and will remain at or near the MCL for the first few years of operation of this well. The model predicted concentrations for both Lochland wells decrease over the simulation time because the area upgradient of the wells is an area of relatively low nitrate concentrations (see Figure 5-5). The simulation results reflect optimistic conditions in that no additional nitrate sources are assumed to exist within the model. Because the present day nitrate concentrations near the Lochland wells are above the MCL, and the projected peak capacity of Wells 31 and 32 is lower than other HU wells, development of the Lochland wells is not recommended.

5.3.3 20-YEAR FACILITY IMPLEMENTATION PLAN SIMULATIONS

The Phase II Model was used to predict nitrate concentrations in HU wells over a 20-year period. Four different scenarios were evaluated and are described in Table 5-3. In Scenario 1, all currently active wells were evaluated assuming a treated injected water nitrate concentration of 5 mg/L as N. In Scenario 2, Wells 31 and 32 were added. Although these wells are currently out of service, they are located in the Lochland area and sampling data obtained in 2010 showed lower nitrate levels in this area. Wells used for Scenario 1 and 2 analysis were also used for Scenarios 3 and 4, respectively. However, in Scenarios 3 and 4, a treated injected water nitrate concentration of 2 mg/L as N was assumed.

Table 5-3 – Model Evaluation Result Scenarios

Scenario	Wells Included	Treated Injected Water Nitrate Concentration (mg/L as N)
1	1,2,4,6,8,9,15,16,17,19,21,22,23,24,25,26,27,28,29,34,35	5
2	Same as Scenario 1 + 31 & 32	5
3	Same as Scenario 1	2
4	Same as Scenario 1 + 31 & 32	2

The projected nitrate levels were then used to determine total well capacity available for potable water use if wells with nitrate levels greater than 8 mg/L are eliminated on a yearly basis. This total well capacity available for potable water use was then compared to peak hour demand to determine whether ground storage and high service pumping would be required to meet these needs. The results of these model simulations were used to assist in the evaluation of water treatment alternatives and the results are included in the 20-Year Facility Implementation Plan Study.

5.3.4 ALTERATIVE WELL LOCATIONS IN LOW NITRATE AREAS

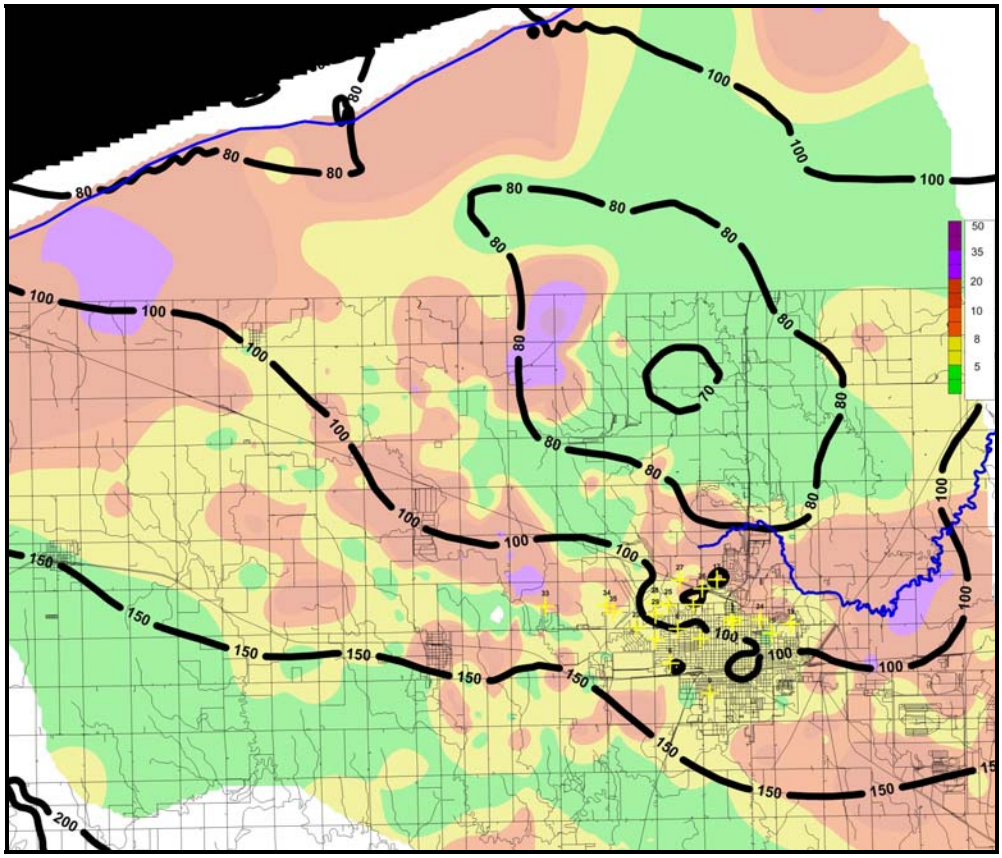
The nitrate sampling results from 2010 identified an area north and east of the HU 20 year time of travel WHPA that has low nitrates. Based on this identification, HU requested that HDR evaluate the potential to develop wells in this area.

To evaluate the potential to develop wells in this area, HDR evaluated the geology in this area to estimate the potential yield of a municipal water supply well. Figures 5-7a presents the saturated thickness of the aquifer and Figure 5-7b presents the transmissivity of the aquifer within the study area. Both figures illustrate these aquifer properties on top of the measured nitrate concentrations within the aquifer. As shown on Figures 5-7a and 5-7b, the area of low nitrate concentrations that is north and east of Hastings also is an area where the aquifer is thinner and has a lower transmissivity than other portions of the study area. Figure 5-7a presents a regional interpretation of that saturated thickness of the Pleistocene sand and gravel aquifer from the data included in the COHYST EMU model. This figure illustrates that most of the HU wells are constructed in a portion of the aquifer where the saturated thickness is near or in excess of 100 feet. This figure also illustrates that the general trend of the aquifer thickness in the aquifer is thickest to the west and south of Hastings and thinnest to the north and east of Hastings. In the area north

of Hastings, where nitrate concentrations are lower, the aquifer thickness is shown as generally 80 feet or less. However, data collected from the Lochland wells show that the aquifer thickness in this area is even shallower and can be as low as 40 to 50 feet due to several localized bedrock highs that are not captured in the COHYST EMU data.

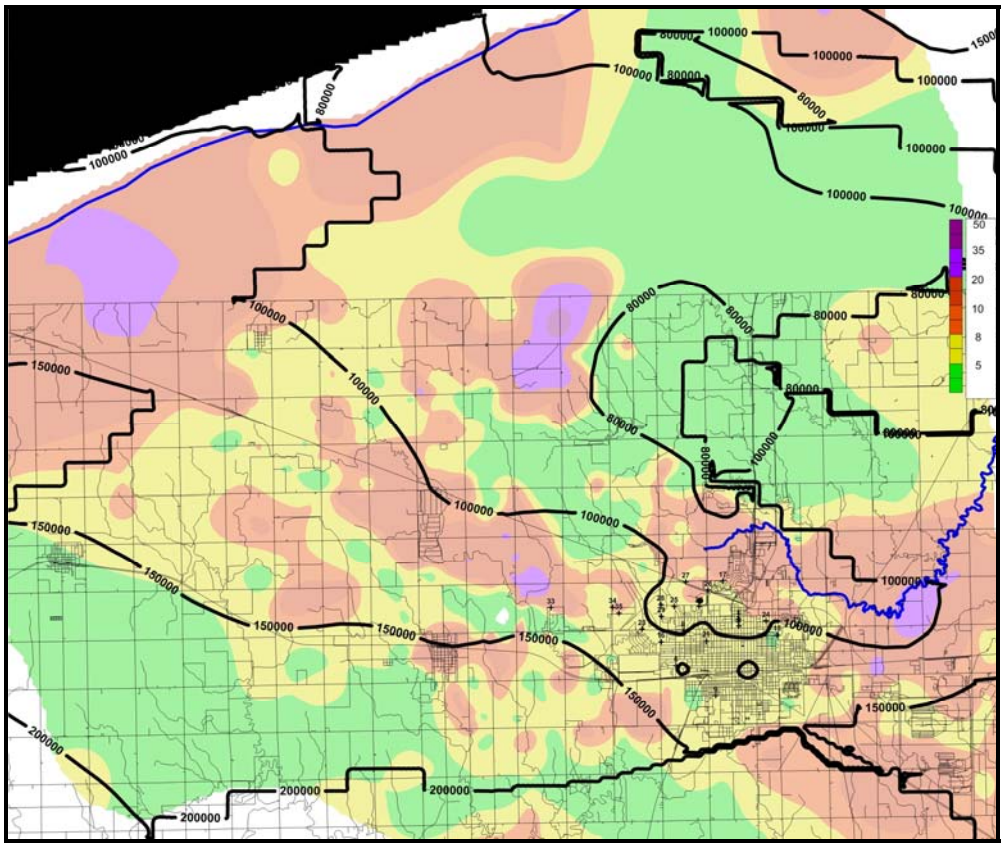
Figure 5-7b shows the aquifer transmissivity in this area is roughly between half to two thirds of the transmissivity of the aquifer where the existing HU wells are constructed. The combination of these issues indicates that municipal wells constructed north of Hastings would produce lower well yields than the current HU wells. For the purposes of the modeling activities, it was estimated that a municipal pumping well completed in the low nitrate area north of Hastings could sustain a pumping rate of 500 gpm.

Figure 5-7a – Distribution of Nitrates (filled color contours) and General Aquifer Thickness (black contours) near Hastings



Note: Regional aquifer thickness values (in feet) are shown in black and nitrate concentrations are shown in color. The nitrate color scale is included for nitrate concentrations in mg/L. HU wells are shown in yellow.

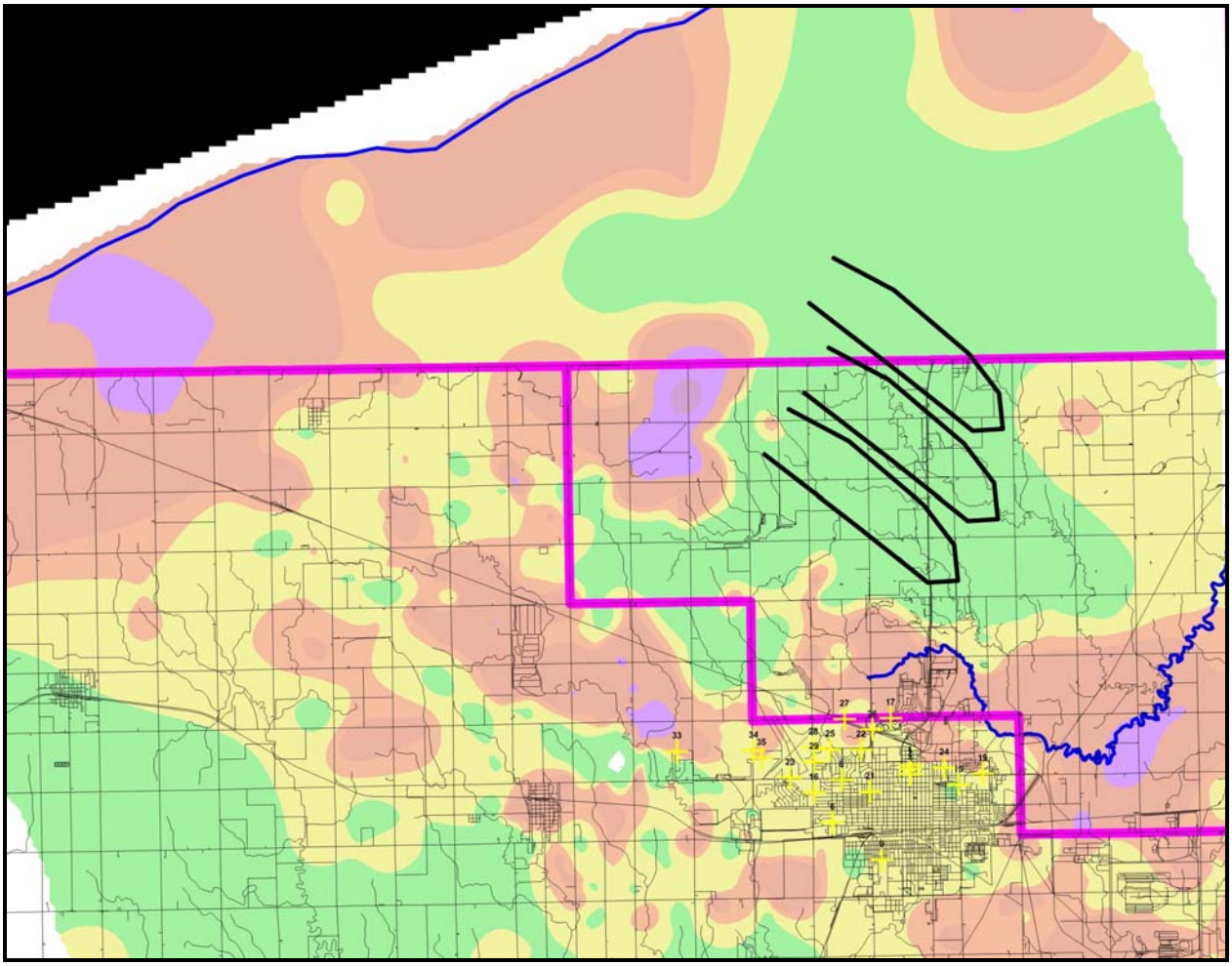
Figure 5-7b – Distribution of Nitrates (filled color contours) and Aquifer Transmissivity (black contours) near Hastings



Note: Aquifer transmissivity value (in gpd/ft) shown in black, nitrate concentrations shown in color. Nitrate color scale is included for nitrate concentrations in mg/L.

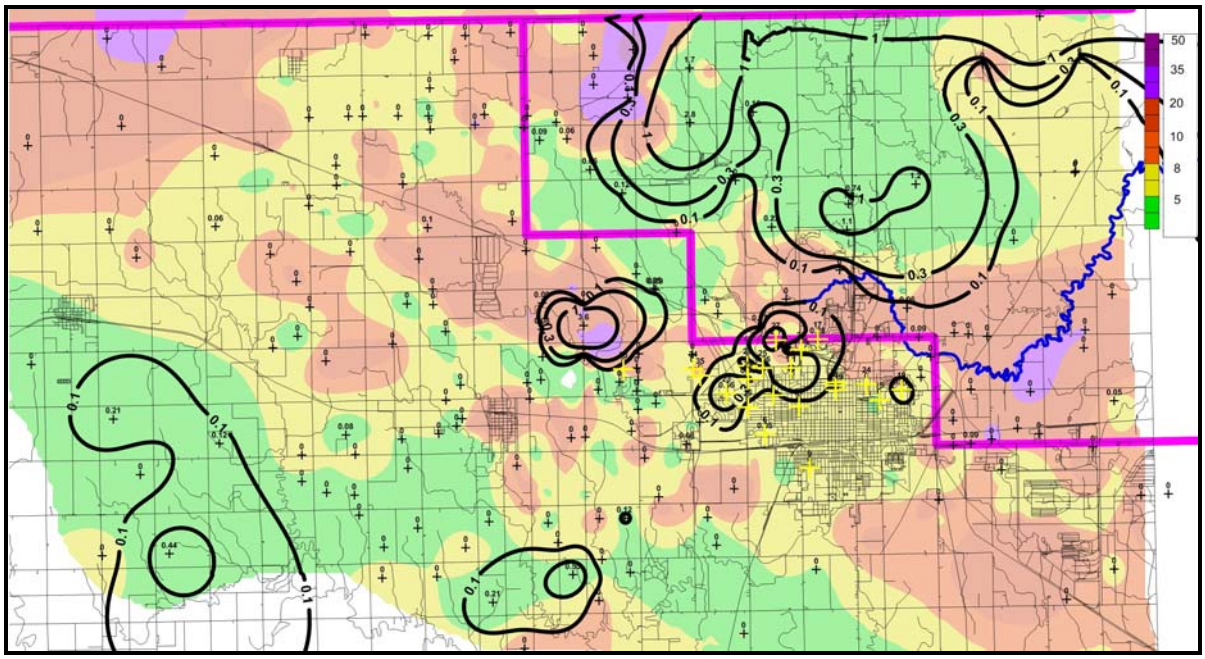
To evaluate potential development scenarios for wells north of Hastings, the groundwater model was used to estimate the 20 year time of travel of wells operating between 400 and 500 gpm, which is the estimated maximum sustainable pumping rate for a municipal well in this area. Figure 5-8 present the results of this analysis, which includes a total of six (6) pumping wells and does not include the two Lochland wells. As shown, between 2,400 gpm and 3,000 gpm of relatively low nitrate water could be produced from wells. However, groundwater samples collected from wells in the low nitrate area indicate the presence of iron in a majority of the wells, as shown on Figure 5-9a. In the area where nitrates are low, iron concentrations as high as 4.2 mg/L were detected, which is more than an order of magnitude more than the EPA secondary standard for iron (0.3 mg/L). The observed distribution on iron and nitrate is primarily related to the oxidation state of the aquifer. In an oxic (high dissolved oxygen concentrations) aquifer, nitrate is stable and iron is insoluble. In an anoxic (low dissolved oxygen) aquifer, nitrate ultimately transforms to nitrogen gas and iron is soluble. The relationship between nitrate and dissolved iron for the samples collected is presented on Figure 5-9b. This figure clearly shows that most nitrate samples that exceeded the MCL were collected from wells where dissolved iron was not detected (shown as 0.001 mg/L in Figure 5-9b). The relationship between dissolved iron and dissolved manganese for the samples collected is presented on Figure 5-9c. This figure clearly shows that iron and manganese are typically both either present or absent in groundwater. This is because both chemicals are more soluble, and therefore more mobile, in reduced groundwater conditions.

Figure 5-8 – Maximum Development Scenario – North Wells



Note: Figure shows 20 year time of travel for 6 wells pumping at 400 gpm each. Nitrate color scale is included for nitrate concentrations in mg/L. Existing HU wells are shown in yellow.

Figure 5-9a – Iron (black contours) and Nitrate (filled color contours) Concentrations near Hastings



Note: Figure shows contours of interpreted iron concentrations (mg/L). Groundwater sample locations for iron are shown as a black cross hatch. Nitrate color scale is the same as in the previous figures. Existing HU wells are shown in yellow.

Figure 5-9b – Relationship between Nitrate and Dissolved Iron in Groundwater

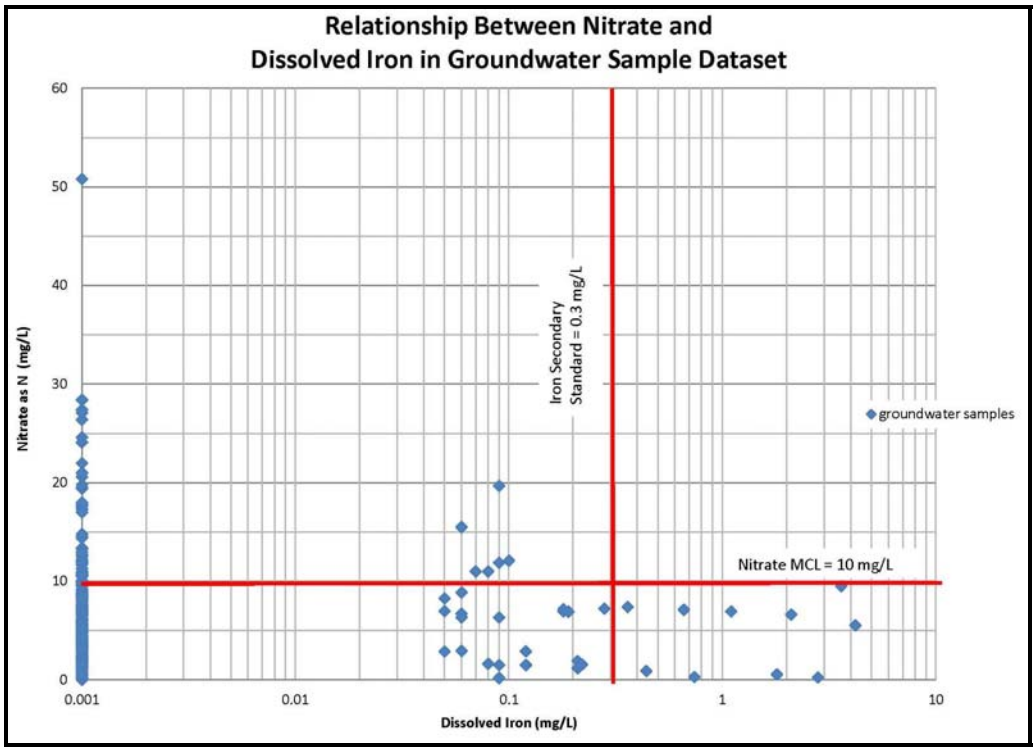
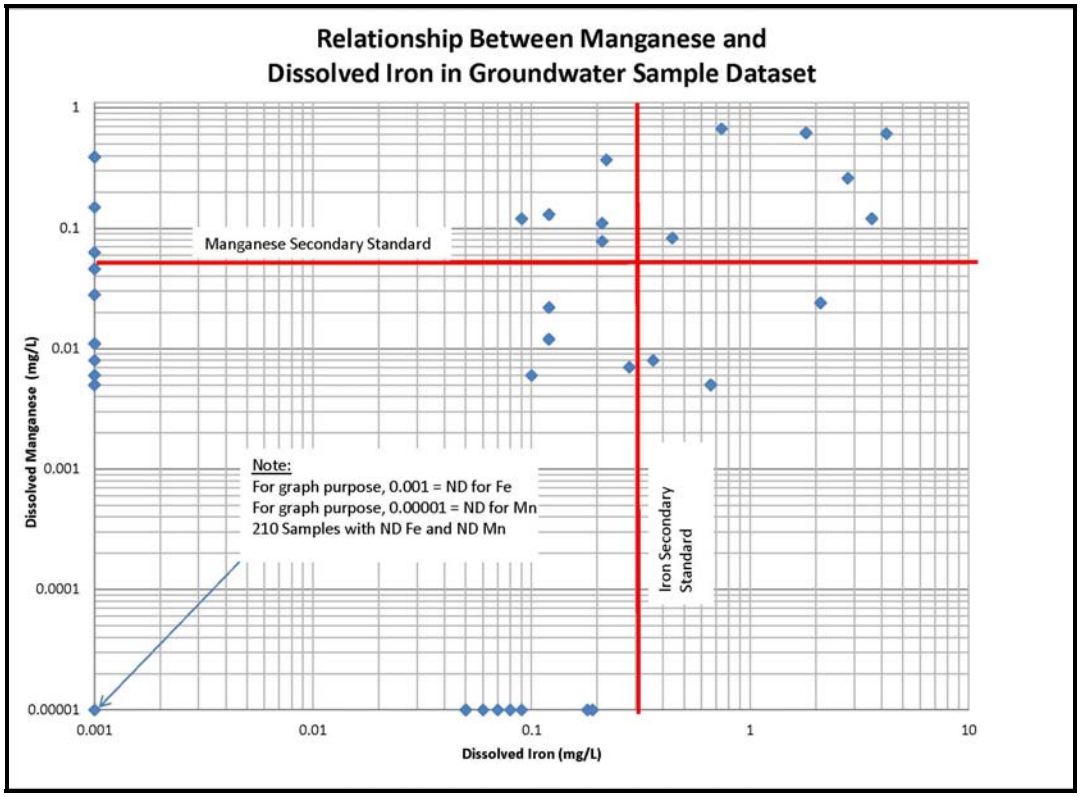


Figure 5-9c – Relationship between Dissolved Iron and Dissolved Manganese in Groundwater



5.4 URANIUM

The primary focus of the groundwater sampling effort summarized in Section 4 was to quantify the distribution of nitrate in the aquifer near Hastings. However, other compounds were also included in the analyses of the groundwater samples. Based on the observed sampling results, HU expressed an interest in evaluating the distribution of uranium and the movement of this compound over the 20 year planning cycle. The following section presents the solute transport modeling performed to evaluate the potential future movement of uranium in the HU well field.

5.4.1 INTERPRETATION OF URANIUM CONCENTRATIONS

The most critical input parameter necessary to generate predictions of future uranium concentrations in the HU water supply wells is the initial uranium concentration field. To characterize the distribution of uranium in the aquifer, HDR used the 2010 and 2011 groundwater sample dataset, which includes over 770 wells that were sampled primarily for nitrates. Of these wells, approximately 42 wells were also sampled for uranium. All samples collected were included in the interpretation of nitrate concentrations in the aquifer regardless of type of well (irrigation well, domestic well etc). Concentrations obtain from each well were assumed to be representative of the average nitrate concentration for the entire aquifer thickness.

The interpretation of uranium concentrations near the HU well field is presented on Figure 5-10. The interpretation presented was developed using a Kriging algorithm in Surfer™. Kriging is typically used to evaluate irregularly spaced data and attempts to express trends suggested evident in the spatial distribution of the data, so that high points might be connected along a ridge rather than isolated by bull's-

eye type contours. The interpreted nitrate concentrations resulting from the Kriging algorithm were checked manually by a hydrogeologist and re-interpreted as necessary. Manual reinterpretation of the Kriging algorithm's contours was minimal.

The interpretation of the distribution of uranium in the aquifer shown on Figure 5-10 could be a function of the limited sample data set, but generally is consistent with the particle tracking results that show the recharge zone for the HU wells (see Figure 4-2b). The uranium contours presented on Figure 5-10 drawing indicate that the HU wells are acting as a containment system, preventing upgradient uranium contamination from moving downgradient of the City wells.

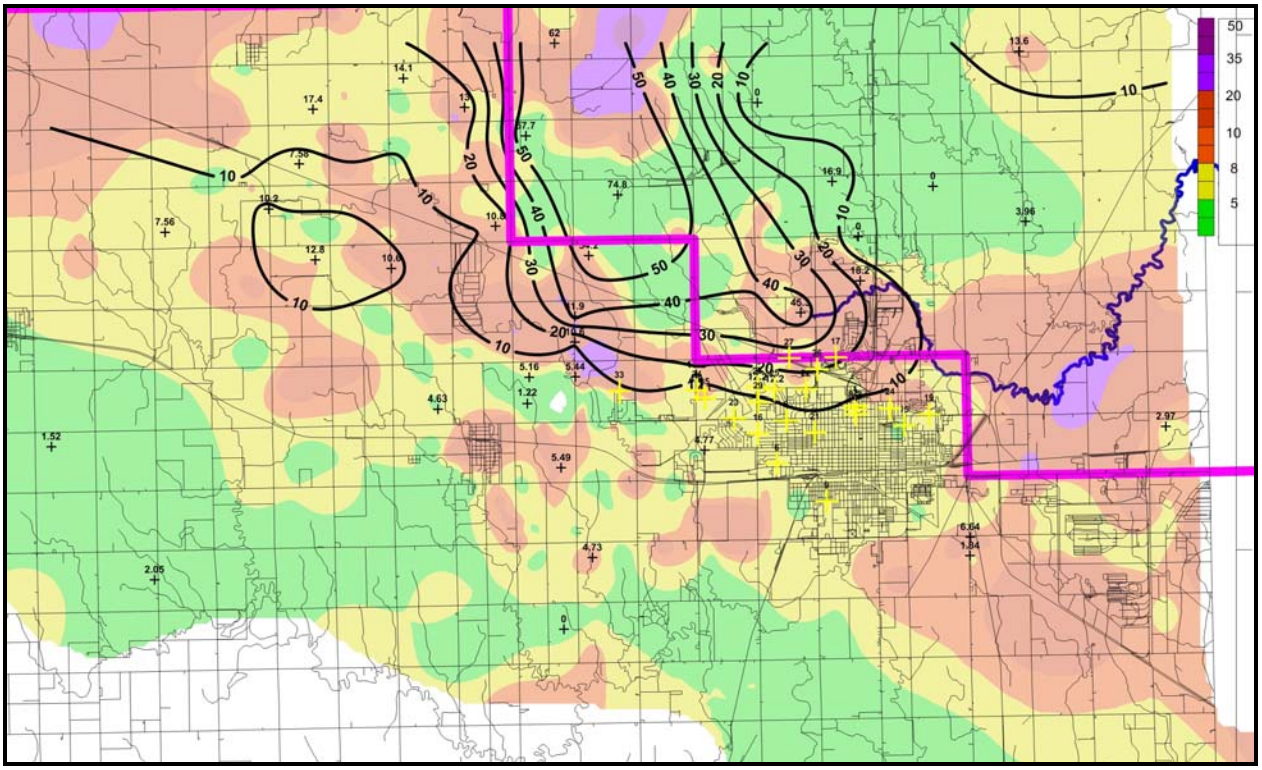
5.4.2 URANIUM TRANSPORT

Uranium is a radioactive material that occurs naturally in many soils and rock types within Nebraska, and occurs primarily as U^{238} with U^{235} being much rarer. According to University of Nebraska Drinking Water Guide G1569, state wide groundwater monitoring has shown that high levels of uranium are found in the aquifers associated with the Republican, North Platte and Platte River valleys. It is thought that the rocks and volcanic ash deposits, which contain uranium, were eroded from the source and then transported and deposited near these river valleys.

Movement of a dissolved chemical such as uranium in an aquifer occurs through three processes: advection, dispersion, and chemical reactions. In advective flow, dissolved chemicals in the aquifer move at the same speed as the average linear groundwater velocity. In most cases advective flow is the dominant transport condition, however to fully represent contaminant transport in an aquifer requires consideration of two other processes: dispersion and chemical reactions. Dispersion accounts for the mixing which occurs along the advancing edge of a flowpath. With dispersion, some chemical travels faster and some slower than the average linear groundwater velocity, causing the contaminant to "spread out." Dispersion occurs in three dimensions (longitudinally, transversely, and vertically) relative to the plume centerline. The concentrations of chemicals in groundwater can be altered through a variety of chemical processes, including: sorption, bio-degradation, retardation, half-life reduction, or oxidation-reduction reactions. Because uranium is a radioactive isotope, the only chemical processes that can alter concentrations in groundwater are the oxidation-reduction process and spontaneous decay (half-life reduction).

The chemistry of dissolved uranium is complex in that it has three valance states, +4, +5, and +6. Uranium can undergo oxidation reduction reactions and is a compound that is sensitive to both the dissolved oxygen and pH conditions of the aquifer; however uranium is insoluble under anoxic conditions. Uranium must be oxidized before it can be transported in groundwater, but once in solution uranium is considered mobile and can travel great distances. Uranium has a very long half life, 4.5×10^9 years (Fetter, 1999); therefore, for the purposes of the groundwater modeling activities, uranium was considered to be a conservative compound and the half life was ignored. Uranium can persist in ground water for decades under oxidizing conditions, but can be naturally attenuated under anoxic (dissolved oxygen concentrations mostly less than 0.5 mg/L) conditions if given enough residence time. Uranium is generally attenuated under anoxic conditions because it precipitates out of ground water as an insoluble mineral (uranite) or sorbs onto aquifer sediments in anoxic conditions. For the purposes of this modeling study, it was assumed that the aquifer conditions are primarily oxidizing, therefore the uranium simulations were performed assuming dissolved uranium is transported as a conservative compound.

Figure 5-10 – Uranium (black contours) and Nitrate (filled color contours) Concentrations near Hastings



Note: Figure shows contours of interpreted uranium concentrations in micrograms per liter (µg/L). Groundwater sample locations for iron are shown as a black cross hatch. Nitrate color scale is the same as in the previous figures. Existing HU wells are shown in yellow.

5.4.1 URANIUM TRANSPORT RESULTS

The uranium solute transport model runs were performed using the well pumping rates presented in Table 5-1. The model predicted uranium concentrations in the HU pumping wells, for the 20 year planning horizon, are shown on Figure 5-11 for selected wells and in Table 5-4 for all HU wells. As previously stated, the uranium model simulations assumed that uranium is a conservative compound, meaning concentrations in groundwater were not reduced as a result of chemical processes in the model. The results of this model simulation indicate the upgradient water supply wells located in the north central portion of the well field (Wells 22, 24, 25, 26, 28, and others) intercept the highest concentration of uranium and that the model predicted concentrations in many these wells rise during the 20 year planning period. HU wells located on the east and west sides of the well field appear to be less impacted by uranium than the previously listed wells.

Figure 5-11 – Model Predicted Uranium Concentration (µg/L) for Select HU Wells

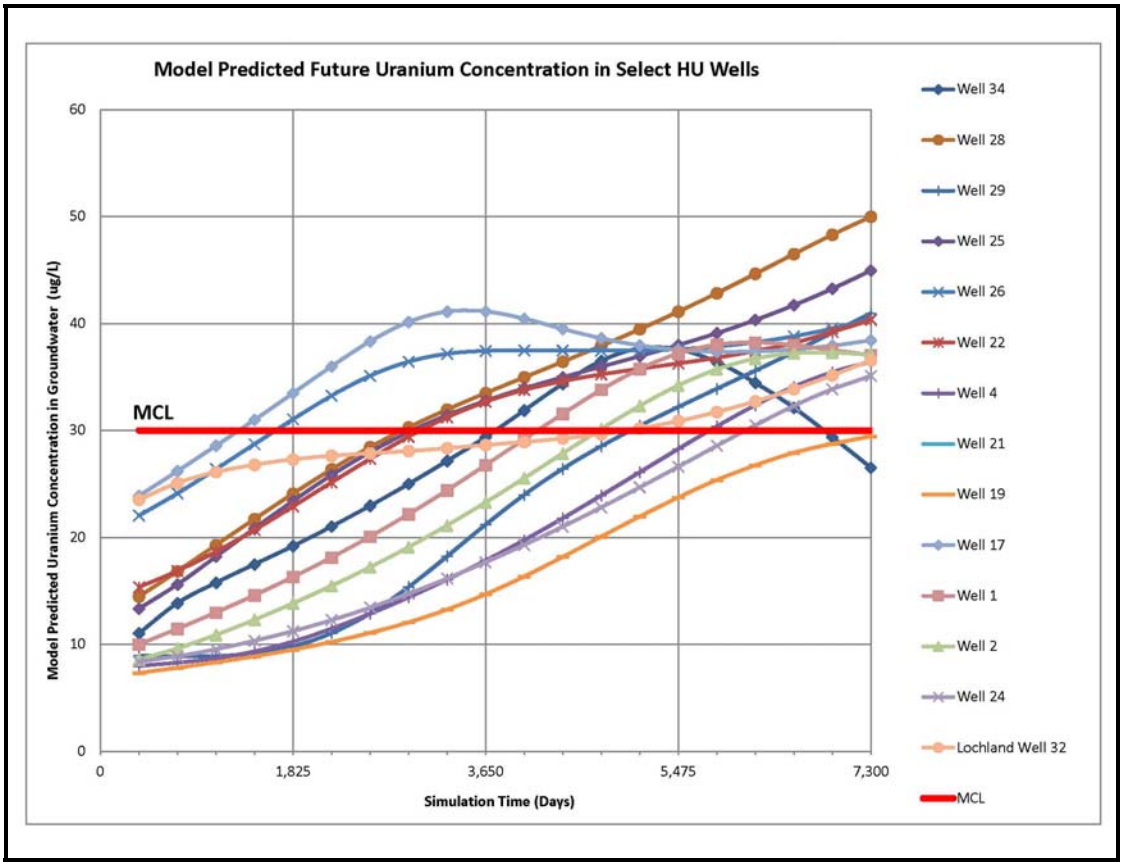


Table 5-4 – Model Predicted Uranium Concentration (µg/L) for All HU Wells

	Well 34	Well 35	Well 15	Well 33	Well 23	Well 28	Well 29	Well 16	Well 6	Well 25	Well 8	Well 27	Well 26	Well 22	Well 9	Well 4	Well 21	Well 19	Well 17	Well 1	Well 2	Well 24	Capture Well	Lochland Well 32	Lochland Well 33
Time (Days)	Model Predicted Uranium Concentration in Well (ug/L)																								
365	11.0	6.0	7.0	9.0	5.1	14.5	8.9	5.2	4.0	13.3	7.8	27.1	22.0	15.3	3.0	8.0	7.3	7.2	23.9	10.0	8.6	8.4	21.6	23.5	23.2
730	13.8	8.0	7.0	8.5	4.9	16.8	8.9	5.0	4.0	15.6	7.9	29.1	24.1	16.9	3.0	8.3	7.8	7.8	26.2	11.4	9.6	8.9	23.5	25.1	23.6
1095	15.8	9.8	7.0	7.8	4.7	19.3	8.9	4.7	4.0	18.2	8.0	31.1	26.4	18.7	3.0	8.7	8.3	7.9	28.6	13.0	10.9	9.5	25.7	26.1	23.8
1460	17.5	11.2	7.0	7.4	4.2	21.7	9.2	4.4	3.9	20.8	8.1	32.9	28.7	20.7	3.0	9.3	8.9	8.2	31.0	14.6	12.3	10.3	28.1	26.8	24.2
1825	19.2	12.4	7.1	7.6	3.9	24.1	9.8	4.2	3.9	23.4	8.2	34.2	31.0	22.9	2.9	10.3	9.5	8.6	33.5	16.3	13.8	11.2	31.1	27.3	24.8
2190	21.0	13.4	7.2	8.6	3.8	26.4	11.0	4.0	3.9	25.8	8.4	35.2	33.2	25.1	2.9	11.5	10.2	9.0	36.0	18.1	15.5	12.3	34.9	27.6	25.5
2555	23.0	14.4	7.4	10.0	3.8	28.4	12.9	4.0	3.9	28.0	8.6	35.9	35.1	27.3	2.9	12.9	11.1	9.5	38.3	20.1	17.2	13.4	38.4	27.8	26.0
2920	25.0	15.4	7.6	11.4	3.8	30.3	15.4	3.9	3.9	29.8	8.8	36.4	36.4	29.4	2.9	14.4	12.1	10.1	40.1	22.2	19.1	14.7	39.8	28.1	26.5
3285	27.1	16.4	8.0	12.3	3.7	32.0	18.2	3.9	3.9	31.4	9.1	36.9	37.2	31.2	2.9	16.1	13.2	10.7	41.1	24.4	21.1	16.2	38.8	28.3	26.9
3650	29.4	17.4	8.4	12.7	3.7	33.5	21.2	3.8	3.8	32.8	9.4	37.3	37.4	32.7	2.9	17.8	14.7	11.4	41.1	26.7	23.3	17.7	36.5	28.6	27.2
4015	31.9	18.4	9.0	12.8	3.7	35.0	24.0	3.7	3.8	33.9	10.0	37.7	37.5	33.8	2.9	19.8	16.3	12.2	40.4	29.2	25.5	19.3	33.8	28.9	27.6
4380	34.4	19.4	9.7	12.5	3.7	36.4	26.4	3.7	3.8	35.0	10.7	38.3	37.5	34.6	2.9	21.8	18.2	13.0	39.5	31.5	27.8	21.0	31.0	29.2	27.8
4745	36.5	20.4	10.7	12.1	3.8	37.9	28.5	3.7	3.7	36.0	11.8	38.9	37.5	35.2	2.9	23.9	20.1	13.9	38.6	33.8	30.1	22.8	28.1	29.6	28.0
5110	37.7	21.4	11.8	11.6	3.9	39.5	30.4	3.6	3.7	36.9	13.1	39.6	37.5	35.8	2.8	26.1	21.9	14.9	37.9	35.7	32.3	24.7	25.1	30.2	28.2
5475	37.6	22.3	13.0	10.9	4.0	41.1	32.2	3.6	3.7	38.0	14.8	40.4	37.6	36.3	2.8	28.3	23.7	15.9	37.5	37.2	34.2	26.6	22.1	30.9	28.5
5840	36.4	23.1	14.4	10.3	4.1	42.8	33.9	3.6	3.6	39.1	16.6	41.4	37.8	36.8	2.8	30.4	25.4	16.9	37.4	38.0	35.7	28.6	19.0	31.7	28.9
6205	34.4	23.5	15.9	9.8	4.0	44.6	35.6	3.6	3.6	40.3	18.4	42.6	38.2	37.4	2.8	32.4	26.7	18.1	37.4	38.2	36.7	30.5	16.1	32.7	29.5
6570	32.1	23.5	17.5	9.3	3.9	46.5	37.3	3.6	3.6	41.7	20.2	44.0	38.8	38.2	2.8	34.1	27.9	19.2	37.6	38.0	37.2	32.3	13.6	33.9	30.2
6935	29.4	22.9	19.3	8.9	3.8	48.3	39.1	3.6	3.6	43.3	21.6	45.5	39.5	39.2	2.8	35.4	28.7	20.4	37.9	37.5	37.3	33.8	11.6	35.1	31.0
7300	26.5	22.1	21.1	8.7	3.6	50.0	40.9	3.6	3.6	45.0	23.1	47.2	40.4	40.3	2.9	36.4	29.5	21.5	38.4	37.0	37.1	35.1	10.1	36.6	32.0

6 SUMMARY AND CONCLUSIONS

The Phase II groundwater modeling study presented within this report is an update to the Phase I groundwater and solute transport model that was developed to provide a tool for management of the HU well field. The objective of the modeling study was to evaluate several potential management/development options that could be used to help minimize the impact of the nitrates present within the source water of the well field.

The first step in the model update was to incorporate the 2011 nitrate sampling results into the model and to use the updated nitrate distribution in the aquifer to make predictions about future nitrate concentrations within the HU well field. The nitrate sample database used to interpret the concentration distribution within the aquifer consisted of approximately 770 water samples over the summer of 2010 and 2011 by HU/LBNRD/UBBNRD. These samples were obtained primarily from irrigation wells, but domestic and municipal wells were also sampled. The sample results have shown that nitrate in groundwater is prevalent within and around the Hastings WHPA; and the average nitrate concentration detected was 7.7 mg/L. Approximately 25 percent of the 770 samples collected exceed the 10 mg/L MCL for nitrates and the maximum concentration detected was over 50 mg/L. Other than modifying the initial nitrate concentrations in the model, no structural changes were made to the groundwater and solute transport model presented in the *Hastings Utilities Phase I Groundwater Modeling Study* (HDR, 2010).

6.1 MODELING OBJECTIVES

The objectives for the Phase II groundwater modeling study were to evaluate several specific well field management alternatives, including:

1. *Pump, Treat, and Recharge option*. For this option, upgradient water supply wells are used to intercept areas of high nitrate concentrations. The pumped water would then be treated and returned to the aquifer through recharge/injection wells. The recharge/injected water forms a "bubble" of treated groundwater that travels downgradient at the speed of ambient groundwater flow and is later pumped out of the aquifer by existing HU wells that are located downgradient of the recharge/injection wells.
2. *Determine the feasibility of operating the existing wells near the Lochland Golf Course.* This analysis included a review of operation data of these wells, the geology near the Lochland golf course, estimating a maximum pumping rate for wells in this area, and estimating future nitrate concentrations in the wells.
3. *Provide future nitrate concentration data for each HU well, to be included in the 20-Year Facility Implementation Plan.* This involved updating the model predicted nitrate concentrations for all HU wells using the updated nitrate concentrations, which include the 2011 data.
4. *Evaluate the potential to develop new wells in areas with low nitrate concentrations.*
5. *Evaluate the impact on HU wells from other contaminants in the aquifer, including uranium*.

6.2 CONCLUSIONS AND RECOMMENDATIONS

The conclusions of the Phase II modeling study are presented below, using the same numbering system as the previous objectives list.

1. *Pump, Treat, and Recharge option*. Based on the modeling performed, this option appears to be a viable long term option to manage the nitrate concentrations within the HU well field. This option has two primary benefits:

a. Well 33 and a capture well (or wells) can be used to cut off a large portion of the high concentration nitrate groundwater that is moving south an east towards the HU wells. This water can be treated to a level below the nitrate MCL and then returned to the aquifer.

b. Over years of active recharge, the water that is returned to the aquifer after treatment will form a hydraulic "bubble" of treated water, which will move downgradient at the speed of ambient groundwater flow until it is recovered by existing downgradient HU wells.

Under the scenario modeled, the treated water would be recaptured by HU wells 8, 16, 21, 23, 25, 28, 29, 34, and 35 during the 20-year planning cycle. Over time, the wells that recover the treated recharge water could be become the primary source of water for HU. This would ensure a reasonably constant long term water quality. Based on the modeled results, it appears that increasing the level of treatment of the effluent of the upgradient pumping wells from 5 mg/L to 2 mg/L offers only minimal benefit to the operation of the well field and treatment to a level of 5 mg/L will meet the project objective while also lowering the treatment cost.

At this time, it is recommended that HU initiate meetings and discussions with regulatory agencies to discuss the pump treat recharge concept. If the regulatory community is agreeable towards this concept, it is recommended that a pilot scale demonstration project be initiated to demonstrate the feasibility of this concept. The project should include Well 33 as the pumping well and three new recharge wells. A modeling and monitoring program should be part of the demonstration phase project.

2. *Determine the feasibility of operating the existing wells near the Lochland Golf Course*. Based on our review of the hydrogeology in this area, development of production wells near the Lochland Golf Course is not recommended. The aquifer thickness in this area is significantly shallower than where the other HU wells are constructed. As a result, yields for municipal wells constructed near the golf course are anticipated to be much lower than the other HU wells. Additionally, the present day nitrate concentrations near the Lochland wells are above the nitrate MCL. Finally, the groundwater sample results indicate that iron, manganese, and uranium are all potential water treatment issues for wells near the golf course.

3. *Provide future nitrate concentration data for each HU well, to be included in the 20-Year Facility Implementation Plan*. These data were included in the 20-Year Facility Plan and were used to develop the recommendations presented within that document.

4. *Evaluate the potential to develop new wells in areas with low nitrate concentrations*. The nitrate sampling results from 2010 identified an area north and east of the HU 20 year time of travel WHPA that has low nitrates. HDR evaluated the potential to develop wells in this area and has concluded that it may be possible to develop low nitrate wells in this area. However, the aquifer in this area is thinner and has a lower transmissivity than in the area where the majority of the HU wells are constructed. Therefore, wells constructed in this area would likely produce at a lower flow rate than the current HU wells. Based on the analysis performed, it appears possible that up to six (6) wells, which would likely produce between 2,400 gpm to 3,000 gpm (3.5 to 4.3 mgd), could potentially be constructed in this area of low nitrates. However, test drilling in the areas of the potential wells is should be performed to evaluate site specific geologic conditions before this option is further explored.

   Iron has been detected in this portion of the aquifer at concentrations that exceed the EPA secondary MCL standard of 0.3 mg/L. Therefore, if wells are constructed in this portion of the aquifer, a centralized treatment plant to remove iron may be required. Finally, the groundwater sample results indicate that manganese and uranium are also potential water treatment issues for wells near this area.

5. *Evaluate the impact on HU wells from other contaminants*. Several groundwater contaminants, in addition to nitrates, were discovered during the summer 2011 sampling event, including: uranium, total dissolved solids, iron and manganese. Each of these contaminants impacts the ability to locate "pristine" areas of the aquifer. The quantitative evaluation of the impact of these compounds on the HU well field is beyond the scope of this investigation; however several model runs were performed to evaluate the potential future concentrations of uranium. The model simulations performed to evaluate uranium show that the HU wells located in the north central portion of the HU well field (Wells 22, 24, 25, 26, 28, and others) intercept the highest concentration of uranium and that the model predicted concentrations in many these wells rise during the 20 year planning period. Based on the distribution of uranium observed in the aquifer, and the model simulations performed, it appears as though the HU wells are acting as a hydraulic containment system that is capturing much of the uranium and limiting the potential for uranium to move downgradient, beyond the HU wells. At this time, it is recommended that sampling for these compounds be expanded if possible. Additionally, these compounds should be included in any pre-design investigation of a future water supply well.

6.3 FUTURE MODEL USES AND LIMITATIONS

The HU groundwater model continues to serve as a powerful well field management tool that can be used to complete future evaluations of how changes well field pumping can impact nitrate concentrations in wells. To maintain the usefulness of the model will require continued groundwater sample collection and analysis, and maintenance of those data in a GIS database.

6.3.1 MODEL LIMITATIONS

Groundwater and solute transport modeling are state of the practice tools applied by groundwater hydrologists to solve complex problems. Given the complexity of the problems solved through groundwater modeling, it is unreasonable to expect that model results will represent the absolute aquifer response to future stresses. Rather, when applied by an experienced practitioner, the results of a groundwater and solute modeling study should represent a reasonable approximation of future aquifer behavior under the modeled conditions.

Specific to the study presented within this document, the largest source of uncertainty is the interpretation of nitrate concentrations in the aquifer (Figure 4-2b). This interpretation was based on 770 water samples collected from irrigation, domestic, and municipal water supply wells. Concentrations obtained from each well were assumed to be representative of the average nitrate concentration for the entire aquifer thickness, which may not always be an accurate assumption. However, this simplifying assumption was necessary given the compressed project schedule. It is possible that if additional data are collected, the interpretation of the nitrate concentrations will change which could impact the predicted concentrations presented in this report. **An additional simplification was the assumption of no continuous nitrate or uranium sources with the model domain. If nitrates or uranium are present in the unsaturated zone of the soil profile, it is possible that the observed future nitrate concentrations could be higher than the model predicted concentrations presented within this report.** As the understanding of the nitrate plume migration and source(s) is improved through future data collection, the limitations of the model can be further reduced. This concept is a key driver for continued groundwater sampling and modeling.

Uncertainty in the flow model was decreased by using the COHYST EMU regional groundwater modeling study as a building block for groundwater model. Uncertainties in the flow model input parameters are reasonably well controlled, when considering the modeling objectives, given that the groundwater model parameters were obtained from a regional study which includes physical aquifer boundaries and aquifer heterogeneity. Uncertainty in the solute transport model is limited, as the only

transport processes simulated were advection and dispersion. The greatest source of uncertainty in the solute transport model are the input values used for the dispersion parameters.

6.4 FUTURE DATA COLLECTION

The groundwater sampling that was performed to support the Phase I and Phase II models has shown that the aquifer is impacted by contaminants other than nitrate. Continuing to collect samples from portions of the aquifer that have not been sampled before and maintaining a sampling program that rotates sample collection from wells would be an invaluable source of data for the management of the HU well field and for any future model updates. It is recommended that the migration of the nitrate plume near Well 33 be monitored by collection of semi-annual or annual water quality samples from select wells. Additionally, it would be beneficial to collect groundwater samples for phosphorous in order to better understand the relationship of nitrates and phosphorous in groundwater. Groundwater samples collected for phosphorous could potentially give an indication as to the source(s) of uranium and whether it is man made or naturally occurring.

REFERENCES CITED

COHYST, 2007. Groundwater Flow Model of the Easter Model Unit of the Nebraska Cooperative Hydrology Study Area. Prepared by Steven M. Peterson. November.

Fetter, C.W. 1999. Contaminant Hydrogeology Second Edition. Prentice Hall. Upper Saddle River, New Jersey.

HDR, 2010. Hastings Utilities Phase I Groundwater Modeling Study. Prepared for Hastings Utilities. October.

HDR, 2011. Utilities Well Based Nitrate Management Approach Technical Memorandum. Prepared for Hastings Utilities. October.

Pyne, R. D. G. Groundwater Recharge and Wells: A Guide to Aquifer Storage Recovery. Lewis Publishers, CRC Press. 1995.

APPENDICES

Appendix 1-1: *Hastings Utilities Phase I Groundwater Modeling Study*

HASTINGS UTILITIES 2010 AND 2011 WATER QUALITY SUMMARY TECHNICAL MEMORANDUM

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0.0 INTRODUCTION

In 2010, Hastings Utilities (HU) hired HDR to develop a 20-Year Facility Implementation Plan (Plan) for potable water supply that included treatment options, residual waste stream treatment and disposal requirements, opinion of probable construction costs, and the best alternative for primary treatment and residual waste stream treatment and disposal. In October 2010, HDR presented the proposed Plan to the HU Board. Due to the high cost associated with full-scale nitrate treatment proposed in the Plan, the HU Board decided they would like to pursue other avenues aimed at delaying full-scale treatment as long as possible. As a result, Phase 2 of the Plan, which focuses on further evaluation of groundwater quality, identification of additional water supply sources, and evaluation of alternative well management approaches was initiated in early 2011.

During 2010 and 2011, approximately 770 groundwater samples were collected as part of the Hastings Wellhead Protection Plan (WHPP). The samples were obtained primarily from irrigation wells. However, domestic and municipal wells were also sampled. All obtained samples were analyzed for nitrate. Select water quality parameters of concern identified during Phase 1 of the Plan as well as additional parameters of interest were also analyzed. The objective of this technical memorandum (TM) is to summarize this collected water quality data and to compare to corresponding available historical data.

1.0 BACKGROUND

1.1 Hastings Well Head Protection Plan

In 2009, the Hastings Wellhead Protection Area (WHPA) Committee, represented by various stakeholders, recommended that all domestic, irrigation, municipal, and industrial wells located with the WHPA be sampled for nitrate along with other related constituents. This recommendation was adopted as part of the WHPP. To accomplish the requested water sampling, an inter-local agreement was executed between the Upper Big Blue Natural Resources District (UBBNRD), the Little Blue Natural Resources District (LBNRD), and HU. This inter-local agreement allows for each entity to collect and analyze water samples in the WHPA and share the results. As recommended by the Hastings WHPA Committee, these data are to be used to assess the fate and transport of the nitrate contamination within the Hastings WHPA.

1.2 Water Quality Parameters of Concern

As part of the Phase 1 Plan, historical water quality and projected water quality for key parameters for the City of Hastings (City) was reviewed, evaluated, and summarized in *TM 1 – Water Demand, Water Quality, and Design Parameters (June 2010)*, hereafter referred to as the '2010 Water Quality TM'. Key water quality parameters of concern identified during Phase 1 of the Plan are listed in Table 1. As shown, blended nitrate, the primary contaminant of concern, is projected to increase to between 12.7 and 15.4 mg/L as N (nitrate references hereafter shown as 'mg/L' instead of 'mg/L as N') by 2030 depending on wells used to meet water demands. This exceeds the current MCL of 10

mg/L. Arsenic was also identified as a parameter of concern. Based on limited data available, the arsenic MCL could be exceeded in several wells by 2030. Although Synthetic Organic Chemicals (SOCs) such as atrazine and other herbicides and pesticides are not listed in Table 1, these were also mentioned in the Phase 1 Plan as they could potentially become parameters of concern in the future.

TABLE 1 – PHASE 1 PLAN WATER QUALITY PARAMETERS OF CONCERN

Parameter	2007 Study Blended*	2030 Projected Blended*	MCL	Comments
Nitrate (mg/L as N)	10.5	12.7-15.4	10	
Arsenic (µg/L)	1.9	9.6	10	•If true linear relationship, MCL exceeded in Well 22 by 2025 and Wells 1, 4, 8, 19, 24, and 28 by 2030.
				•Limited arsenic data.
Gross Alpha (pCi/L)	6.2	6.8	15	•MCL exceeded in Wells 1 and 35 in 2009.
				•Based on limited data, general increase over time.
				•More data needed.
Lead (µg/L)	1.2	1.3	15	•Occasional spikes over MCL – attributed to sample fixtures.
				•Levels reduced after newer sampling fixtures added.
Total Dissolved Solids (mg/L)	343	378	Secondary-500	•Fluctuating but overall increase.
				•Several wells could approach 500 mg/L by 2030.
Hardness (mg/L as $CaCO_3$)	224	364	None	•General increase over time.
				•If true linear relationship, hardness could go as high 575 mg/L as $CaCO_3$ in Well 33.

2.0 WATER QUALITY DATA EVALUATION

Select water quality parameters of concern identified during Phase 1 of the Plan as well as additional parameters of interest were analyzed in 2010 and 2011. Water quality results for all analyzed parameters are summarized in this section. Where applicable, HU municipal wells are analyzed separately from other WHPA wells (i.e. domestic and irrigation).

2.1 Water Quality Parameters of Concern

2.1.1 Nitrate

As mentioned previously, HU, the LBNRD, and the UBBNRD collected approximately 770 water samples over the summers of 2010 and 2011. The samples were obtained primarily from irrigation wells. However, domestic and municipal wells were also sampled. The samples collected in 2010 were mostly collected within the HU well field's WHPA. Conversely, the majority of samples collected in 2011 were collected from outside the HU well field WHPA. All nitrate data collected in 2010 and 2011 can be found in Appendix A. Locations for samples collected in 2010 and 2011 are shown in Figure 1. Samples collected in 2010 are shown in blue while samples collected in 2011 are shown in pink.

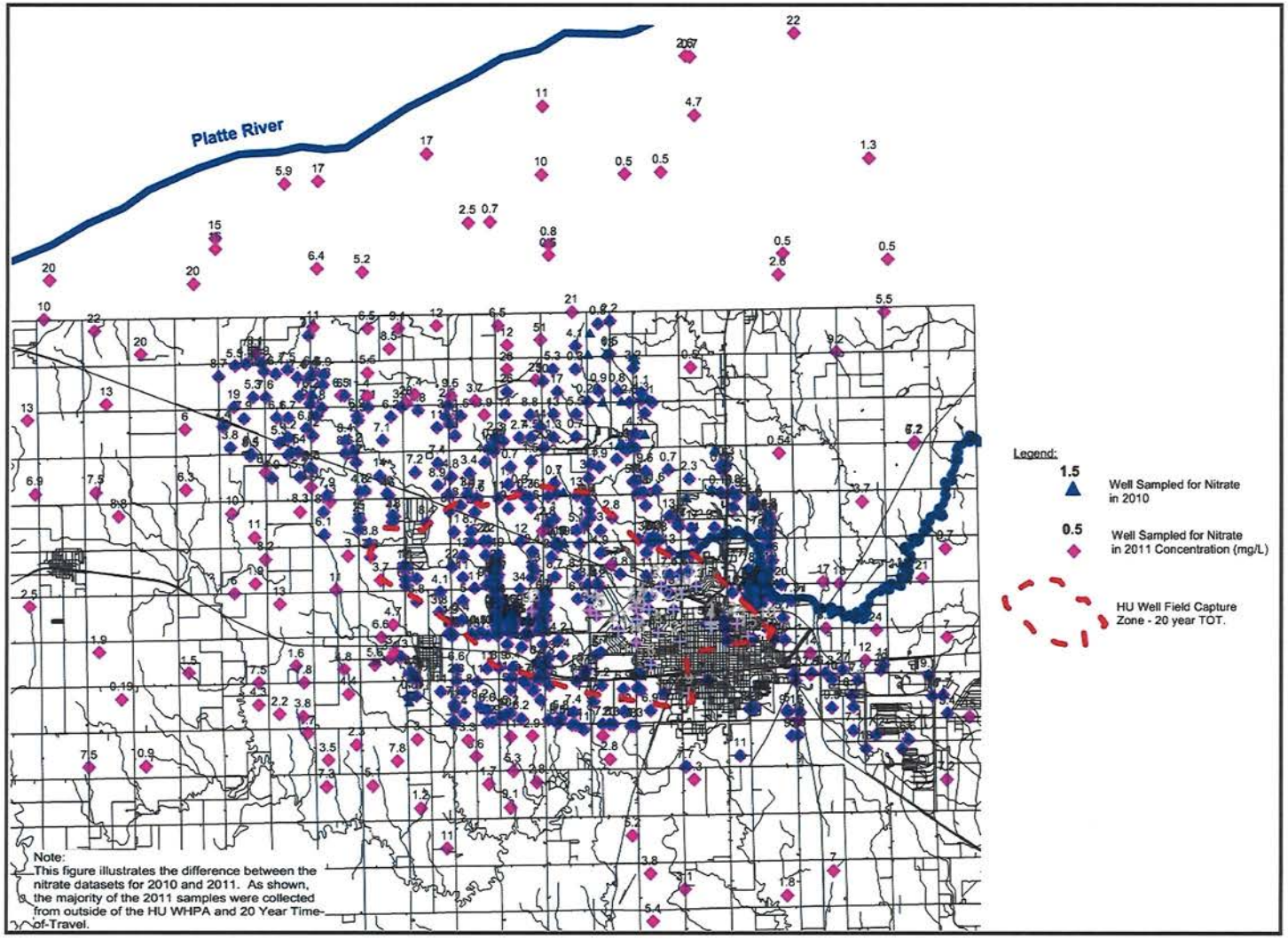


FIGURE 1 – COMPARISON OF 2010 AND 2011 NITRATE GROUNDWATER SAMPLE LOCATIONS

A thorough analysis of nitrate data obtained during 2010 and 2011 can be found in the *HU Groundwater Modeling Study TM Phase II (November 2011),* hereafter referred to as the '2011 Groundwater Modeling Report'. As discussed in the report, measured nitrate concentrations ranged from non-detect to 50.8 mg/L. Approximately 25 percent of the 770 samples collected exceeded the 10 mg/L MCL for nitrate. The average nitrate concentration detected within the aquifer was 7.7 mg/L. Interpreted nitrate concentrations based on 2010 and 2010 collected nitrate data are depicted graphically in Figure 2. Green areas refer to nitrate levels in the zero to five mg/L range while dark purple areas denote nitrate levels greater than 35. As shown on the figure, the green areas are primarily located northeast and southwest of the City of Hastings.

Nitrate data obtained for HU municipal wells in 2010 and 2011 is summarized in Table 2. For comparison purposes, this data was plotted on historical nitrate graphs developed for the 2010 Water Quality Report. Well 33 nitrate data is shown in Figure 3. As discussed in the 2010 Water Quality Report, 'High' and 'Median' trend lines were obtained from trending analysis conducted by HU. These lines were generated by graphing high and median nitrate values, respectively, for each year. For comparison, the 'All Data Trend' was obtained by performing a linear regression analysis on all nitrate data (i.e. no nitrate data was eliminated during this analysis). As can be seen on the figure, the nitrate data point obtained during the summer of 2010 almost falls on the 'All Data Trend' line. However, the data point obtained during the summer of 2011 falls below all trend lines. Similar figures for HU municipal wells where nitrate data was obtained in 2010 and/or 2011 can be found in Appendix B. In summary, most of the nitrate data points obtained in 2010 and 2011 follow the 'Median' and 'All Data Trend' lines fairly closely. Some are just above and some are just below these lines. No data points are close to the 'High' trend line.

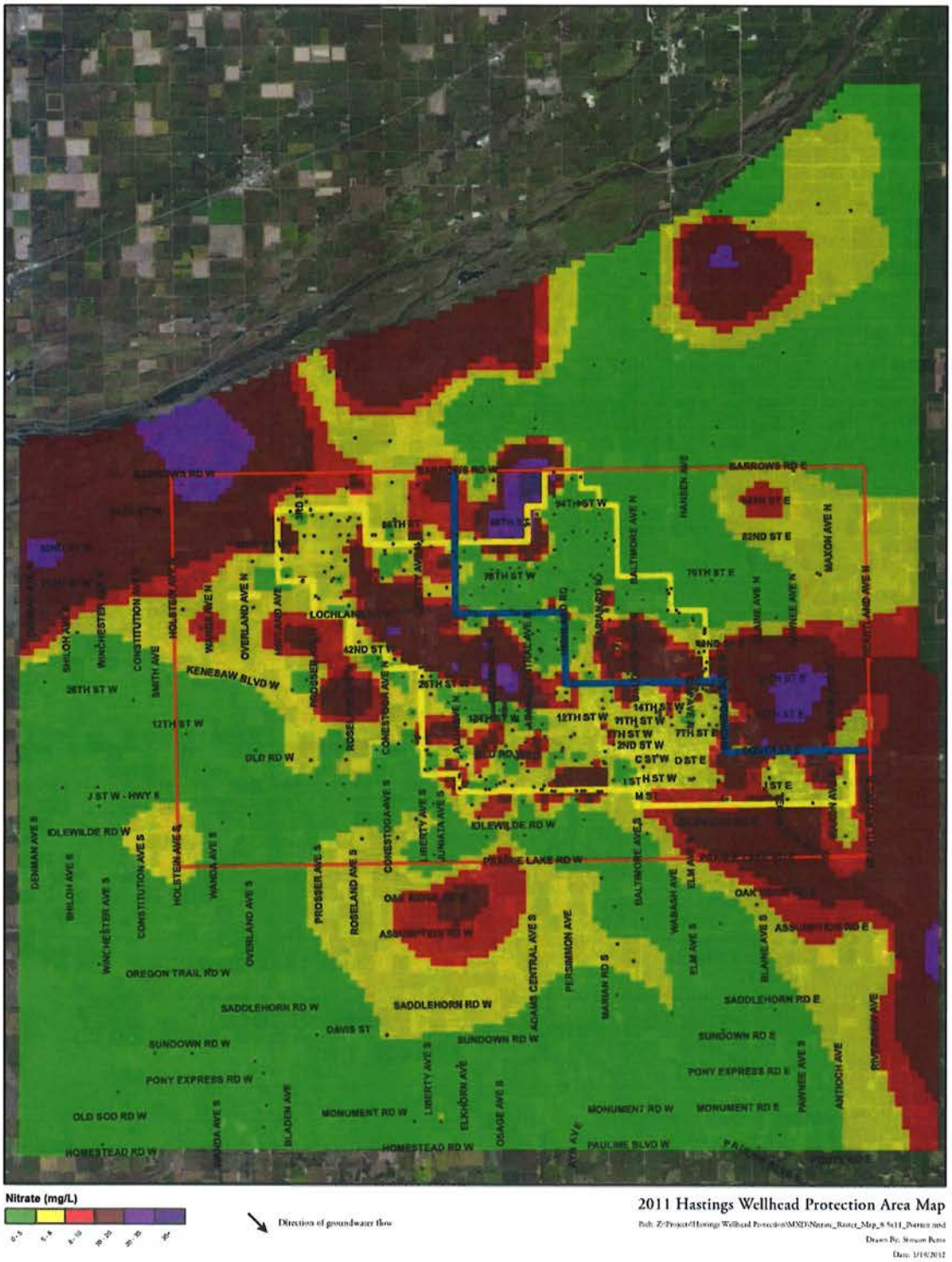


FIGURE 2 – INTERPRETED NITRATE CONCENTRATIONS BASED ON 2010 AND 2011 DATA

TABLE 2 – HU MUNICIPAL WELLS 2010-2011 NITRATE DATA (MG/L)

Well	2010 Actual	2011 Actual
1	6.88	
2	7.25	6.92
3	7.10	
4	7.30	
6	8.28	
8	7.99	6.55
9	8.93	6.79
15	7.49	3.80
16	8.10	
17	7.23	
19	7.07	7.16
21	7.25	
22	6.94	
23	7.40	7.11
24	7.22	
25	6.73	
26	6.96	
27	6.63	
28	6.90	6.97
29	7.39	
33	9.27	8.16
34	8.45	
35	7.91	8.09

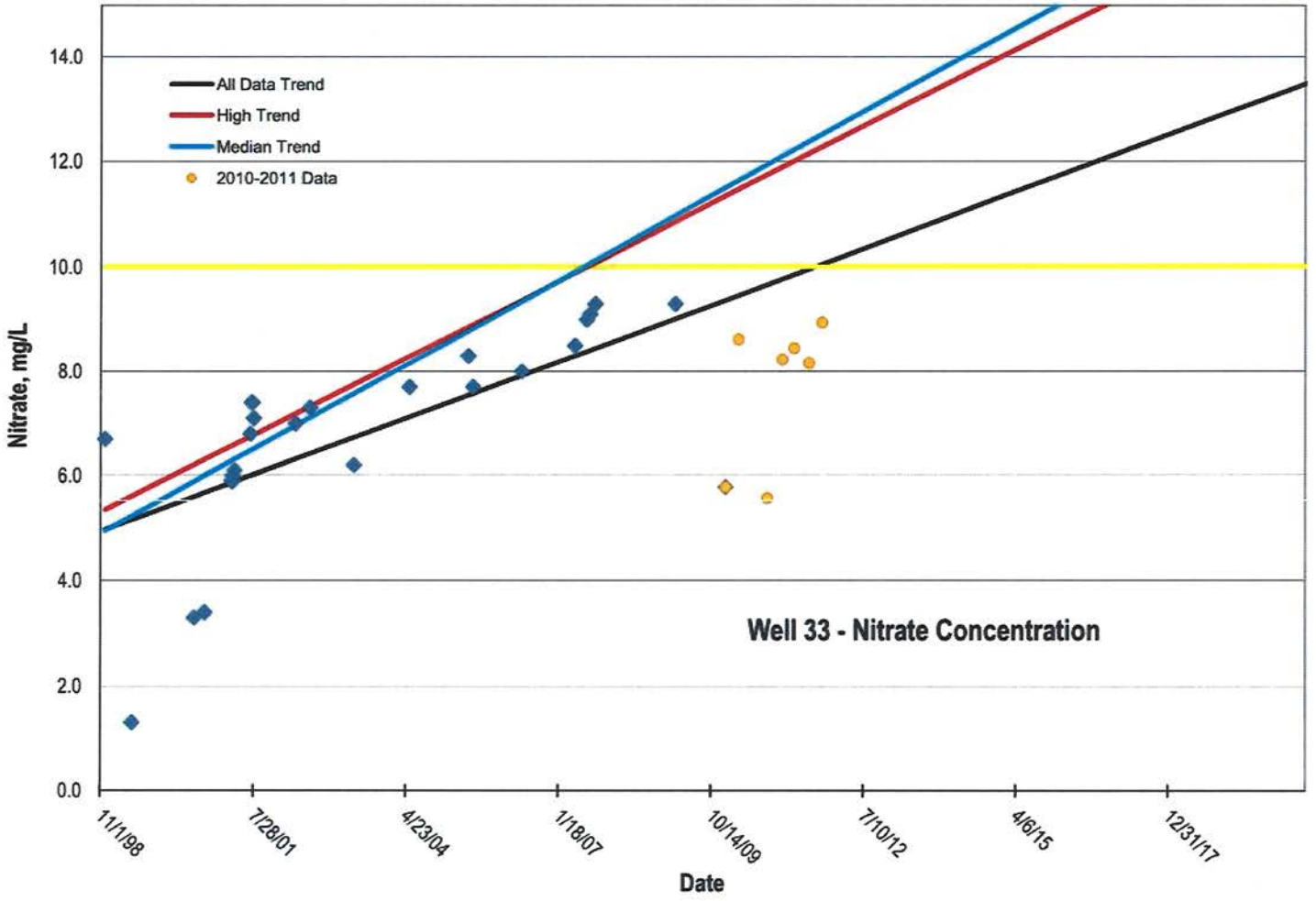


FIGURE 3 – WELL 33 HISTORICAL AND 2010-2011 NITRATE LEVELS

2.1.2 Arsenic

Historical arsenic data for HU municipal wells was analyzed and summarized in the 2010 Water Quality Report. As discussed in this report, arsenic levels steadily increased through 2005. However, in 2008, wells 15, 17, and 26, which exhibited the highest arsenic levels in 2005, were sampled and showed a decrease. A linear regression analysis was performed to predict arsenic values for all wells in five-year intervals from 2010 to 2030. With this assumption, arsenic levels in several wells were expected to exceed the MCL (10 µg/L) by 2030. Although it was stated that a direct linear relationship most likely does not exist, it was recommended that more data be obtained to rule out the need for future arsenic treatment.

In 2010 and 2011, 19 HU municipal wells were analyzed for arsenic levels (see Table 3). In all but one of the tested wells (Well 17), the arsenic levels decreased between 2005 and 2011. For Well 17, the level increased from 5.04 to 5.3 µg/L. Based on this data, it appears that a linear correlation is not applicable. However, as the existing arsenic levels are approaching half of the MCL, it is recommended that arsenic levels continue to be tested over time.

TABLE 3 – HU MUNICIPAL WELLS HISTORICAL AND 2011 ARSENIC DATA (UG/L)

Well	1993	2005	2010/2011
1	0.8	4.41	2.84
2	2.34	4.06	2.71
3	2		
4	1.36	4.77	2.85
5	1.46		
6	2	2.94	2.6
7	1.96		
8	0.84	4.18	2.59
9	2.06	3.91	2.43
10			
11	0.46		
12			
13	1.68		
14	2	2.38	
15	1.21	5.64	3.46
16			2.59
17	1.17	5.04	5.3
18			
19	0.89	4.3	3.7
20	1.23		
21	1.07	3.82	2.11
22	0.82	5.12	4.56
23	1.59	4.12	
24	0.89	4.73	2.75
25	1.9	4.43	2.79
26	1.9	5.23	
27	2.2	4.37	4.01
28	1.9	4.77	3.06
29		4.19	3.42
30			
31			
32			
33		3.97	2.63
34			2.08
35			

2.1.3 Uranium

As discussed in the 2011 Groundwater Modeling Report, uranium is a radioactive material that occurs naturally in many soils and rock types within Nebraska, and occurs primarily as U238 with U235 being much rarer. According to the Nebraska Drinking Water Guide G1569, state-wide groundwater monitoring has shown that high levels of uranium are found in the aquifers associated with the Republican, North Platte, and Platte River Valleys. It is thought that the rock and volcanic ash deposits, which contain uranium, were eroded from the source and then transported and deposited near these river valleys.

Another potential source of uranium could be from phosphate fertilizers. Phosphate rock, which is used to make phosphate fertilizers, may contain significant quantities of naturally occurring radioactive materials such as uranium including radium and thorium (US EPA, Fertilizer and Fertilizer Production Wastes, http://www.epa.gov/radiation/tenorm/fertilizer.html).

Forty-two (42) wells were analyzed for uranium in 2011. Corresponding results are summarized in Table 4. As shown, the maximum and minimum uranium levels obtained are 74.8 µg/L and 1.22 µg/L, respectively. Overall, the MCL of 30 µg/L was exceeded by six wells (see red highlighted values). However, levels in the HU municipal wells were well below the regulatory limit.

TABLE 4 – WHPA WELLS 2011 URANIUM DATA (UG/L)

HWPA ID	Uranium 201	HWPA ID	Uranium 201
8	57.70	478	5.16
27	16.90	715 (Well 28	12.20
80	74.80	725 (Well 1)	8.30
119	45.30	731 (Well 25)	12.20
151	18.20	738 (Well 35	4.10
162	4.77	739 (Well 34)	4.80
169	10.80	830	7.56
204	6.64	844	12.80
221	1.84	867	1.52
251	5.44	876	4.63
267	17.40	922	4.73
273	41.90	954	2.97
313	54.20	965	3.96
317	10.60	975	13.60
328	5.49	1001	62.00
389	7.58	1008	13.00
413	1.22	1031	14.10
451	17.20	1054	10.20
459	10.60	1232	2.05
Maximum Uranium:		74.80	
Minimum Uranium:		1.22	
Average Uranium:		16.01	
Median Uranium:		10.40	

Interpreted uranium concentrations based on 2011 collected data are depicted graphically in Figure 4. Green refers to areas with uranium levels in the zero to ten µg/L range while dark purple areas denote uranium levels greater than 50 µg/L. As shown on the figure, based on sampling conducted to date, higher uranium levels reside in northern area. More data needs to be collected to understand the full extent of uranium levels.

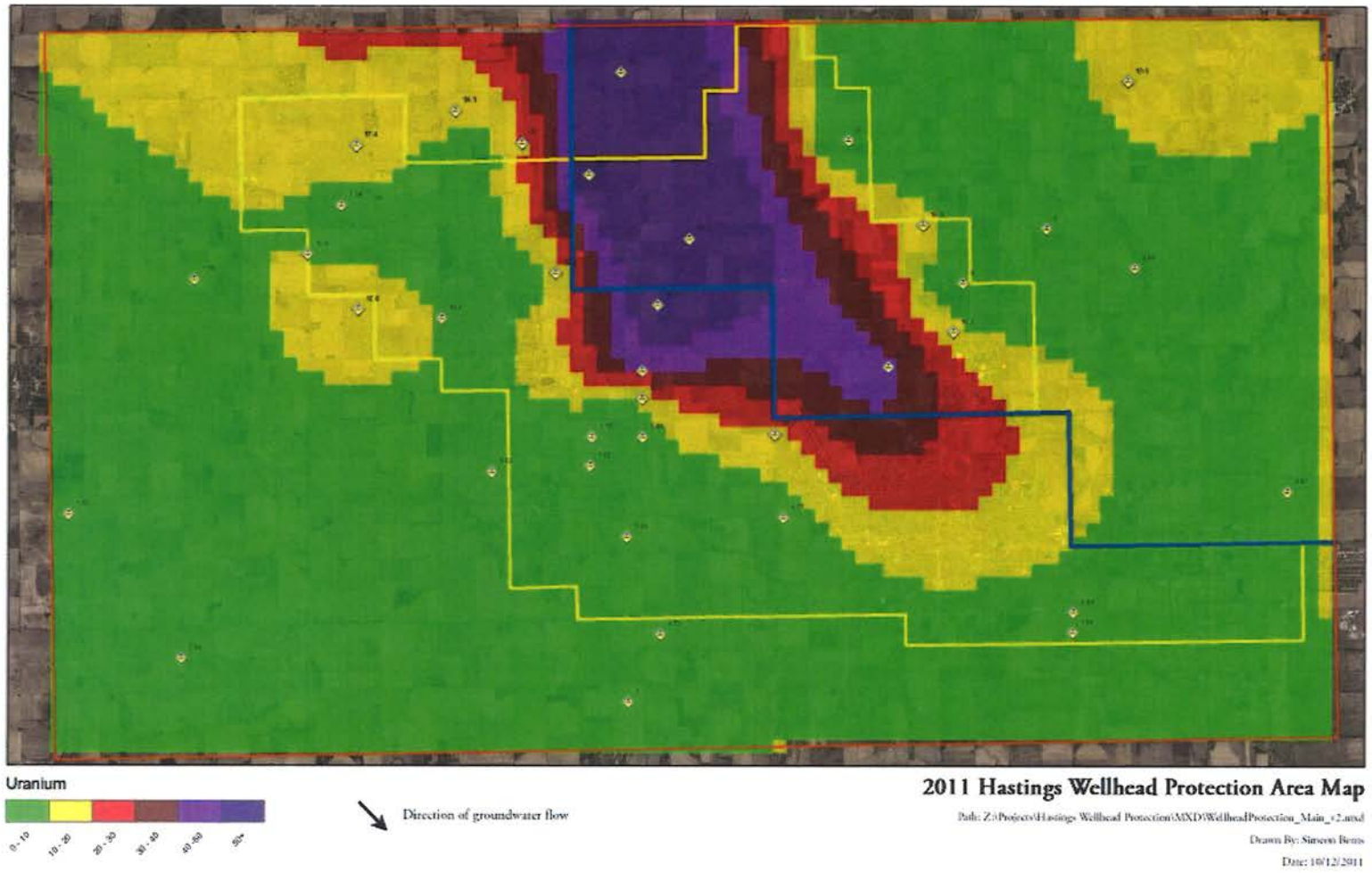


FIGURE 4 – INTERPRETED URANIUM CONCENTRATIONS BASED ON 2011 DATA (UG/L)

2.1.4 Gross Alpha

In the 2010 Water Quality Report, the gross alpha MCL (15 pCi/L) was exceeded for four different HU municipal wells. However, when two of these wells were retested at a later date, the gross alpha values decreased to well below the MCL. Overall, based on the limited data available, there appeared to be a general increase in gross alpha over time. However, for some of the wells, this increase was followed by a decrease.

In 2010 and 2011, 10 HU municipal wells were analyzed for gross alpha levels. Gross alpha levels for 2010, 2011, and previous years are summarized in Table 5. Of the four wells that were sampled in both 2009 and 2010, the gross alpha increased in two wells (Wells 1 and 34) and decreased in one well (Well 23). For Well 35, three water samples were analyzed in 2009, each with varying results. Gross alpha results obtained in 2010 for Well 35 remained within the lower end of the range obtained the previous year. Of the five wells that were sampled in both 2010 and 2011, the gross alpha level increased in all wells except one. In this well (Well 1), the level remained approximately the same between 2010 and 2011.

As shown in the table, Well 1 was tested for gross alpha in 2011. As noticed with other wells in the past, a higher gross alpha level was followed by a lower gross alpha level. For Well 1, the level obtained in 2011 was much lower than that obtained during 2010.

TABLE 5 – HU MUNICIPAL WELLS HISTORICAL AND 2011 GROSS ALPHA DATA (PCI/L)

Well	2003	2005	2006	2007	2009	2010	2011
1					17.1	20.4	19.6
2	6.4		12		12.6		
4	6.4		12.9		11		
6	1.6/7.5				7.8		
8			11.7		8.7		
9	3.8				8.2		
10							
14	8.5						
15	3.9				13.7		
16				5.1			
17	4.5				10.9		
19	5.5				13.1		
20	15.1						
21	5.3						
22	6					15.5	
23	3.3				7	3.4	
24	5.1					11.5	
25	3.1					13.6	20
26	3.6					5.6	
27	6.5/13.8				7		25
28	3.2					15.1	18.5
29	2.5				6		
31	21.1						
33	2.6						
34		3.3/5.4			7/6.2	7.3	8.7
35			4.1		15.5/7.5/4.6	6.1	9.8

As it is anticipated that gross alpha may be occurring due to uranium, gross alpha and uranium levels for HU municipal wells are compared in Table 6. According to the National Primary Drinking Water Regulations Final Rule 65 FR 236, published by the US EPA in 2000, activity to mass conversion factors for uranium range from 0.67 to 1.5 pCi/µg. Uranium activity levels assuming 0.67 and 1.5 pCi/µg conversion are included in the table. Based on this data, it appears that uranium is responsible for a large portion of the gross alpha activity.

TABLE 6 – HU MUNICIPAL WELLS URANIUM AND GROSS ALPHA COMPARISON – 2011 DATA

Well	Uranium (µg/L)	Calculated Uranium (pCi/L at 0.67pCi/µg)	Calculated Uranium (pCi/L at 1.5 pCi/µg)	Gross Alpha (pCi/L)
1	8.3	5.6	12.5	19.6
25	12.2	8.2	18.3	20
28	12.2	8.2	18.3	18.5
34	4.8	3.2	7.2	8.7
35	4.1	2.7	6.2	9.8

2.1.5 Lead

As summarized in the 2010 Water Quality Report, lead levels have remained fairly constant over time and well below the MCL. It is believed that occasional spikes in

levels occur due to sample fixtures as the levels were reduced after newer sampling fixtures were added. No additional lead data was collected during 2010 and 2011.

2.1.6 Total Dissolved Solids

As concluded in the 2010 Water Quality Report, TDS has exhibited fluctuating patterns over time (i.e., increasing and then decreasing) but has appeared to increase overall. Several HU WHPA wells were analyzed for TDS in 2010 and 2011 and the results are summarized in Table 7. As shown, the TDS levels in several wells are above the secondary MCL of 500 mg/L (highlighted in red). Overall, the maximum and minimum TDS levels obtained are 833 and 205 mg/L, respectively. The average and median TDS obtained are 462 and 466 mg/L, respectively.

TABLE 7 – WHPA WELLS 2010-2011 TDS DATA (MG/L)

HWPA ID	TDS	HWPA ID	TDS	HWPA ID	TDS
14	864	306	341	580	415
16	467	317	691	581	500
29	581	319	553	592	424
46	526	345	219	594	685
47	559	367	214	595	556
50	813	375	417	601	653
74	431	408	346	605	496
89	883	417	534	606	315
120	819	428	237	607	365
126	550	431	594	609	608
128	568	432	346	614	525
152	535	433	500	624	376
162	339	440	205	628	429
214	369	451	397	644	470
223	479	454	296	645	444
242	402	470	438	666	474
260	289	507	432	689	525
274	445	514	559	706	309
278	348	525	369	747	353
279	318	526	416	755	536
286	608	531	603	762	491
291	337	540	704	763	749
292	342	541	431	767	465
301	232	546	552	779	515
305	477	578	420		
Maximum TDS:		883			
Minimum TDS:		205			
Average TDS:		462			
Median TDS:		466			

Historical TDS and 2010 and 2011 TDS data for HU municipal wells is summarized in Table 8. Of the 22 wells sampled, TDS levels obtained in 2010 and 2011 for 15 of the wells are higher than all previous years. These levels are highlighted in yellow in the table. Although no TDS levels exceed the secondary MCL, it appears that TDS levels continue to increase over time.

TABLE 8 – HU MUNICIPAL WELLS HISTORICAL AND 2010-2011 TDS DATA (MG/L)

Well	1975	1990	1995	1998	2000	2001	2002	2004	2005	2010-2011	Maximum
1	278	333	352	352			390		359	447	447
2	274	333	339	378	410		384		374	410	410
4	274	358	358	365			384		379	422	422
6	218	301	346	326	358		435	342	339	412	435
8	234	288	307	333	333		339		317	415	415
9	238	282	282	320	320		346		344	417	417
15	282	326	448	422	410		448		375	460	460
16	234	282	301	326	326	448			371	397	448
17		358	390	422			442	429	367	415	442
19		326	339	384	384		390	432	368	414	432
21		294	333	365	410	371	320	410	360	422	422
22		368	326	339			390		376	403	403
23			256	314	288		339	358	333	392	392
24			378	390			403		357	460	460
25			326	294	333	454	346	390	351	403	454
26			400	416	442		467	486	325	397	486
27					424	288	442	486	417	399	486
28					320		339	358	317	389	389
29				301	339		326		313	401	401
33					294		378	397	360	404	404
34									329	429	429
35										378	378

2.1.7 Hardness

Based on historical hardness data, hardness levels have increased over time. In the 2010 Water Quality Report, a regression analysis was conducted to determine if an increasing linear relationship exists for wells that are currently in operation. When the worst-case scenario linear based trend is assumed, hardness levels are projected to increase for all wells. For Well 33, the hardness level could increase to 578 mg/L as $CaCO_3$ based on this assumed linear correlation.

Historical hardness and 2010 TDS data for HU municipal wells is summarized in Table 9. Of the 22 wells sampled, hardness levels obtained in 2010 for nine of the wells are higher than all previous years. These levels are highlighted in yellow in the table. Overall, hardness levels have continued to increase over time.

TABLE 9 – HU MUNICIPAL WELLS HISTORICAL AND 2010 HARDNESS DATA (MG/L AS CACO3)

Well	1990	1995	1998	2002	2004	2005	2010	Max
1	206	216	206	284		240	250	284
2	221	207	219	276		252	240	276
4	228	229	216	444		249	240	444
5	211	219	214	214				219
6	186	232	196	334		229	250	334
7	228	276	252	252				276
8	192	199	201	199		205	240	240
9	177	180	196	250		237	250	250
11	218	317	410	476				476
13	155	154	165	165				165
14	170	300	332	449		249		449
15	198	274	247	295		252	260	295
16	172	191	191	210		260	250	260
17	229	253	255	286		244	230	286
19	204	207	221	219	264	247	230	264
20	190	170	264	254				264
21	190	215	225	196	256	246	250	256
22	200	206	211	231		252	230	252
23		158	196	191	213	217	240	240
24		229	235	243		240	270	270
25		216	185	210	233	244	230	244
26		260	267	289		210	230	289
27				279		284	230	284
28				197	211	209	240	240
29				185		199	240	240
32				325				325
33				227	246	236	250	250
34							270	270
35							230	230
Ave	**199**	**223**	**232**	**266**	**237**	**238**	**243**	**266**
Max	**229**	**317**	**410**	**476**	**264**	**284**	**270**	**476**
Min	**155**	**154**	**165**	**165**	**211**	**199**	**230**	**230**

2.1.8 Atrazine and Other SOCs

During 2011, several HU WHPA wells were analyzed for 25 SOCs including atrazine. In summary, all wells that were analyzed had atrazine levels below the MCL of 3 µg/L.

Approximately 180 deep soil samples were also analyzed for atrazine in 2011, The results of this analysis are summarized in the *Hastings Groundwater Quality Project Report (2011).* Per the report, '…the data confirm that trace amounts of atrazine…have leached into and through the vadose zone and there will be detectable atrazine…concentrations in the municipal wells for a considerable number of years. However, these detected concentrations should be at trace levels' below the MCL.'

2.2 Other Water Quality Parameters

2.2.1 Chloride

As mentioned in the 2010 Water Quality Report, based on historical data, no issue of exceeding the secondary chloride MCL of 250 mg/L is anticipated. Chloride data

obtained in 2010 and 2011, summarized in Table 10, supports this assumption. In all but two of the municipal wells that were sampled in 2010 and 2011, the chloride level increased. However, these levels are well below the secondary MCL.

TABLE 10 – HU MUNICIPAL AND WHPA WELLS HISTORICAL AND 2010-2011 CHLORIDE DATA (MG/L)

Well	HU Database Range (1965-2005)	2010-2011
1	8-16	25
2	10-14	21
4	8-13	24
6	6-12	25
8	7-16	24
9	6-20	27
15	14-24	48
16	6-9	23
17	10-21.3	21
19	12-22	20
21	9-14	19
22	10-16.3	21
23	20	22
24	12	26
25	8-18	19
26	6-23.5	20
27	18-19	20
28	14-24	20
29	7-12	22
33	8-27	28
34	18.9	30
HWPA ID 440		5
HWPA ID 706		12
HWPA ID 762		19
HWPA ID 526		23
HWPA ID 546		38

2.2.2 pH

In 2010 and 2011, approximately 130 WHPA wells were analyzed for pH. Results obtained from this analysis are summarized in Table 11. As shown, pH ranged from 7.5 to 8.4 with an average pH of 8.0. Interpreted pH levels based in 2010 and 2011 data are depicted graphically in Figure 5. As shown, a majority of areas contain pH levels between 7.9 and 8.3.

Historical and 2010 pH data for HU municipal wells is summarized in Table 12. As shown, through 2005, pH has remained fairly constant. However, between 2005 and 2010, the pH has increased dramatically. For wells that were sampled in both 2005 and 2010, the pH has increased between 0.38 and 0.95 units. The cause of this will require further investigation.

TABLE 11 – HU WHPA WELLS 2010-2011 PH DATA

HWPA ID	pH	HWPA ID	pH	HWPA ID	pH	HWPA ID	pH
8	8.0	294	8.3	834	7.6	975	8.0
15	8.2	299	8.1	841	8.0	997	7.8
26	8.0	301	8.1	844	8.1	998	7.8
28	8.0	304	8.1	850	8.2	1006	7.7
42	8.0	313	8.2	856	8.0	1007	7.8
80	7.9	317	8.2	862	8.2	1008	7.7
82	8.3	328	8.0	867	8.1	1010	8.0
95	8.1	330	8.2	869	8.1	1013	7.9
119	8.1	360	8.0	874	8.0	1015	8.1
132	8.1	370	7.6	875	8.1	1016	8.2
147	8.1	381	7.7	876	8.2	1018	8.1
151	7.9	389	8.2	878	8.1	1022	7.9
162	7.9	413	8.2	882	8.3	1030	7.9
167	8.2	430	8.0	889	8.3	1031	8.0
169	7.7	444	8.1	891	8.2	1032	7.9
179	7.9	449	8.1	892	8.1	1033	8.3
182	8.0	451	8.2	894	7.9	1035	7.9
183	8.3	454	8.0	896	8.0	1036	8.0
185	8.1	459	8.2	911	8.0	1037	8.1
204	8.2	473	8.4	920	8.1	1038	8.0
205	8.2	478	7.9	922	8.1	1039	7.9
239	8.0	546	7.5	923	8.3	1040	8.1
247	7.6	575	7.9	928	8.1	1041	8.1
251	8.1	592	7.5	938	7.6	1042	7.9
260	8.4	770	8.2	954	8.0	1043	7.9
263	8.1	784	8.1	956	8.2	1044	8.2
267	8.2	795	8.1	959	7.9	1045	8.2
269	8.1	802	7.8	961	7.9	1046	8.0
272	8.2	810	8.2	964	7.9	1047	8.2
273	8.0	812	8.1	966	8.2	1054	7.6
276	8.2	813	8.1	967	8.0	1055	8.1
285	8.2	830	8.1	970	7.9	1060	8.0
291	8.1	831	8.1	974	8.0	1223	8.0
Maximum pH:		8.4					
Minimum pH:		7.5					
Average pH:		8.0					
Median pH:		8.2					

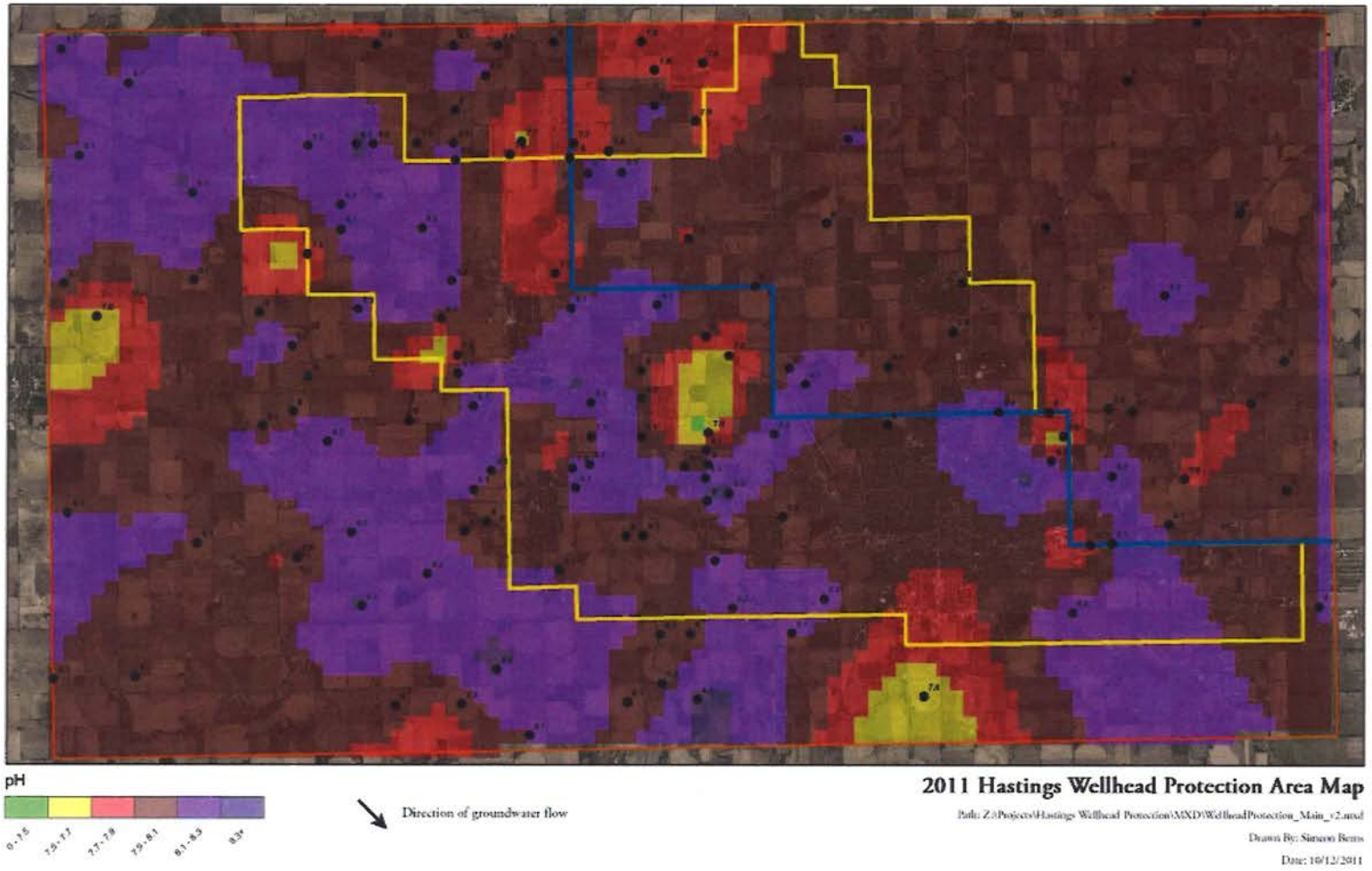


FIGURE 5 – INTERPRETED PH LEVELS BASED ON 2010 AND 2011 DATA

TABLE 12 – HU MUNICIPAL WELL HISTORICAL pH DATA

Well	1990	1995	1998	2002	2005	2010	Max
1	7.50	7.58	7.61	7.52	7.59	8.40	8.40
2	7.50	7.46	7.23	7.37	7.42	8.10	8.10
4	7.30	7.51	7.3	7.39	7.26	8.10	8.10
5	7.70	7.49	7.26	7.26			7.70
6	7.50	7.34	7.38	7.37	7.38	8.20	8.20
7	7.40	7.8	7.17	7.17			7.80
8	7.70	7.47	7.3	7.4	7.36	8.00	8.00
9	7.30	7.58	7.38	7.42	7.31	8.10	8.10
11	7.40	7.24	7.12	7.26			7.40
13	7.50	7.51	7.38	7.38			7.51
14	7.50	7.19	7.51	7.28	7.38		7.51
15	7.50	7.44	7.07	7.26	7.35	8.30	8.30
16	7.90	7.7	7.3	7.28	7.72	8.10	8.10
17	7.50	7.56	7.26	7.47	7.40	8.20	8.20
19	7.70	7.27	7.24	7.71	7.38	8.10	8.10
20	7.40	7.31	7.25	7.42			7.42
21	7.50	7.55	7.35	7.51	7.42	8.30	8.30
22	7.00	7.8	7.56	7.38	7.31	8.20	8.20
23		7.55	7.68	7.4	7.40	8.20	8.20
24		7.46	7.26	7.51	7.35	8.00	8.00
25		7.6	7.45	7.49	7.66	8.30	8.30
26		7	7.31	7.57	7.38	8.30	8.30
27				7.41	7.40	8.20	8.20
28				7.49	7.47	8.00	8.00
29				7.51	7.40	8.00	8.00
32				7.75			7.75
33				7.38	7.38	8.20	8.20
34						8.00	8.00
35						8.30	8.30
Ave	**7.49**	**7.47**	**7.34**	**7.42**	**7.42**	**8.16**	**8.16**
Max	**7.90**	**7.80**	**7.68**	**7.75**	**7.72**	**8.40**	**8.40**
Min	**7.00**	**7.00**	**7.07**	**7.17**	**7.26**	**8.00**	**8.00**

2.2.3 Iron

Historical iron levels between 1965 and 2005 for HU municipal wells obtained from the HU database are summarized in Table 13. As shown, most iron levels have remained below the secondary MCL of 0.3 mg/L. However, there have been instances where this MCL has been exceeded. In 2010 and 2011, the secondary MCL was exceeded in Wells 22, 23, 27, and 29.

TABLE 13 – HU MUNICIPAL WELLS HISTORICAL AND 2010-2011 IRON DATA (MG/L)

Well	1990	1995	1998	2002	2005	2010	Max
1	0.005	0.005		0.005	0.010	0.000	0.010
2	0.020	0.005		0.005	0.070	0.190	0.190
4	0.007	0.005	0.01	0.006	0.010	0.000	0.010
5	0.060	0.01	0.03	0.03			0.060
6	0.005	0.005		0.005	0.005	0.05	0.050
7	0.005	0.005		0.01			0.010
8	0.005	0.005		0.005	0.005	0.0	0.005
9	0.005	0.005		0.005	0.330	0.000	0.330
11	0.005	0.03	0.01	0.005			0.030
13	0.005	0.005		0.005			0.005
14	0.005	0.01		0.2	0.530		0.530
15	0.020	0.005	0.01	0.005	0.020	0.0	0.020
16	0.005	0.04	0.02	0.005	0.010	0.0	0.040
17	0.009	0.005		0.3	0.810	0.280	0.810
19	0.005	0.04	0.005	0.005	0.060	0.180	0.180
20	0.010	0.39	0.13	0.22			0.390
21	0.030	0.005		0.005	0.020	0.000	0.030
22	0.800	0.005	0.02	0.005	0.010	1.100	1.100
23		0.005	0.15	0.005	0.005	0.66	0.660
24		0.005		0.005	0.005	0.0	0.005
25		0.1	0.02	0.005	0.010	0.060	0.100
26		0.1		0.005	0.210	0.180	0.210
27				0.005	0.010	2.100	2.100
28				0.005	0.010	0.000	0.010
29				0.005	0.005	0.36	0.360
32				0.2			0.200
33				0.005	0.010	0.0	0.010
34						0.0	0.000
35						0.0	0.000
Ave	**0.056**	**0.036**	**0.041**	**0.039**	**0.103**	**0.235**	**0.235**
Max	**0.800**	**0.390**	**0.150**	**0.300**	**0.810**	**2.100**	**2.100**
Min	**0.005**	**0.005**	**0.005**	**0.005**	**0.005**	**0.000**	**0.005**

Additional iron data obtained from HU WHPA wells during 2010 and 2011 is shown in Table 14. The maximum and minimum iron levels obtained are 4.2 and 0.05 mg/L, respectively. As shown in red, the secondary MCL was exceeded by 11 of these wells. These corresponding areas (interpreted based on 2010-2011 data) are depicted in dark purple on Figure 6.

TABLE 14 – HU WHPA WELLS 2010-2011 IRON DATA (MG/L)

HWPA ID	Iron	HWPA ID	Iron
8	0.090	628	2.800
26	1.100	644	1.800
47	0.220	762	0.060
80	0.120	763	0.060
82	0.060	767	0.740
95	0.160	784	0.090
126	0.070	830	0.060
152	1.700	867	0.210
167	0.100	869	0.120
239	0.090	892	0.210
260	0.420	911	0.440
294	0.080	920	0.530
305	0.080	954	0.050
317	3.600	964	1.200
319	0.090	974	4.200
370	0.090	1045	0.080
526	0.050	1046	0.120
546	0.050		
Maximum Iron:		4.200	
Minimum Iron:		0.050	
Average Iron:		0.580	
Median Iron:		0.160	

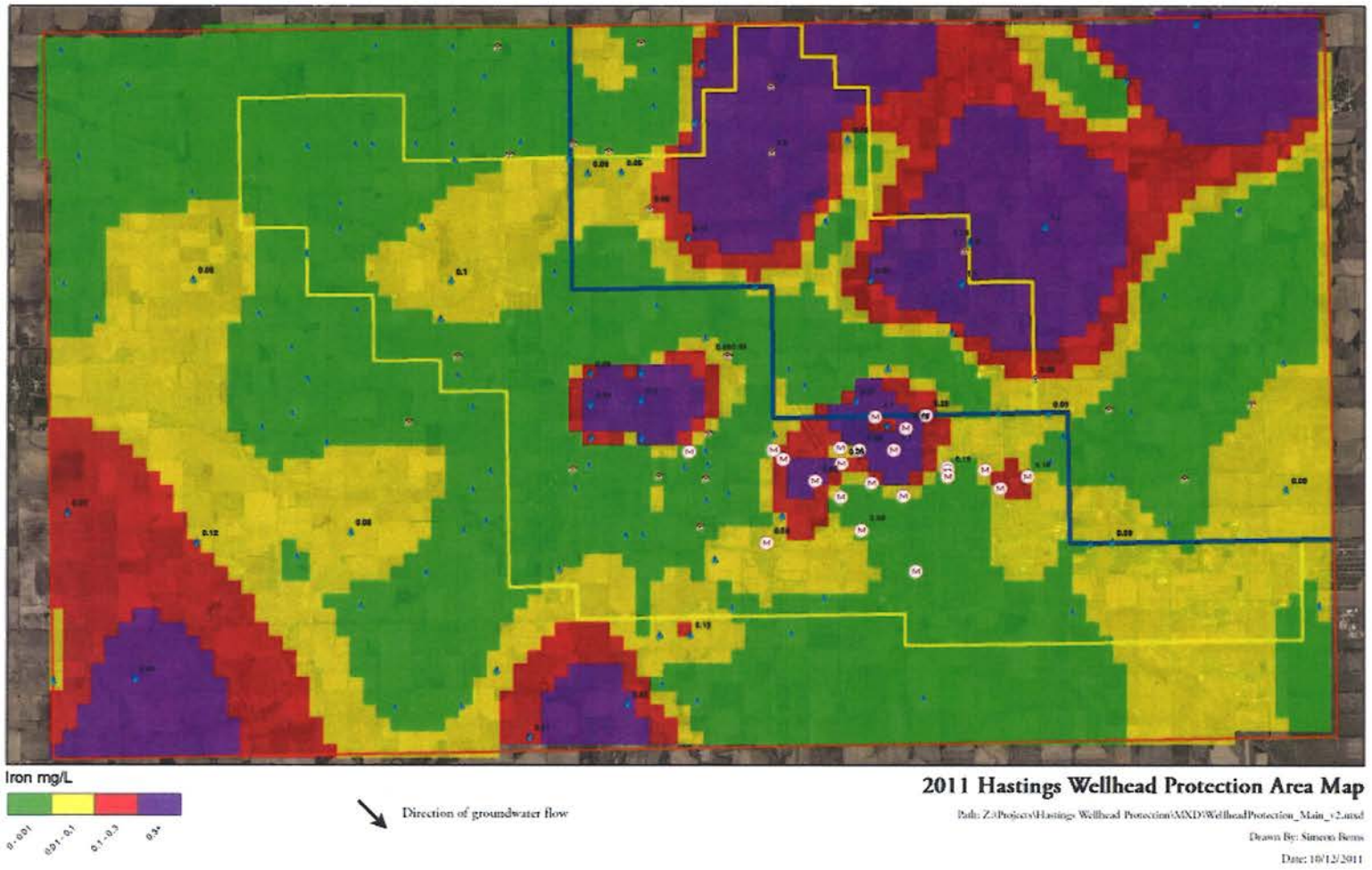


FIGURE 6 – INTERPRETED IRON CONCENTRATIONS BASED ON 2010-2011 DATA (MG/L)

2.2.4 Manganese

Approximately 40 wells were analyzed for manganese in 2010 and 2011. Manganese levels for HU municipal wells are shown in Table 15. Historical manganese levels between 1965 and 2005 for these wells obtained from the HU database are also summarized in Table 15. As shown, historical manganese levels have remained below the secondary MCL of 0.05 mg/L, with the exception of Well 17 where a level of 0.1 was obtained. Manganese levels in 2010 and 2011 are below the secondary MCL.

TABLE 15 – HU MUNICIPAL WELLS HISTORICAL AND 2010-2011 MANGANESE DATA (MG/L)

Well	1990	1995	1998	2002	2005	2010	Max
1	0.001	0.001		0.001	0.001	0.000	0.001
2	0.001	0.001		0.001	0.001	0.000	0.001
4	0.002	0.001		0.001	0.001	0.000	0.002
5	0.001	0.001		0.001			0.001
6	0.001	0.001		0.001	0.001	0.000	0.001
7	0.001	0.001		0.001			0.001
8	0.001	0.001		0.001	0.001	0.000	0.001
9	0.001	0.001		0.001	0.001	0.000	0.001
11	0.001	0.001		0.001			0.001
13	0.001	0.001		0.001			0.001
14	0.001	0.001		0.001	0.001		0.001
15	0.001	0.001		0.001	0.001	0.000	0.001
16	0.001	0.001		0.001	0.001	0.000	0.001
17	0.001	0.001		0.001	0.010	0.007	0.010
19	0.001	0.001	0.001	0.001	0.001	0.000	0.001
20	0.001	0.001	0.002	0.011			0.011
21	0.001	0.001		0.001	0.001	0.000	0.001
22	0.050	0.001	0.003	0.001	0.001	0.000	0.050
23		0.001	0.002	0.001	0.001	0.005	0.005
24		0.001		0.001	0.001	0.000	0.001
25		0.000		0.001	0.001	0.000	0.001
26		0.050		0.001	0.001	0.000	0.050
27				0.001	0.001	0.024	0.024
28				0.001	0.001	0.000	0.001
29				0.001	0.001	0.008	0.008
32				0.001			0.001
33				0.001	0.001	0.000	0.001
34						0.000	0.000
35						0.000	0.000
Ave	**0.004**	**0.003**	**0.002**	**0.001**	**0.001**	**0.002**	**0.004**
Max	**0.050**	**0.050**	**0.003**	**0.011**	**0.010**	**0.024**	**0.050**
Min	**0.001**	**0.000**	**0.001**	**0.001**	**0.001**	**0.000**	**0.001**

In contrast, manganese levels obtained in several of the other HU WHPA wells are above the secondary MCL, as exhibited in Table 16. As shown, the maximum and minimum manganese levels are 0.77 and 0.01 mg/L, respectively. The average and median levels (0.20 and 0.10 mg/L, respectively) are both above the secondary MCL.

TABLE 16 – HU WHPA WELLS 2010-2011 MANGANESE DATA (MG/L)

HWPA ID	Manganese	HWPA ID	Manganese
26	0.77	779	0.03
28	0.01	856	0.01
47	0.37	867	0.08
80	0.02	869	0.13
95	0.12	892	0.11
120	0.33	894	0.03
147	0.03	911	0.08
152	0.41	920	0.01
167	0.01	923	0.06
260	0.01	938	0.01
317	0.12	964	0.73
370	0.12	974	0.61
430	0.05	975	0.39
507	0.10	1035	0.15
628	0.26	1044	0.01
644	0.62	1046	0.01
767	0.67		
Maximum Manganese:		0.77	
Minimum Manganese:		0.01	
Average Manganese:		0.20	
Median Manganese:		0.10	

2.2.5 Sulfate

Historical sulfate data was not evaluated in the 2010 Water Quality Report. In 2010 and 2011, approximate 80 WHPA wells were analyzed for sulfate. Results obtained from WHPA wells excluding HU municipal wells are summarized in Table 17. As shown, sulfate ranged from 18 to 570 mg/L with an average and median of 90 and 57 mg/L, respectively. Only four samples exceeded the secondary MCL of 250 mg/L (highlighted in red).

TABLE 17 – HU HWPA WELLS 2010-2011 SULFATE DATA (MG/L)

HWPA ID	Sulfate	HWPA ID	Sulfate	HWPA ID	Sulfate
14	330	367	19	592	36
16	60	375	87	594	150
29	120	408	39	595	120
46	130	428	18	601	150
47	180	432	26	605	36
89	330	433	51	606	30
120	570	440	20	607	28
128	160	451	48	609	130
152	240	454	26	614	33
162	26	470	78	624	72
214	36	507	130	628	87
223	69	514	45	644	140
242	33	525	66	645	84
278	30	526	57	666	51
279	30	531	57	689	120
286	120	540	48	706	24
292	29	541	42	747	39
301	18	546	57	755	110
317	60	578	36	762	140
319	87	580	39	763	260
345	26	581	39	779	130
Maximum Sulfate:		570			
Minimum Sulfate:		18			
Average Sulfate:		90			
Median Sulfate:		57			

Historical and 2010 sulfate levels are summarized in Table 18. In general, sulfate levels remained the same or changed slightly. Although there appears to be no danger of sulfate exceeding the secondary MCL, sulfate should continue to be sampled as it can contribute to scaling in membrane technologies being considered as potential future treatment. Also, sulfate levels are needed as nitrate selective anion exchange resins (another potential treatment technology being considered) preferentially remove sulfate before nitrate.

TABLE 18 – HU MUNICIPAL WELLS HISTORICAL AND 2010-2011 SULFATE DATA (MG/L)

Well	1990	1995	1998	2002	2004	2005	2010	Max
1	14	42	48	42		54	57	57
2	17	42	51	39		57	48	57
4	18	48	45	48		57	51	57
5	17	42	48	48				48
6	10	30	27	33		42	39	42
7	15	54	60	60				60
8	14	39	45	42		42	42	45
9	10	30	30	24		51	36	51
11	14	66	75	66				75
13	7	21	21	21				21
14	7	30	36	30		36		36
15	17	66	57	36		57	39	66
16	11	36	36	39		57	45	57
17	22	72	81	54		57	48	81
19	16	51	54	51	63	57	48	63
20	11	24	42	39				42
21	13	48	54	42	54	51	51	54
22	60	42	45	42		57	48	60
23		30	39	36	42	39	45	45
24		57	57	60		54	60	60
25		34	39	42	48	51	51	51
26		52	63	63		45	48	63
27				60		63	48	63
28				39	42	42	54	54
29				42		48	45	48
32				87				87
33				36	39	36	39	39
34							63	63
35							54	54
Ave	**16**	**43**	**48**	**45**	**48**	**50**	**48**	**50**
Max	**60**	**72**	**81**	**87**	**63**	**63**	**63**	**87**
Min	**7**	**21**	**21**	**21**	**39**	**36**	**36**	**39**

2.2.6 Total Organic Carbon

In May of 2010, 14 municipal wells were analyzed for total organic carbon (TOC). As shown in Table 19, all but three of the wells sampled had TOC levels less than the quantitative limit of 1.00 mg/L. The other three wells had very low levels of TOC. As TOC can be a fouling component for technologies being considered for potential treatment, it should continue to be tested periodically. In addition, TOC levels in potential new wells should be tested.

TABLE 19 – HU MUNICIPAL WELLS 2010 TOC DATA (MG/L)

Well	TOC (mg/L)
8	< 1.00
9	< 1.00
16	< 1.00
17	< 1.00
22	< 1.00
23	< 1.00
25	1.14
26	1.00
27	< 1.00
28	< 1.00
29	< 1.00
33	1.02
34	< 1.00
35	< 1.00

2.2.7 Miscellaneous Water Quality Data

Various HU municipal wells were sampled and analyzed for barium, cadmium, chromium, selenium, fluoride, and mercury in the summer of 2010. Results of this analysis are summarized in Table 20. Cadmium and mercury results for all tested wells were below the analytical recordable limit. Barium, chromium, selenium, and fluoride results were well below their corresponding primary and secondary MCLs. As barium and fluoride can contribute to scaling in membrane technologies being considered for potential treatment, it should continue to be sampled.

TABLE 20 – HU MUNICIPAL WELLS MISCELLANEOUS WATER QUALITY DATA

Well	Barium, Total (µg/L)	Cadmium, Total (µg/L)	Chromium, Total (µg/L)	Selenium, Total (µg/L)	Fluoride (mg/L)	Mercury, Total (µg/L)
25	180	< 1	11.3	21.8	0.319	< 1
26	194	< 1	9.03	20.1	0.294	< 1
27	198	< 1	10.2	23.0	0.299	< 1
28	187	< 1	9.84	21.3	0.294	< 1
29	159	< 1	8.53	19.8	0.315	< 1
33	207	< 1	9.32	25.6	0.286	< 1
34	208	< 1	9.01	24.5	0.282	< 1
35	209	< 1	9.75	23.8	0.297	< 1

2.3 Water Quality Composite Map

Nitrate, uranium, and iron levels (three parameters key to treatment selection) that are above 80-percent of their corresponding MCLs (8 mg/L for nitrate, 24 µg/L for uranium, and 0.24 mg/L for iron) as of 2011 are depicted on Figure 7. As shown, nitrate levels greater than 8 mg/L are prevalent throughout the City and surrounding area. Based on limited data to date, uranium levels greater than 24 µg/L are north of the City. Iron levels greater than 0.24 mg/L can be found within the City and to the northeast and southwest of the City.

The areas north and southwest of the City have low nitrate levels. However, iron, manganese, and uranium levels in the north could reduce the viability of the northern area. As such, the area southwest of the City warrants additional consideration. In the

HU Well Based Nitrate Management Approach TM (2012), this map and data is evaluated further to identify potential additional water supply sources around the City.

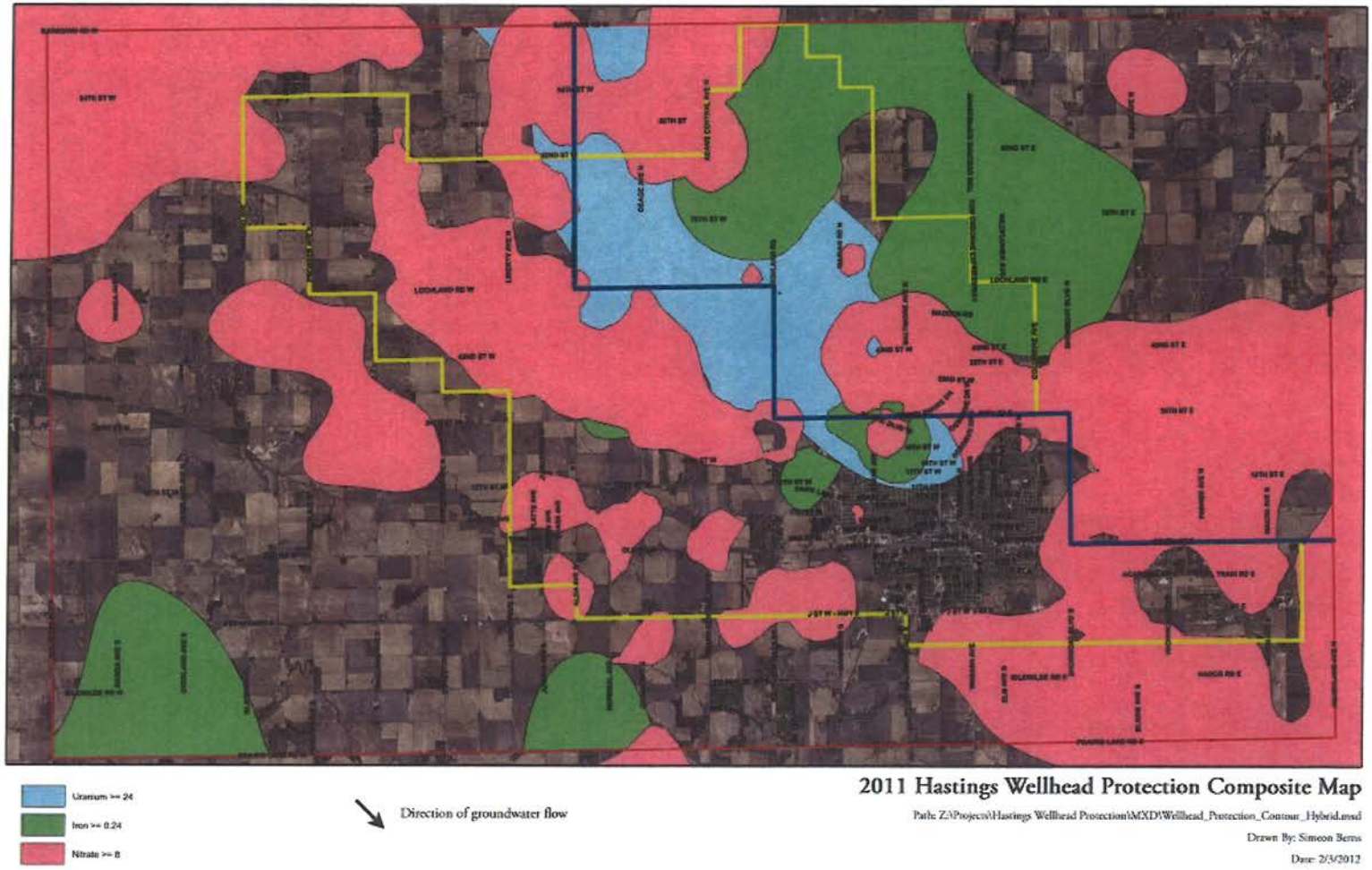


FIGURE 7 – 2011 HASTINGS WELLHEAD PROTECTION WATER QUALITY COMPOSITE MAP

3.0 CONCLUSIONS AND RECOMMENDATIONS

As mentioned previously, due to the high cost associated with full-scale nitrate treatment proposed in the Plan, HU decided they would like to pursue other options to delay full-scale treatment as long as possible, and instead focus on further evaluation of groundwater quality and identification of additional water supply sources. Although delaying treatment is the goal, it is anticipated that some form of treatment will be required in the future for a portion of the water supply. As such, data will need to be collected continually to assess the viability and amount of future treatment options for any new and existing well locations. In addition, parameters affecting pre-treatment and residual waste stream treatment and disposal need to be tested. Key analysis parameters identified by corresponding need (i.e. pre-treatment, primary treatment, and residual treatment and disposal) are summarized in Table 21. This list contains parameters required based on all previously identified primary treatment options (i.e. reverse osmosis, ion exchange, and electrodialysis reversal). As the overall water quality management plan becomes more defined (i.e. a primary treatment technology is selected and wells requiring treatment are identified), required parameters and corresponding quantities of data will need to be reevaluated.

TABLE 21 – HU KEY WATER QUALITY ANALYSIS PARAMETERS

Parameter	Pre-Treatment	Primary Treatment	Residual Treatment and Disposal
Nitrate		X	X
Arsenic		X	X
Uranium / Gross Alpha		X	X
Lead		X	X
TDS	X		
Hardness	X		
Atrazine / SOCs		X	X
Chloride			X
pH	X		
Iron	X		
Manganese	X		
Sulfate	X	X	
TOC	X		
Barium	X		
Strontium	X		
Silica	X		
Fluoride	X		
Alkalinity	X		
Chromium		X	

In summary:

- Nitrate continues to be the key parameter of concern.
- The increasing arsenic trend noticed in the previous water quality report has reversed in all but one well.
- Uranium levels are highest north of the City.
- Gross alpha appears to correlate with uranium and should continue to be monitored.

- Lead levels have remained fairly constant over time and well below the MCL. No additional lead data was collected during 2010 and 2011.
- TDS and hardness levels continue to increase over time.
- Based on historical data, no issue of exceeding the secondary chloride MCL of 250 mg/L is anticipated. Chloride data obtained in 2010 and 2011 supports this assumption.
- All wells that were analyzed had atrazine levels below the MCL of 3 µg/L.
- Through 2005, pH has remained fairly constant. However, between 2005 and 2010, pH levels have increased dramatically. The cause of this will require further investigation.
- There are higher iron and manganese levels in the area north of the City. This could impact the viability of the water supply in that area.
- Although there appears to be no danger of sulfate exceeding the secondary MCL, sulfate should continue to be sampled as it can contribute to scaling in membrane technologies being considered as potential future treatment. Also, sulfate levels are needed as nitrate selective anion exchange resins (another potential treatment technology being considered) preferentially remove sulfate before nitrate.
- The areas north and southwest of the City have low nitrate levels. However, iron, manganese, and uranium levels in the north could reduce the viability of the northern area. As such, the area southwest of the City warrants additional consideration

APPENDIX A – 2010 AND 2011 NITRATE DATA

HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011
26	0.02	0.19	1146		2.10	1148		4.00	1120		5.40
370		0.19	28	2.10	2.16	1152		4.00	1185		5.40
917		0.19	1159		2.20	928		4.04	1031		5.49
1145		0.30	1181		2.20	474	4.80	4.10	291		5.51
1155		0.50	1193		2.30	1126		4.10	974		5.54
804		0.50	413	2.60	2.38	1210		4.10	878		5.58
964		0.54	179	2.53	2.46	260	4.40	4.17	1108		5.60
1192		0.60	1133		2.50	938		4.29	1131		5.60
1156		0.80	1122		2.70	1198		4.30	1212		5.60
1203		0.80	923		2.75	891		4.38	132		5.67
911		0.90	1135		2.80	430		4.46	183	5.60	5.73
458	1.90	1.00	1178		2.80	876		4.70	1121		5.80
1141		1.00	1046		2.91	1205		4.70	205	6.20	5.84
1157		1.00	1139		3.00	454	4.68	4.77	1040		5.99
1194		1.00	847		3.01	1160		4.80	1033		6.03
95	1.40	1.08	1207		3.10	1206		4.80	807		6.13
1154		1.10	1117		3.20	792		4.80	546	20.00	6.15
892		1.21	1138		3.30	575	4.80	4.86	389	5.70	6.15
1123		1.30	1169		3.30	147	4.34	4.89	1111		6.20
330	0.96	1.34	1038		3.36	1125		4.90	1113		6.20
1183		1.40	1140		3.50	1144		4.90	473	6.30	6.22
1195		1.40	1173		3.50	162	5.12	4.97	1201		6.30
1196		1.40	1151		3.60	478	4.80	4.97	784	5.74	6.34
8	1.50	1.50	791		3.60	445	5.23	5.00	830		6.35
80	1.40	1.50	1007		3.66	1182		5.00	1018		6.46
1197		1.50	875		3.70	894		5.06	997		6.53
869		1.52	1161		3.70	1153		5.10	1022		6.53
1045		1.64	966		3.72	1176		5.10	1041		6.61
920		1.70	882		3.80	269	5.80	5.11	1119		6.70
1208		1.70	1158		3.80	1106		5.20	970		6.73
1150		1.80	1186		3.80	1107		5.20	1054		6.73
1187		1.80	1149		3.90	1116		5.20	1171		6.80
1124		1.90	1015		3.97	1190		5.20	1104		6.90
856		1.91	1100		4.00	787		5.20	1215		6.90
867		1.92	1115		4.00	1142		5.30	451	7.03	6.98
1132		2.00	1118		4.00	1042		5.34	954		6.98
1147		2.00	1134		4.00	1221		5.38	267	6.80	6.99

HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011
1105		7.00	1211		9.00	167	10.00	12.10	1127		21.00
1188		7.00	1136		9.10	1010		12.20	810		22.00
1102		7.10	750	9.55	9.14	862		12.50	801		23.00
770	8.87	7.12	1030		9.14	813		12.70	1043		24.10
1036		7.17	313	8.25	9.17	1110		13.00	1035		24.60
1189		7.20	975		9.18	1164		13.00	1174		25.00
299	9.50	7.30	376	8.57	9.31	1166		13.00	1044		26.40
1163		7.30	317	21.90	9.50	1167		13.00	1222		27.10
247	7.50	7.33	1006		9.50	1175		13.00	806		27.40
896		7.33	185	10.20	9.63	1191		13.00	1013		28.40
1184		7.40	967		9.74	1216		13.00	802		50.80
1219		7.40	151	11.20	9.90	42	5.10	13.30	256	16.00	
1008		7.42	841		10.00	119	16.00	13.40	548	16.00	
831		7.48	1109		10.00	360	12.00	13.40	3	15.90	
1039		7.49	1112		10.00	1204		14.00	595	15.80	
182	5.90	7.50	1172		10.00	808		14.40	687	15.80	
1055		7.52	15	11.30	10.10	459	14.00	14.60	581	15.70	
272	7.34	7.59	372		10.40	1060		14.80	763	15.50	
381		7.63	328	10.80	10.50	1162		15.00	286	15.00	
1165		7.70	1047		10.60	1101		16.00	586	15.00	
1199		7.80	850		10.70	1209		16.00	588	15.00	
889		7.82	922		10.70	1128		17.00	613	15.00	
1114		8.20	794	14.60	10.80	1200		17.00	657	15.00	
1223		8.22	251	14.20	10.90	1218		17.00	669	15.00	
844		8.29	294	10.30	11.00	304	16.30	17.00	253	14.60	
444	6.70	8.30	874		11.00	959		17.30	1088	14.60	
956		8.33	1098		11.00	204	7.20	17.60	22	14.30	
1168		8.50	301	4.32	11.30	1037		17.80	30	14.00	
1016		8.53	1032		11.30	1129		18.00	210	14.00	
1137		8.60	795		11.70	1170		19.00	363	14.00	
285	8.30	8.61	998		11.90	1220		19.00	515	14.00	
263	7.60	8.67	1099		12.00	273	17.00	19.40	590	14.00	
834		8.76	1103		12.00	276	6.12	19.50	639	14.00	
592	8.58	8.77	1130		12.00	239	18.00	19.70	627	13.90	
449	8.87	8.86	1177		12.00	812		19.80	288	13.80	
82		8.87	1213		12.00	1214		20.00	433	13.80	
169	9.30	8.93	1217		12.00	961		20.60	704	13.80	

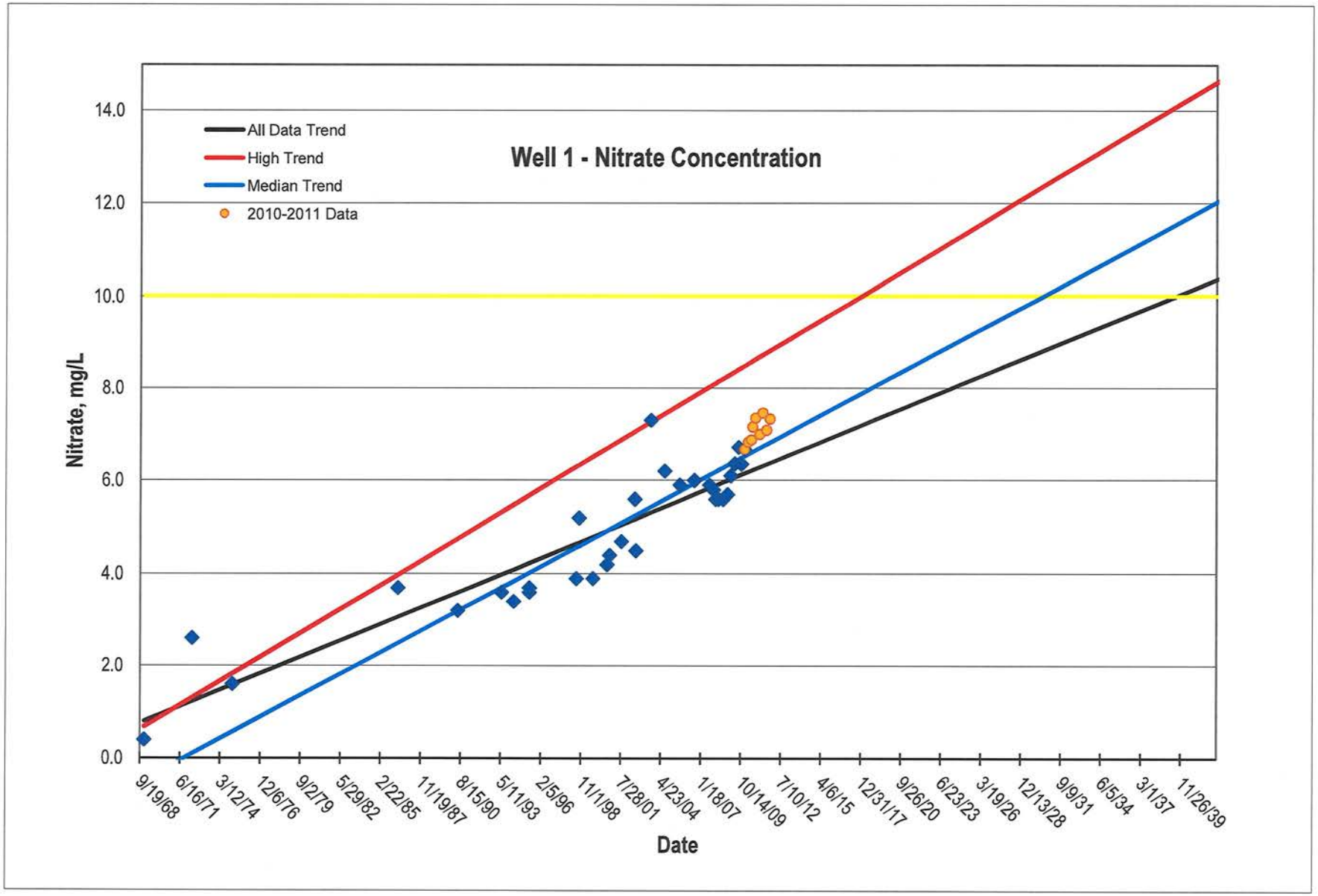
HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011
137	13.70		305	11.00		703	9.12		271	8.00	
574	13.60		442	11.00		170	9.10		453	7.97	
572	13.40		518	11.00		646	9.05		688	7.92	
579	13.30		520	11.00		469	9.00		244	7.90	
338	13.20		654	11.00		537	8.87		321	7.90	
714	13.20		680	11.00		69	8.80		662	7.90	
61	13.00		685	11.00		222	8.80		757	7.90	
89	13.00		708	11.00		427	8.80		751	7.88	
138	13.00		383	10.90		1068	8.80		566	7.82	
139	13.00		677	10.80		638	8.74		298	7.80	
188	13.00		712	10.70		211	8.72		664	7.80	
236	13.00		578	10.60		600	8.72		674	7.71	
343	13.00		1078	10.50		673	8.71		268	7.70	
431	13.00		194	10.40		164	8.70		710	7.70	
563	13.00		1077	10.30		425	8.70		1064	7.70	
598	13.00		391	10.20		426	8.70		503	7.69	
652	13.00		1067	10.20		769	8.70		283	7.67	
665	13.00		1092	10.20		456	8.54		172	7.60	
702	13.00		7	10.10		605	8.53		658	7.60	
532	12.60		793	10.10		742	8.50		470	7.51	
747	12.40		216	10.00		395	8.40		262	7.50	
366	12.00		568	10.00		417	8.40		607	7.43	
414	12.00		660	10.00		465	8.40		362	7.42	
528	12.00		709	10.00		774	8.40		215	7.40	
663	12.00		403	9.94		248	8.30		785	7.40	
699	12.00		232	9.93		277	8.30		783	7.39	
319	11.90		300	9.90		573	8.30		309	7.38	
609	11.80		16	9.79		707	8.20		78	7.37	
666	11.80		580	9.79		193	8.19		237	7.20	
701	11.80		35	9.60		230	8.15		434	7.20	
1093	11.70		541	9.58		289	8.10		691	7.13	
585	11.50		584	9.56		583	8.10		29	7.12	
384	11.30		39	9.50		640	8.10		327	7.10	
126	11.00		12	9.40		656	8.10		461	7.10	
198	11.00		259	9.40		786	8.05		743	7.10	
212	11.00		713	9.31		689	8.01		754	7.06	
274	11.00		242	9.19		24	8.00		670	7.00	

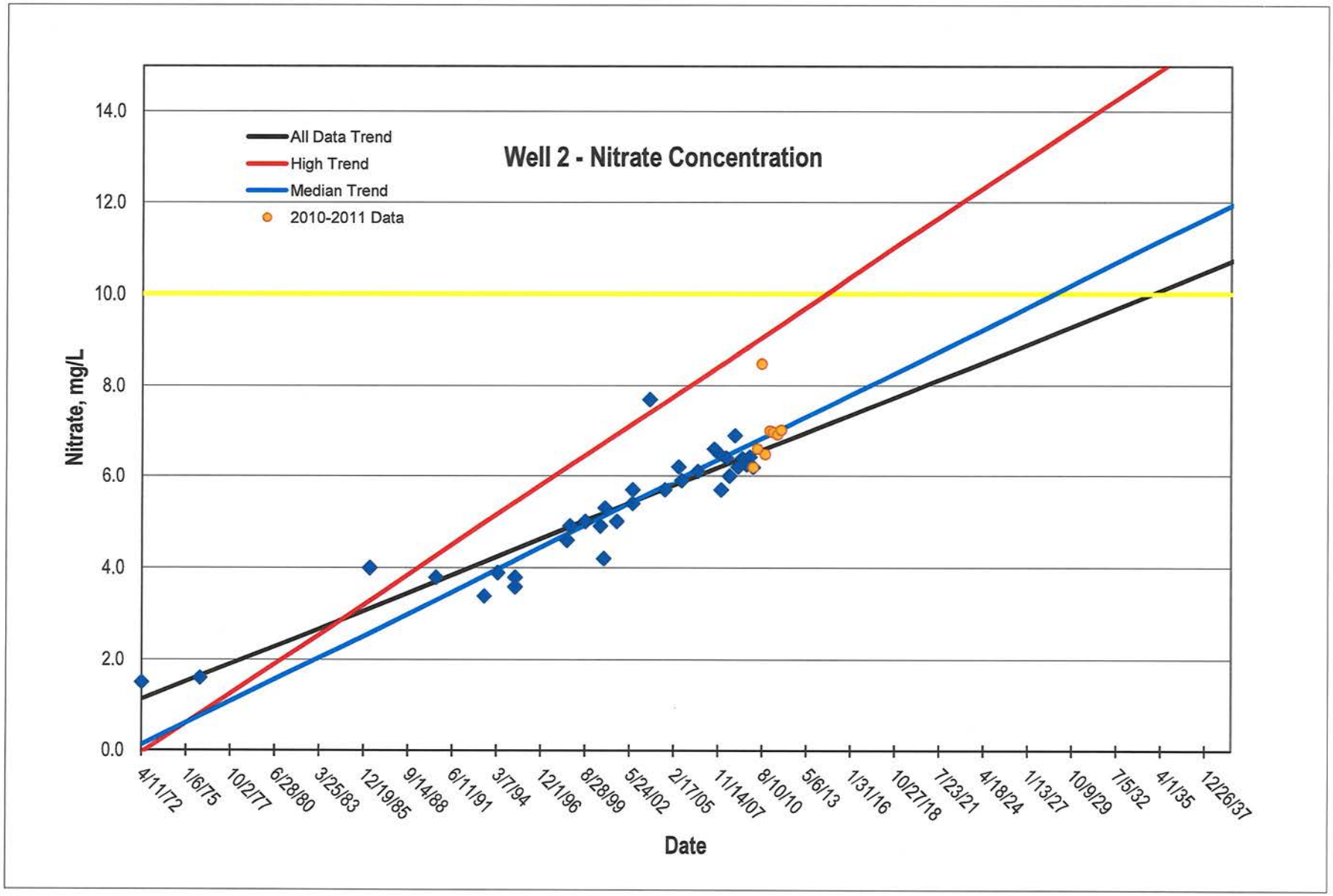
HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011
692	7.00		773	6.30		615	5.32		624	3.85	
695	7.00		497	6.26		332	5.30		74	3.80	
214	6.93		290	6.20		455	5.30		206	3.80	
280	6.91		310	6.20		761	5.23		606	3.77	
706	6.91		323	6.20		307	5.20		58	3.71	
589	6.90		659	6.20		436	5.20		622	3.70	
620	6.90		567	6.16		1083	5.20		349	3.69	
668	6.90		32	6.12		223	5.14		411	3.56	
698	6.90		166	6.10		225	5.10		75	3.50	
777	6.90		218	6.10		1066	5.10		756	3.50	
292	6.88		220	6.10		690	5.09		295	3.42	
134	6.80		348	6.10		187	5.03		104	3.40	
221	6.80		781	6.10		617	4.92		535	3.40	
621	6.80		128	6.05		217	4.90		1069	3.40	
1062	6.80		209	5.99		110	4.80		38	3.26	
432	6.78		554	5.97		596	4.80		4	3.20	
608	6.78		109	5.91		597	4.80		782	3.06	
320	6.74		219	5.90		753	4.80		755	3.05	
406	6.74		477	5.90		1073	4.70		565	3.00	
519	6.68		1087	5.90		672	4.60		57	2.97	
311	6.61		112	5.89		153	4.50		762	2.95	
226	6.60		350	5.82		468	4.50		526	2.88	
238	6.60		165	5.80		616	4.50		59	2.84	
315	6.60		264	5.80		64	4.47		524	2.81	
357	6.60		472	5.80		798	4.44		577	2.80	
645	6.60		416	5.70		514	4.36		759	2.80	
671	6.60		796	5.70		149	4.30		46	2.77	
711	6.50		306	5.60		635	4.30		375	2.75	
684	6.49		1065	5.60		741	4.30		125	2.70	
679	6.43		45	5.57		94	4.27		766	2.70	
279	6.42		681	5.51		190	4.20		63	2.60	
258	6.40		114	5.50		466	4.20		642	2.60	
275	6.40		611	5.45		408	4.18		764	2.60	
1084	6.40		393	5.40		54	4.10		1072	2.60	
694	6.37		758	5.40		397	4.08		1095	2.60	
278	6.32		373	5.35		314	4.00		49	2.58	
254	6.30		129	5.32		227	3.91		385	2.57	

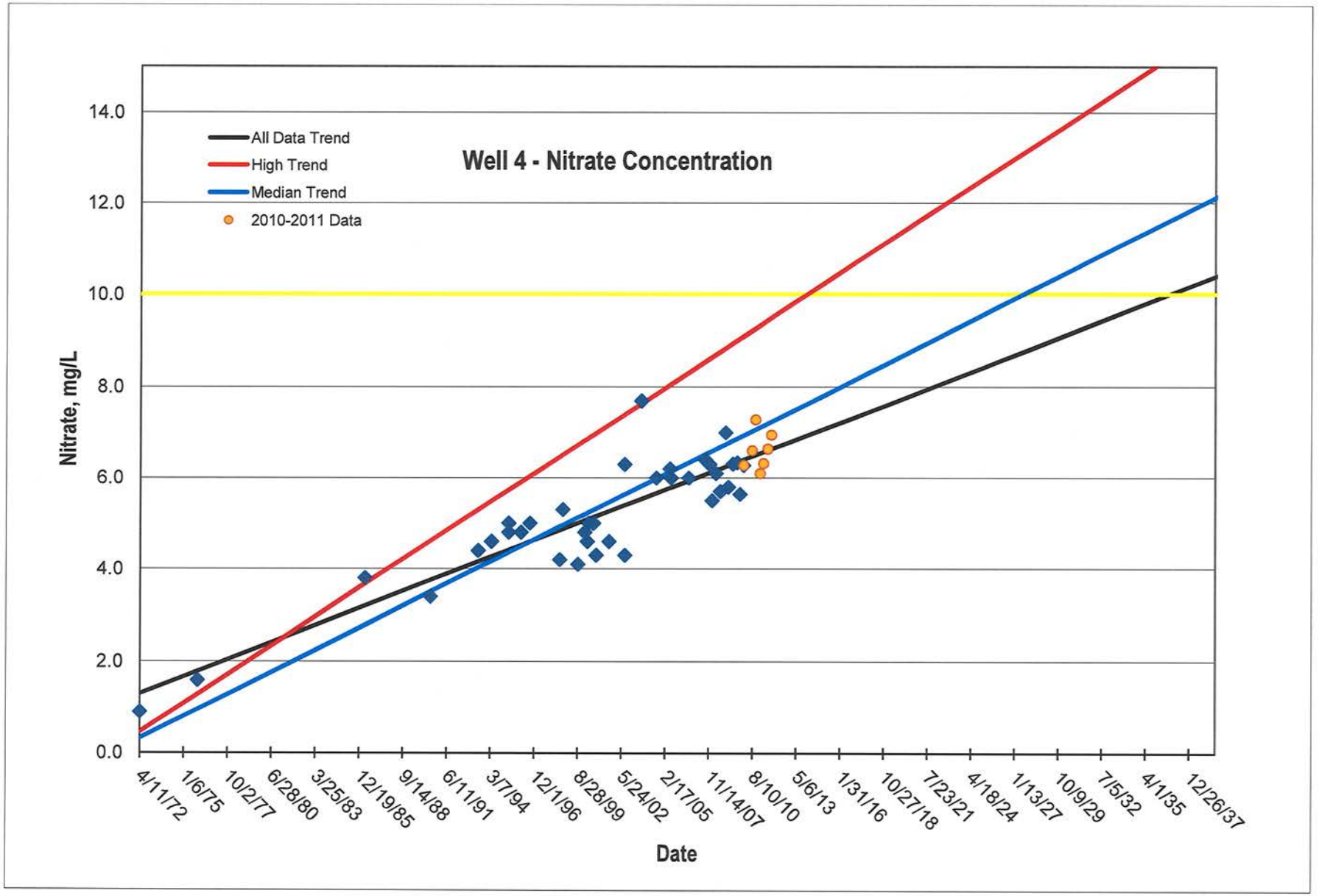
HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011	HWPA ID	2010	2011
612	2.50		626	1.35		55	0.70		628	0.26	
1080	2.50		368	1.32		115	0.70		525	0.19	
352	2.44		779	1.32		136	0.70		335	35.00	
358	2.44		18	1.30		157	0.70		542	34.20	
20	2.30		56	1.30		334	0.70		538	32.00	
122	2.28		505	1.30		382	0.70		141	30.00	
776	2.20		599	1.30		1071	0.70		536	28.00	
507	2.19		1097	1.30		1079	0.70		539	28.00	
340	2.15		379	1.28		345	0.69		775	26.00	
386	2.13		367	1.23		559	0.67		569	23.00	
336	2.08		266	1.20		558	0.65		540	22.50	
421	2.00		70	1.10		369	0.60		531	22.20	
661	1.96		341	1.10		405	0.60		749	22.00	
25	1.90		365	1.10		410	0.60		1070	21.90	
394	1.79		402	1.10		420	0.60		533	21.80	
331	1.78		560	1.10		510	0.60		529	21.50	
404	1.70		342	1.04		636	0.60		593	21.00	
419	1.70		2	1.00		101	0.59		594	21.00	
428	1.67		105	1.00		440	0.59		641	21.00	
344	1.65		508	1.00		371	0.57		1094	20.70	
158	1.60		748	0.99		571	0.57		557	20.60	
354	1.60		400	0.98		356	0.56		1091	20.30	
71	1.59		441	0.95		644	0.56		530	20.20	
47	1.57		329	0.91		51	0.50		50	20.00	
359	1.55		44	0.90		77	0.50		229	20.00	
399	1.54		62	0.90		462	0.50		653	20.00	
33	1.50		438	0.90		805	0.50		534	19.80	
127	1.50		564	0.90		1063	0.50		555	19.50	
424	1.50		378	0.86		1074	0.50		1090	19.50	
562	1.50		797	0.82		1075	0.50		614	19.30	
570	1.50		65	0.80		1076	0.50		550	19.20	
364	1.44		361	0.80		1082	0.50		68	19.10	
100	1.40		401	0.80		1096	0.50		551	19.00	
423	1.40		1081	0.80		475	0.40		552	19.00	
412	1.39		511	0.76		131	0.30		41	18.50	
407	1.38		355	0.74		512	0.30		556	18.10	
467	1.35		11	0.70		767	0.30		202	18.00	

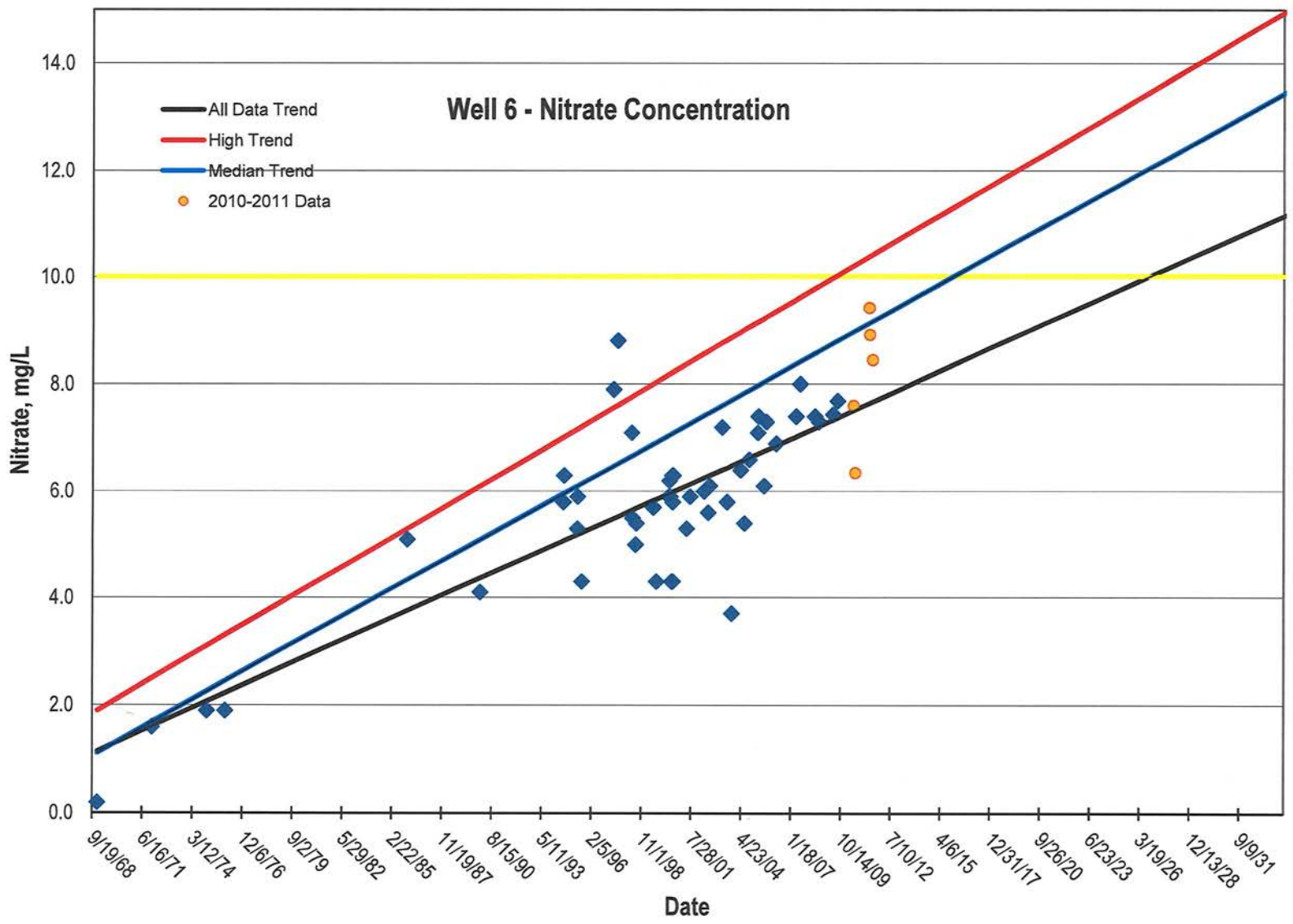
HWPA ID	2010	2011
549	18.00	
647	17.90	
48	17.70	
377	17.70	
14	17.40	
1086	17.40	
21	17.30	
130	17.00	
545	17.00	
591	17.00	
543	16.90	
1085	16.80	
601	16.70	
1089	16.20	

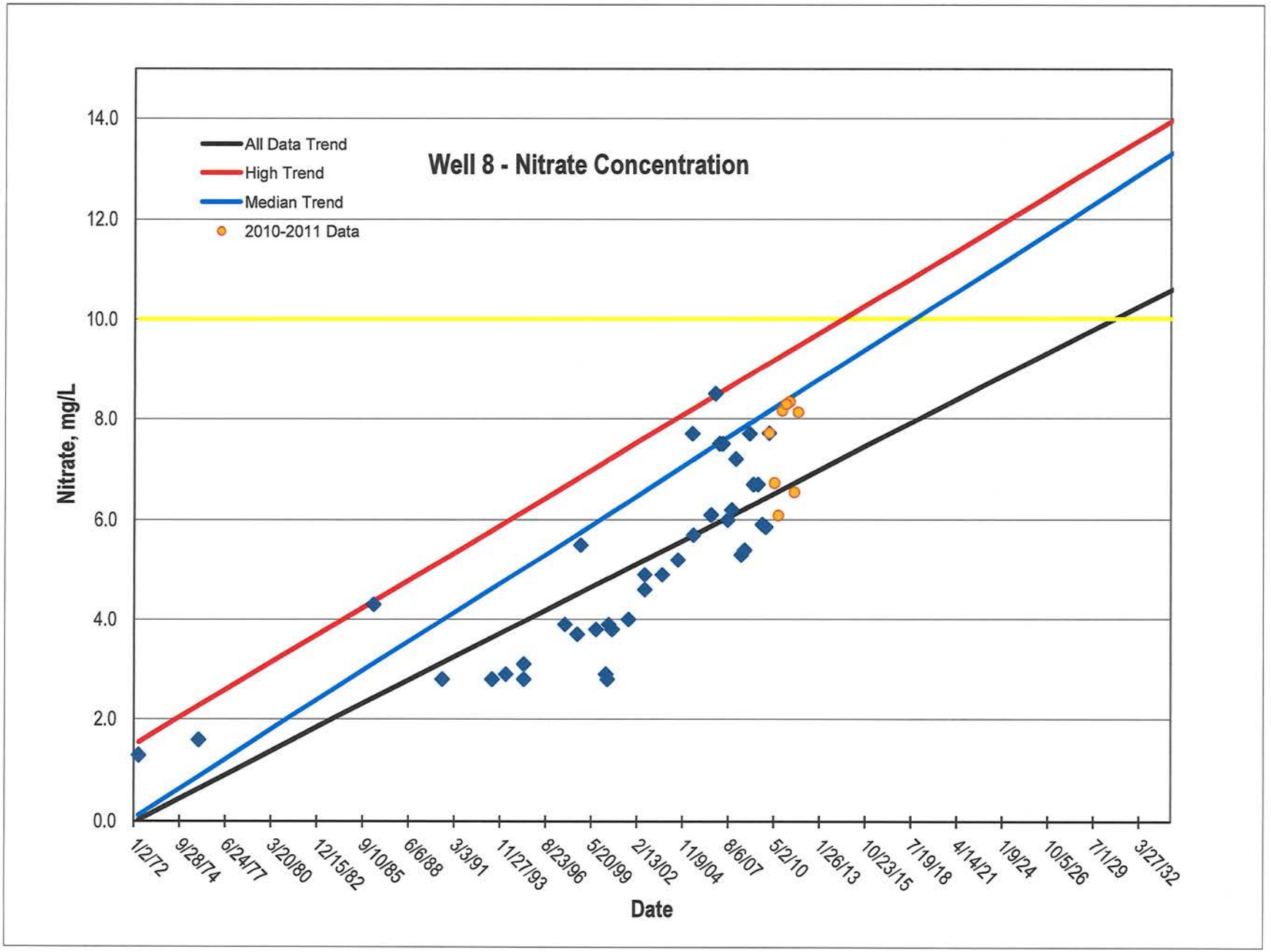
APPENDIX B – HU MUNICIPAL WELL NITRATE FIGURES WITH HISTORICAL AND 2010-2011 DATA

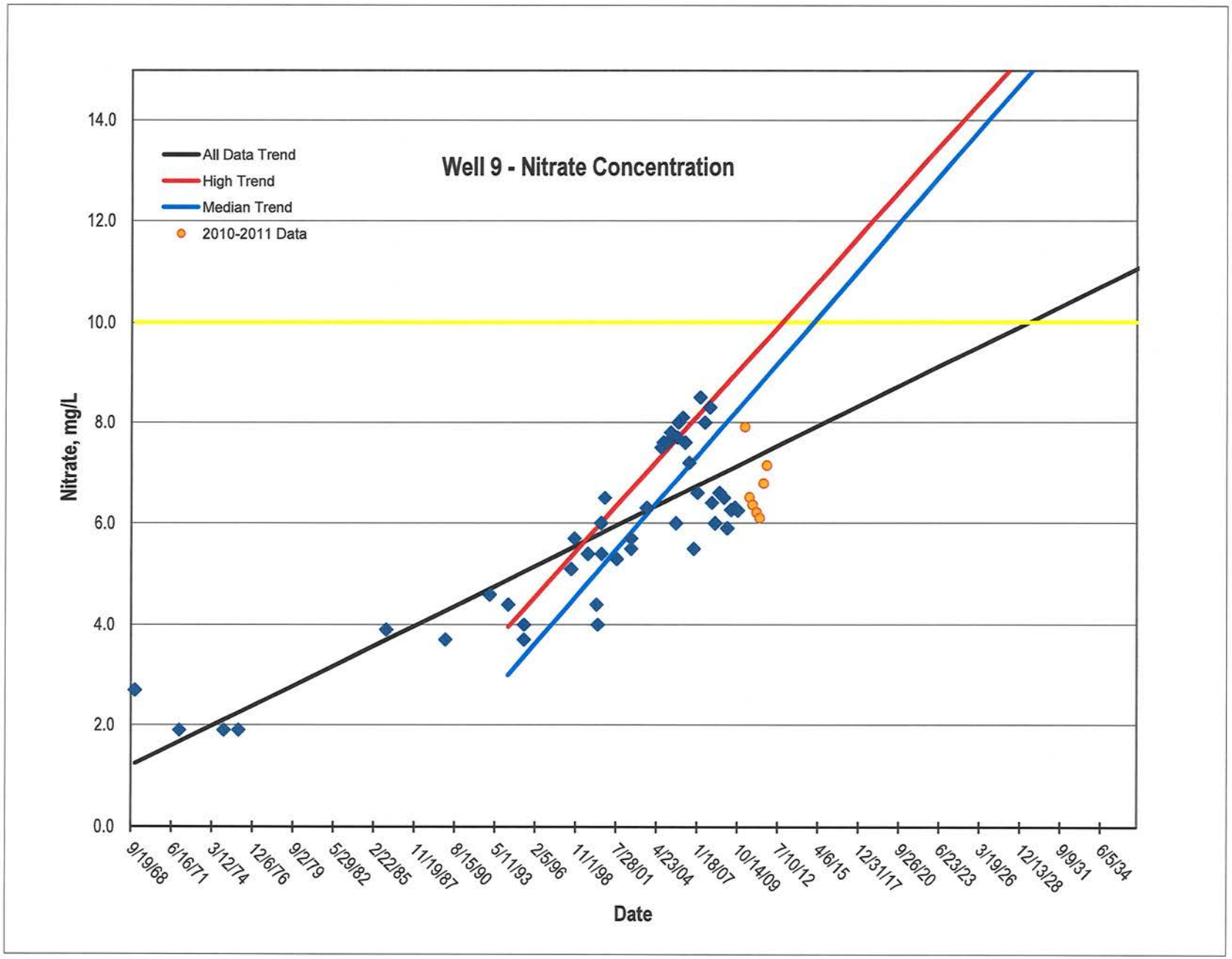

Well 1 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
9/19/68
6/16/71
3/12/74
12/6/76
9/2/79
5/29/82
2/22/85
11/19/87
8/15/90
5/11/93
2/5/96
11/1/98
7/28/01
4/23/04
1/18/07
10/14/09
7/10/12
4/6/15
12/31/17
9/26/20
6/23/23
3/19/26
12/13/28
9/9/31
6/5/34
3/1/37
11/26/39
Date

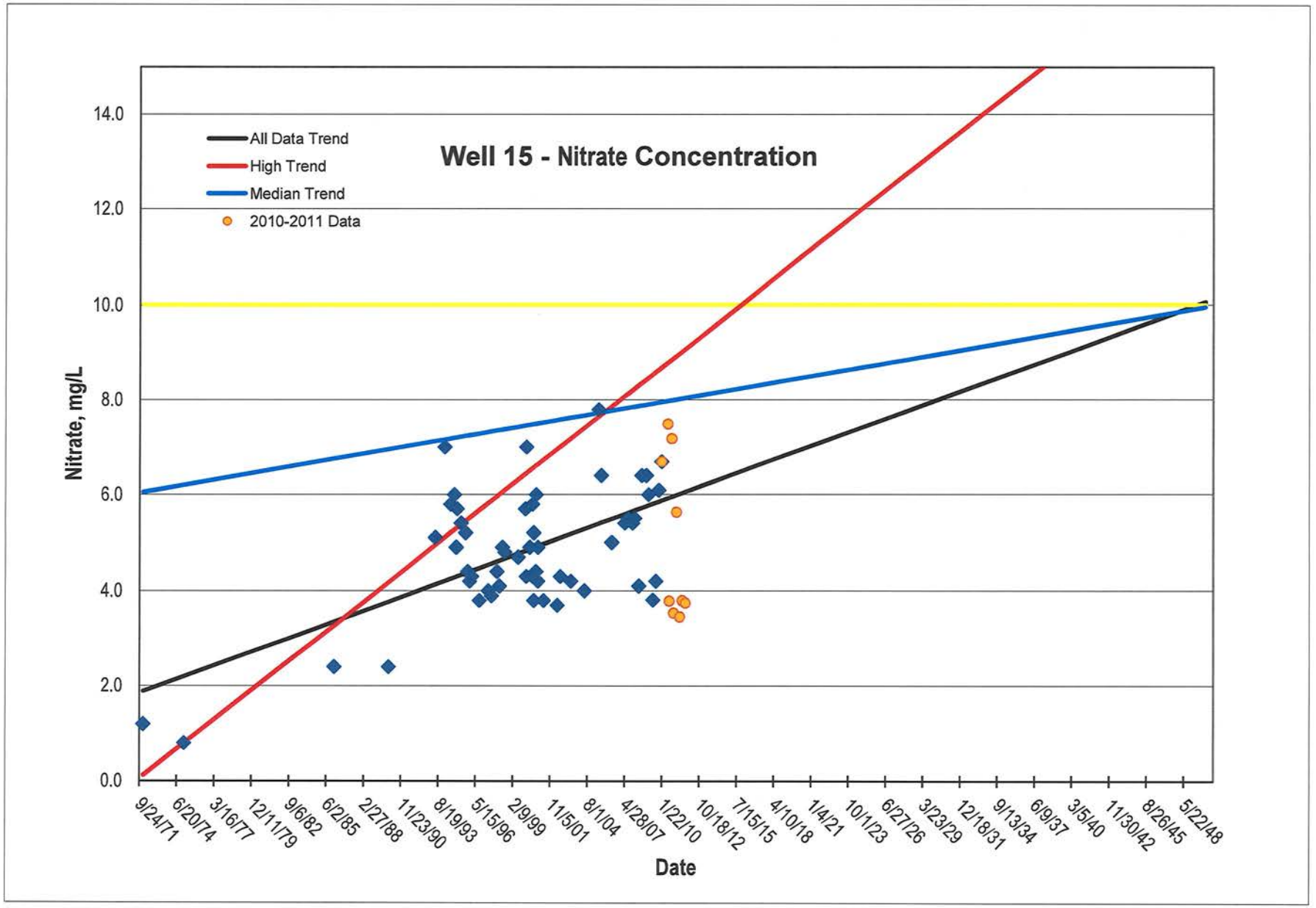

Well 2 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/11/72
1/6/75
10/2/77
6/28/80
3/25/83
12/19/85
9/14/88
6/11/91
3/7/94
12/1/96
8/28/99
5/24/02
2/17/05
11/14/07
8/10/10
5/6/13
1/31/16
10/27/18
7/23/21
4/18/24
1/13/27
10/9/29
7/5/32
4/1/35
12/26/37
Date

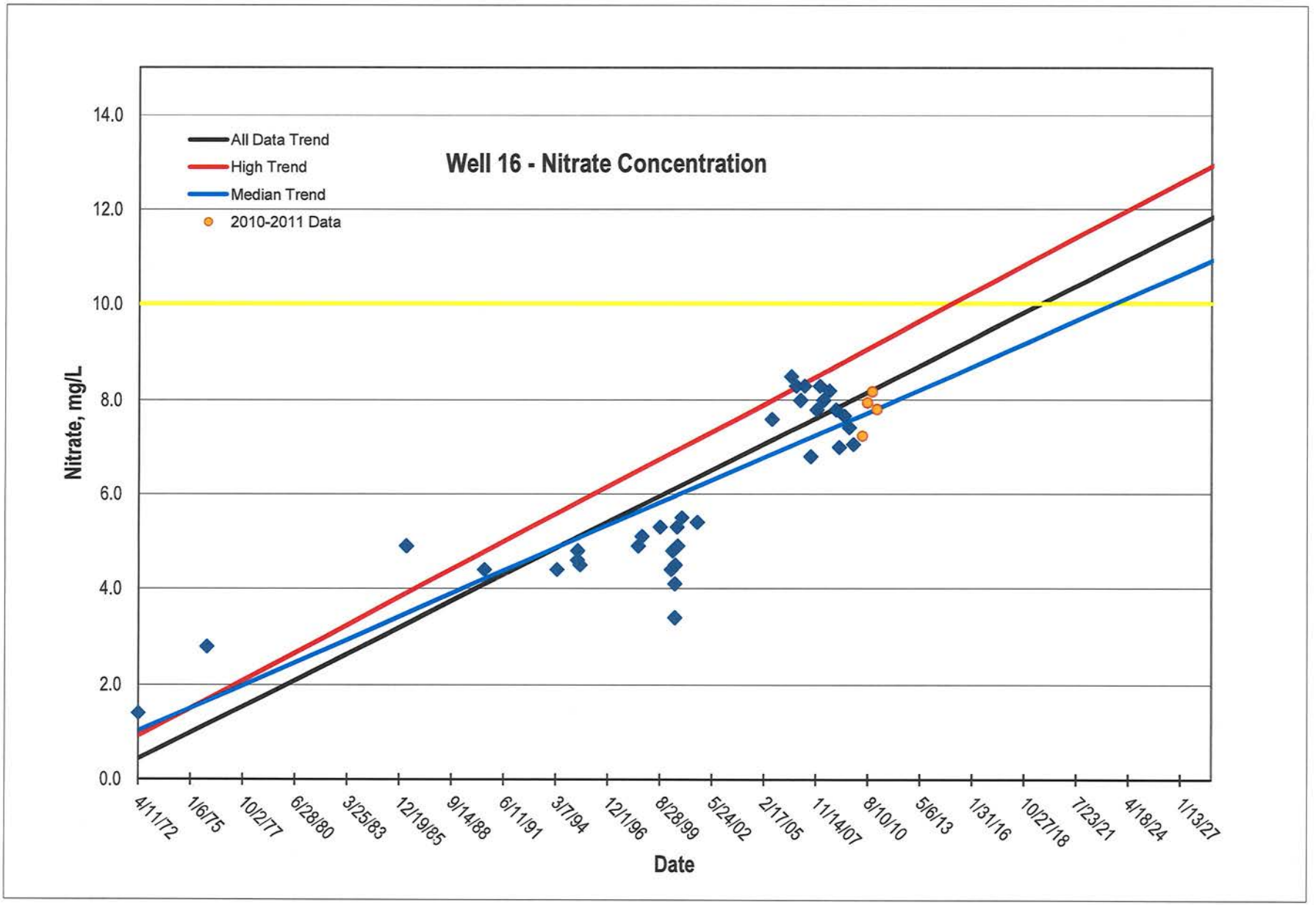

Well 4 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/11/72
1/6/75
10/2/77
6/28/80
3/25/83
12/19/85
9/14/88
6/11/91
3/7/94
12/1/96
8/28/99
5/24/02
2/17/05
11/14/07
8/10/10
5/6/13
1/31/16
10/27/18
7/23/21
4/18/24
1/13/27
10/9/29
7/5/32
4/1/35
12/26/37
Date

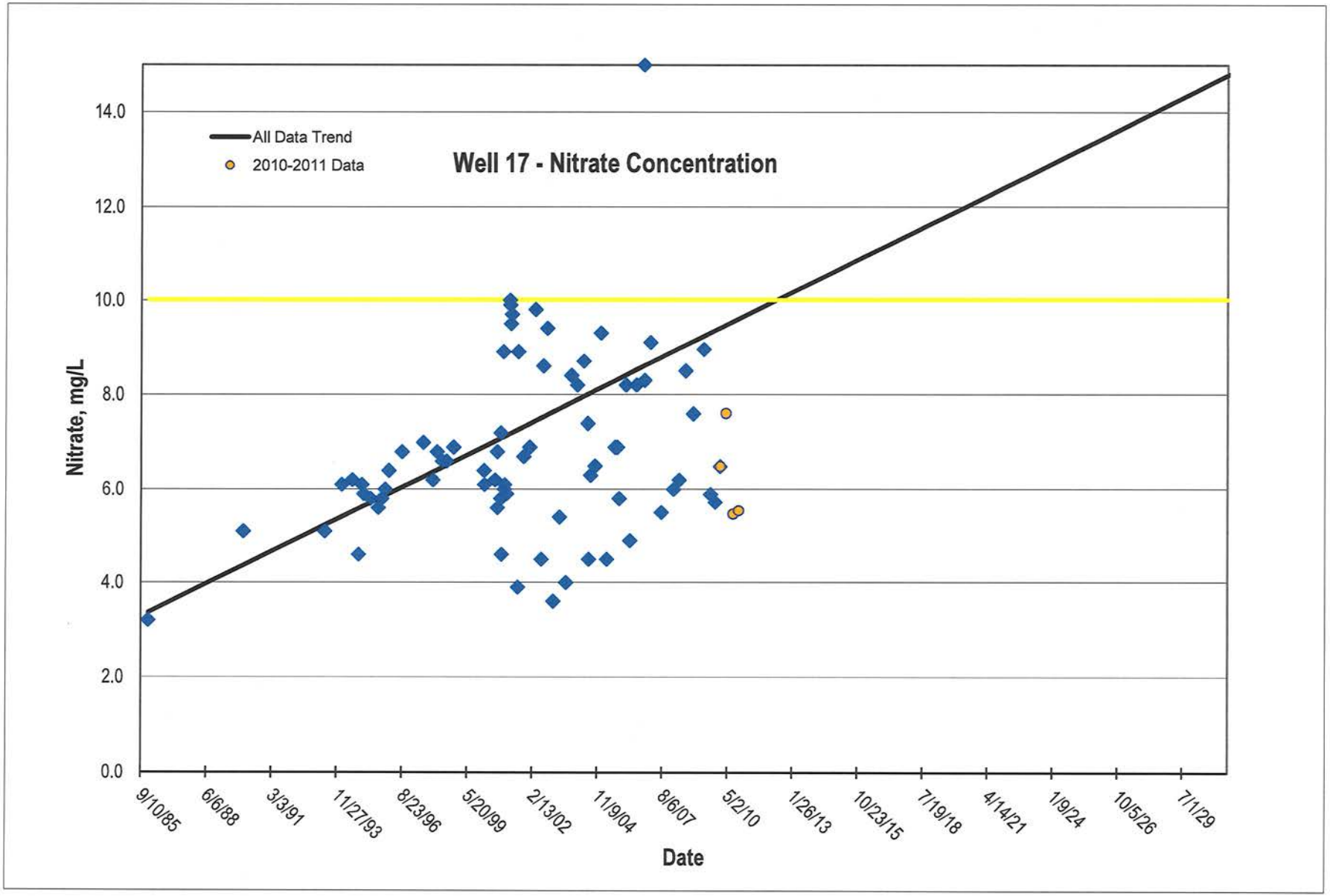

Well 6 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
9/19/68
6/16/71
3/12/74
12/6/76
9/2/79
5/29/82
2/22/85
11/19/87
8/15/90
5/11/93
2/5/96
11/1/98
7/28/01
4/23/04
1/18/07
10/14/09
7/10/12
4/6/15
12/31/17
9/26/20
6/23/23
3/19/26
12/13/28
9/9/31
Date

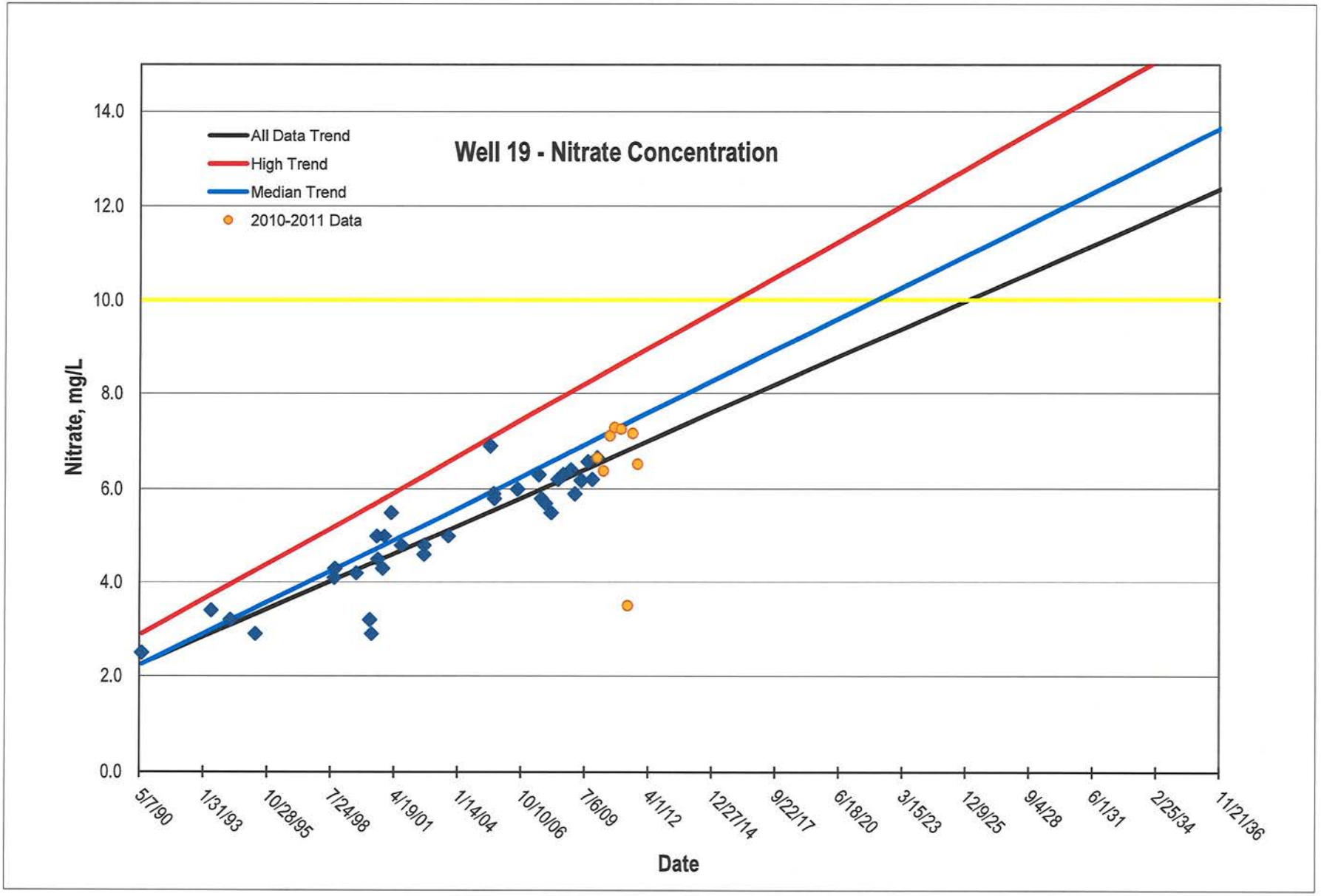

Well 8 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1/2/72
9/28/74
6/24/77
3/20/80
12/15/82
9/10/85
6/6/88
3/3/91
11/27/93
8/23/96
5/20/99
2/13/02
11/9/04
8/6/07
5/2/10
1/26/13
10/23/15
7/19/18
4/14/21
1/9/24
10/5/26
7/1/29
3/27/32
Date

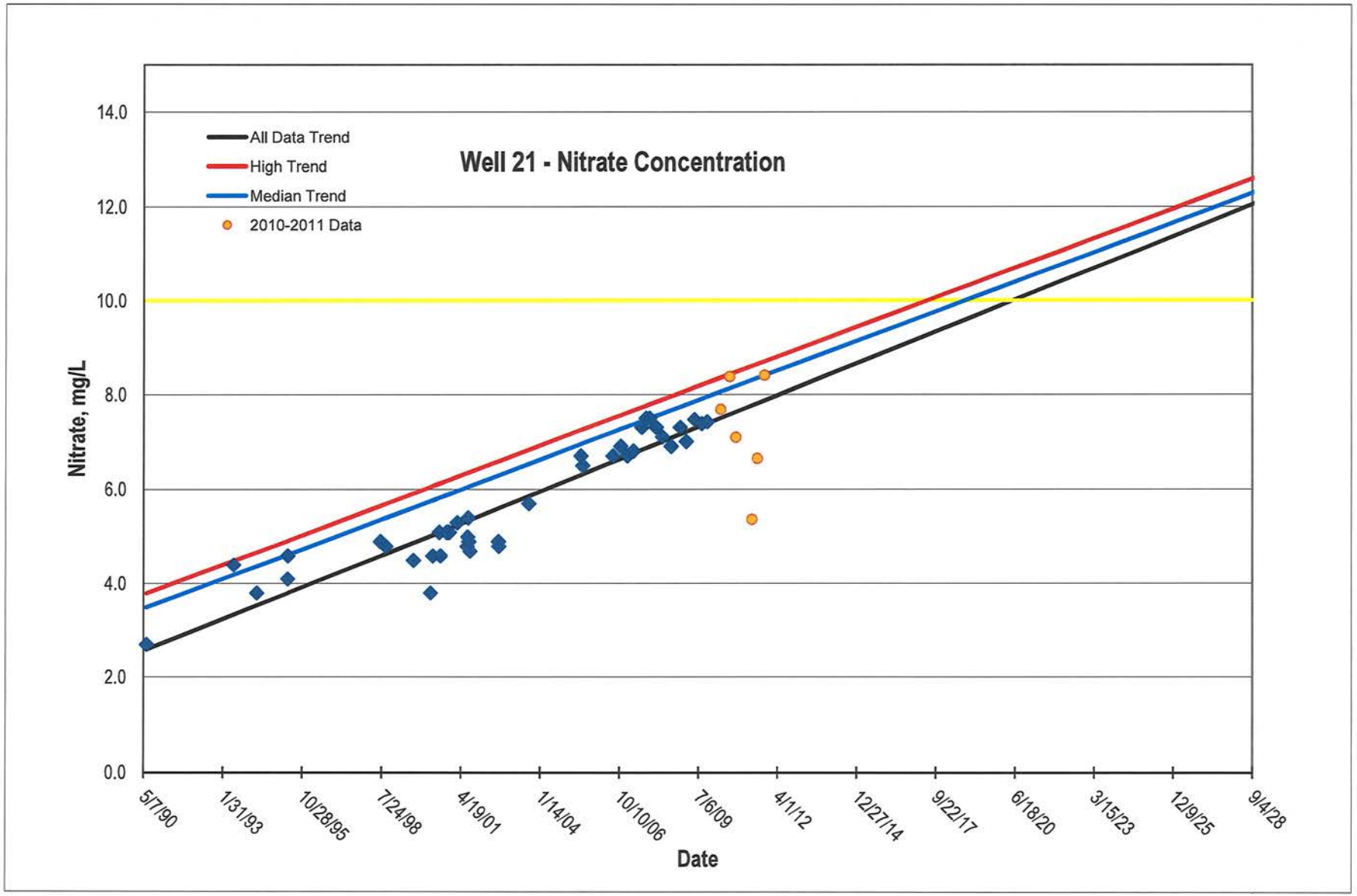

Well 9 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
9/19/68
6/16/71
3/12/74
12/6/76
9/2/79
5/29/82
2/22/85
11/19/87
8/15/90
5/11/93
2/5/96
11/1/98
7/28/01
4/23/04
1/18/07
10/14/09
7/10/12
4/6/15
12/31/17
9/26/20
6/23/23
3/19/26
12/13/28
9/9/31
6/5/34
Date

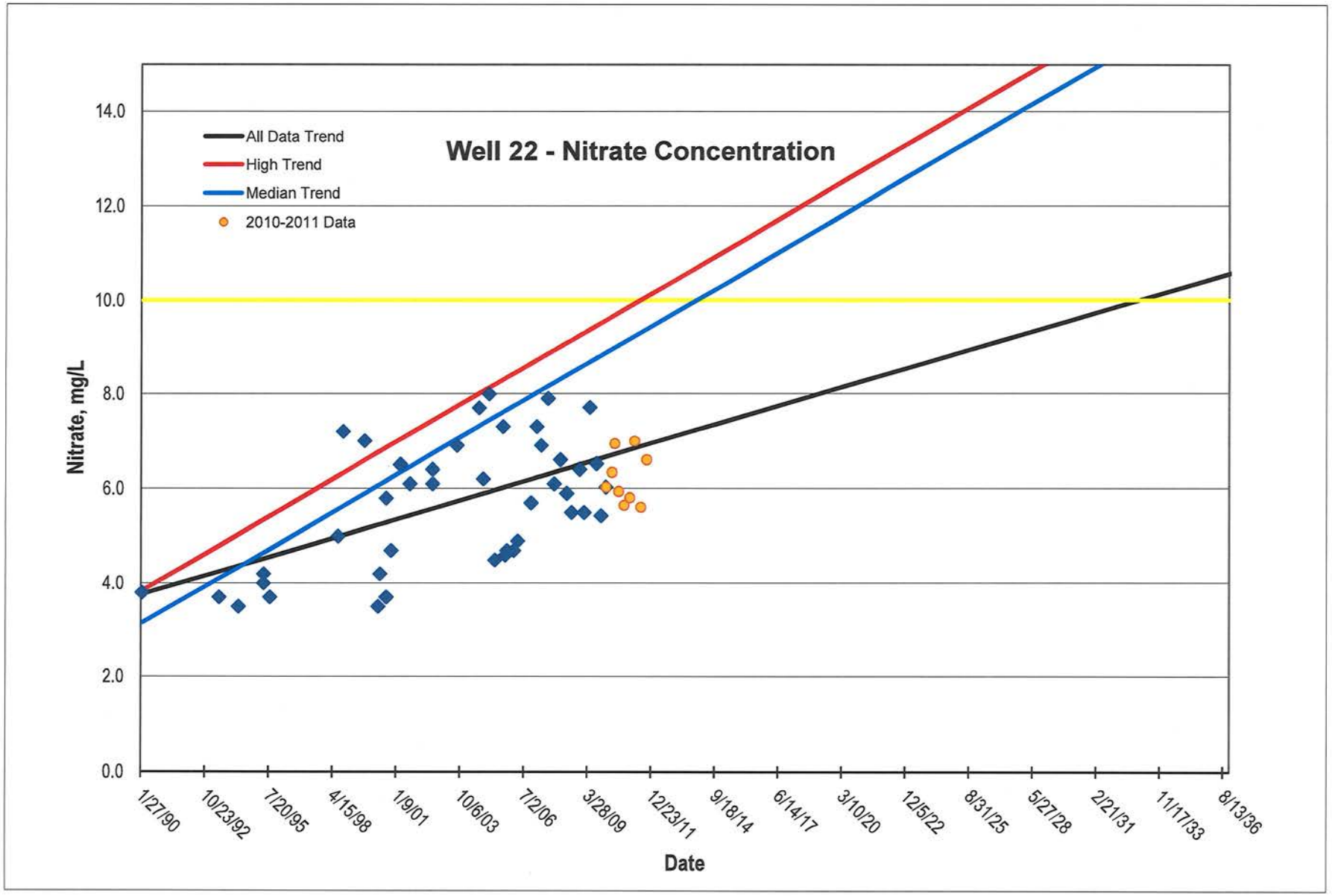

Well 15 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
9/24/71
6/20/74
3/16/77
12/11/79
9/6/82
6/2/85
2/27/88
11/23/90
8/19/93
5/15/96
2/9/99
11/5/01
8/1/04
4/28/07
1/22/10
10/18/12
7/15/15
4/10/18
1/4/21
10/1/23
6/27/26
3/23/29
12/18/31
9/13/34
6/9/37
3/5/40
11/30/42
8/26/45
5/22/48
Date

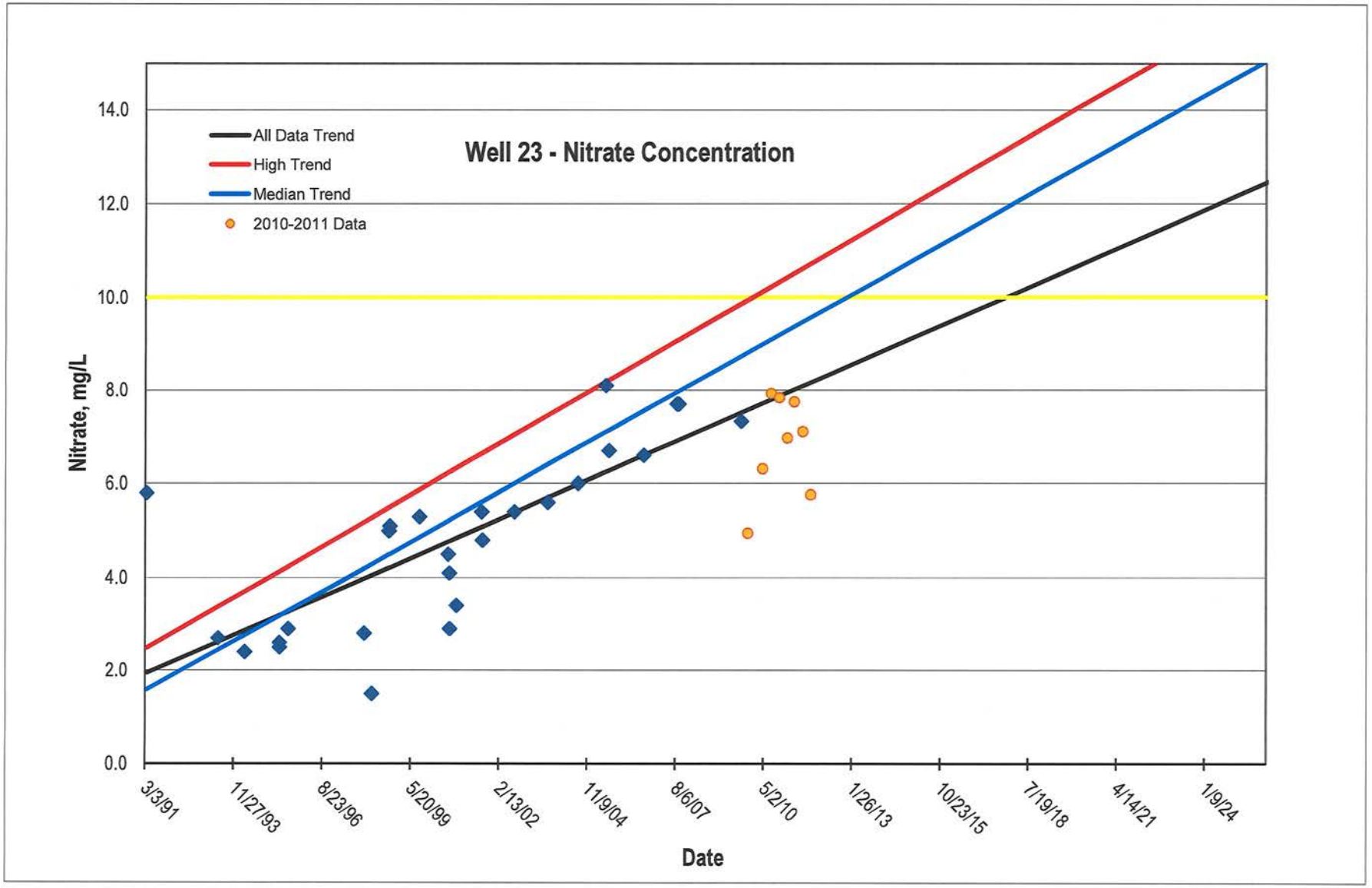

Well 16 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/11/72
1/6/75
10/2/77
6/28/80
3/25/83
12/19/85
9/14/88
6/11/91
3/7/94
12/1/96
8/28/99
5/24/02
2/17/05
11/14/07
8/10/10
5/6/13
1/31/16
10/27/18
7/23/21
4/18/24
1/13/27
Date

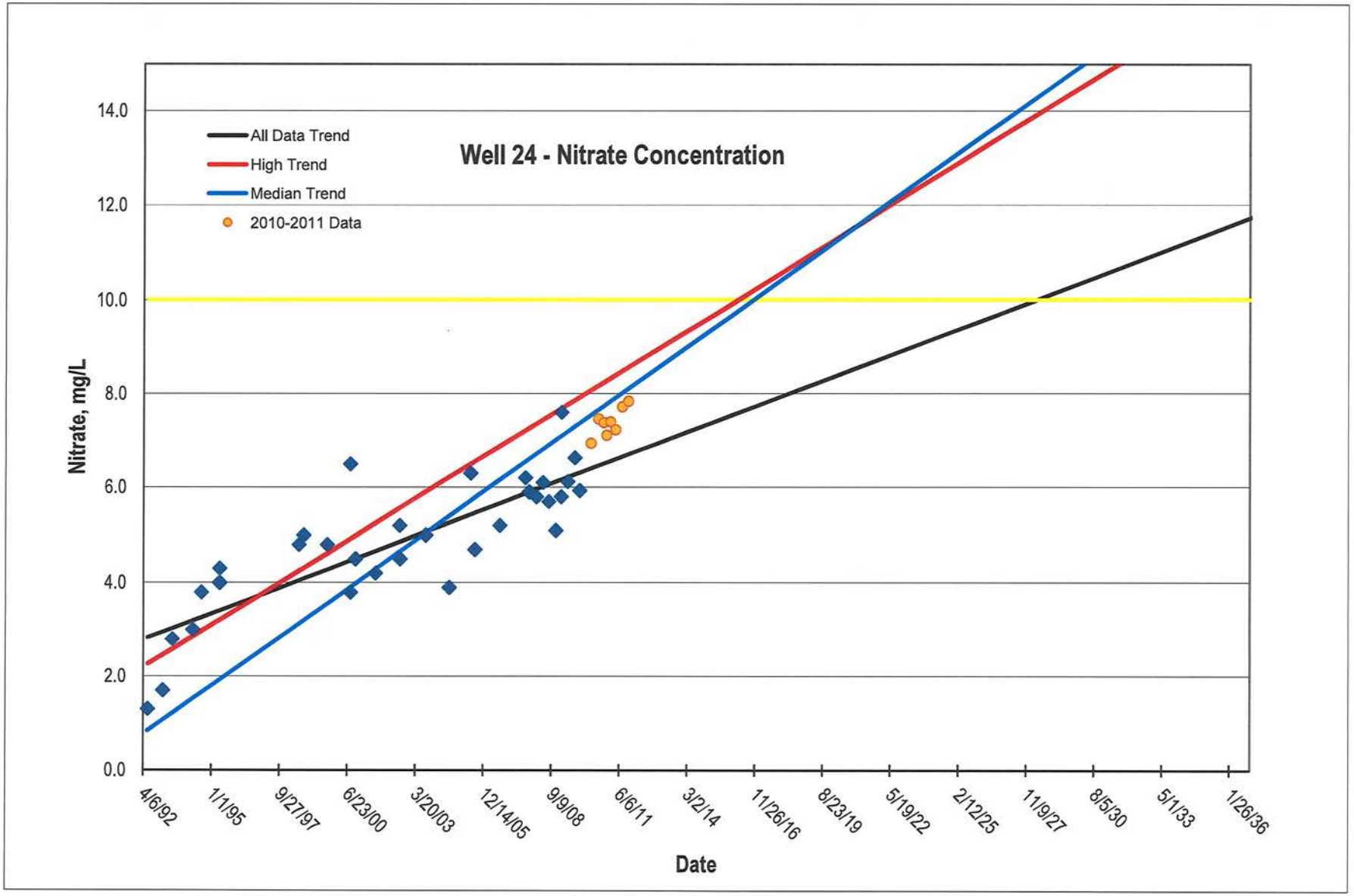

Well 17 - Nitrate Concentration
All Data Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
9/10/85
6/6/88
3/3/91
11/27/93
8/23/96
5/20/99
2/13/02
11/9/04
8/6/07
5/2/10
1/26/13
10/23/15
7/19/18
4/14/21
1/9/24
10/5/26
7/1/29
Date

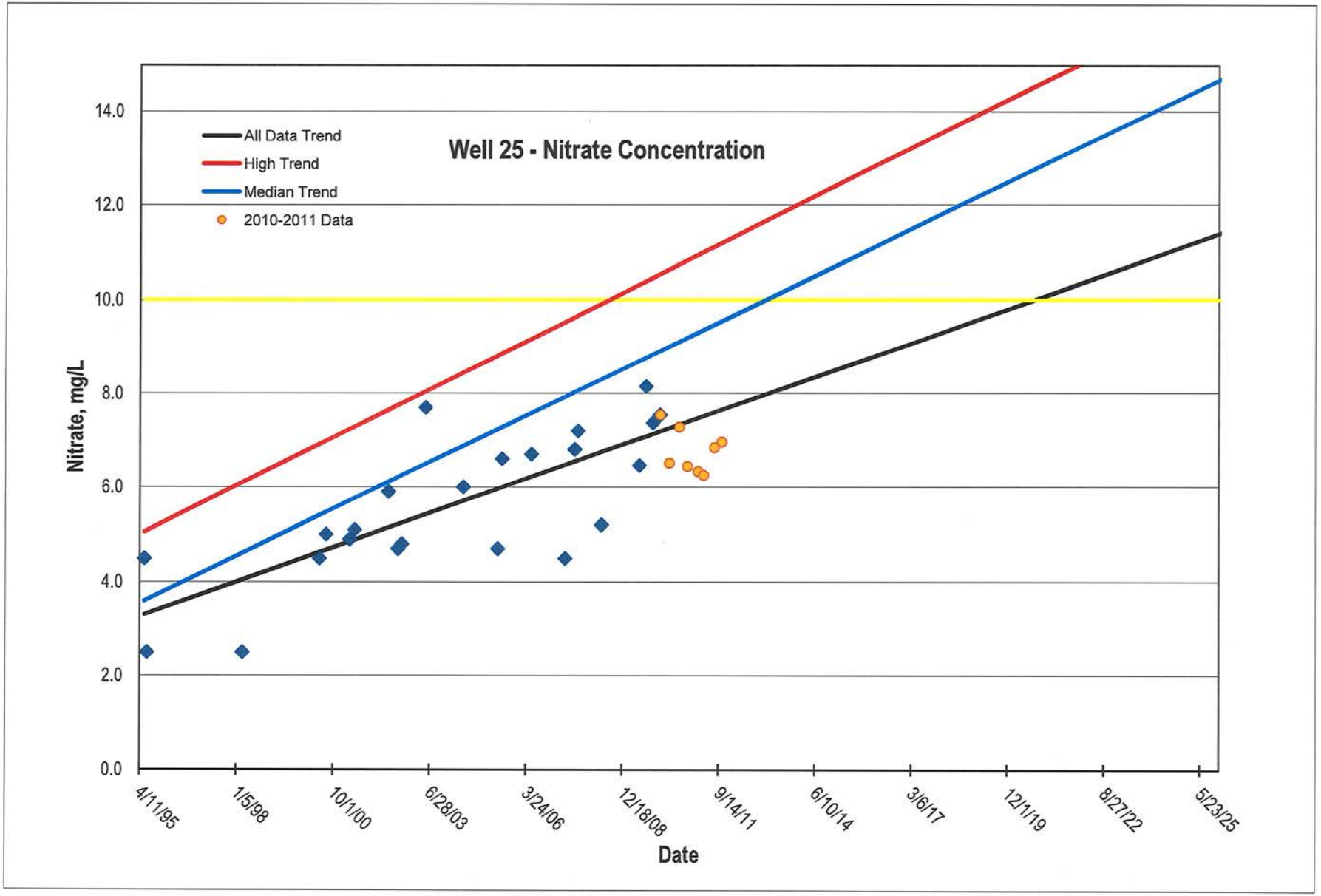

Well 19 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
1/14/04
10/10/06
7/6/09
4/1/12
12/27/14
9/22/17
6/18/20
3/15/23
12/9/25
9/4/28
6/1/31
2/25/34
11/21/36
Date

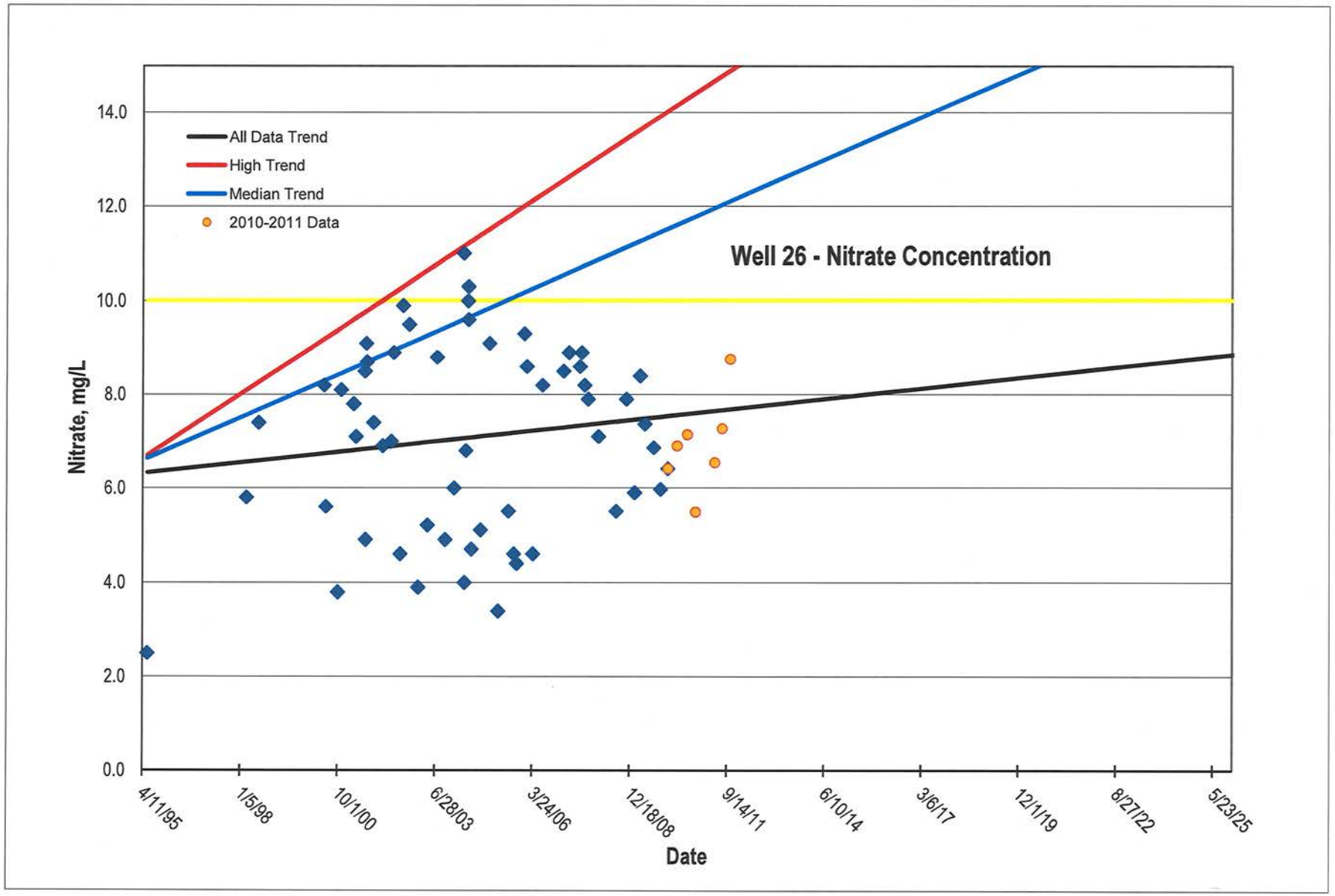

Well 21 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
5/7/90
1/31/93
10/28/95
7/24/98
4/19/01
1/14/04
10/10/06
7/6/09
4/1/12
12/27/14
9/22/17
6/18/20
3/15/23
12/9/25
9/4/28
Date

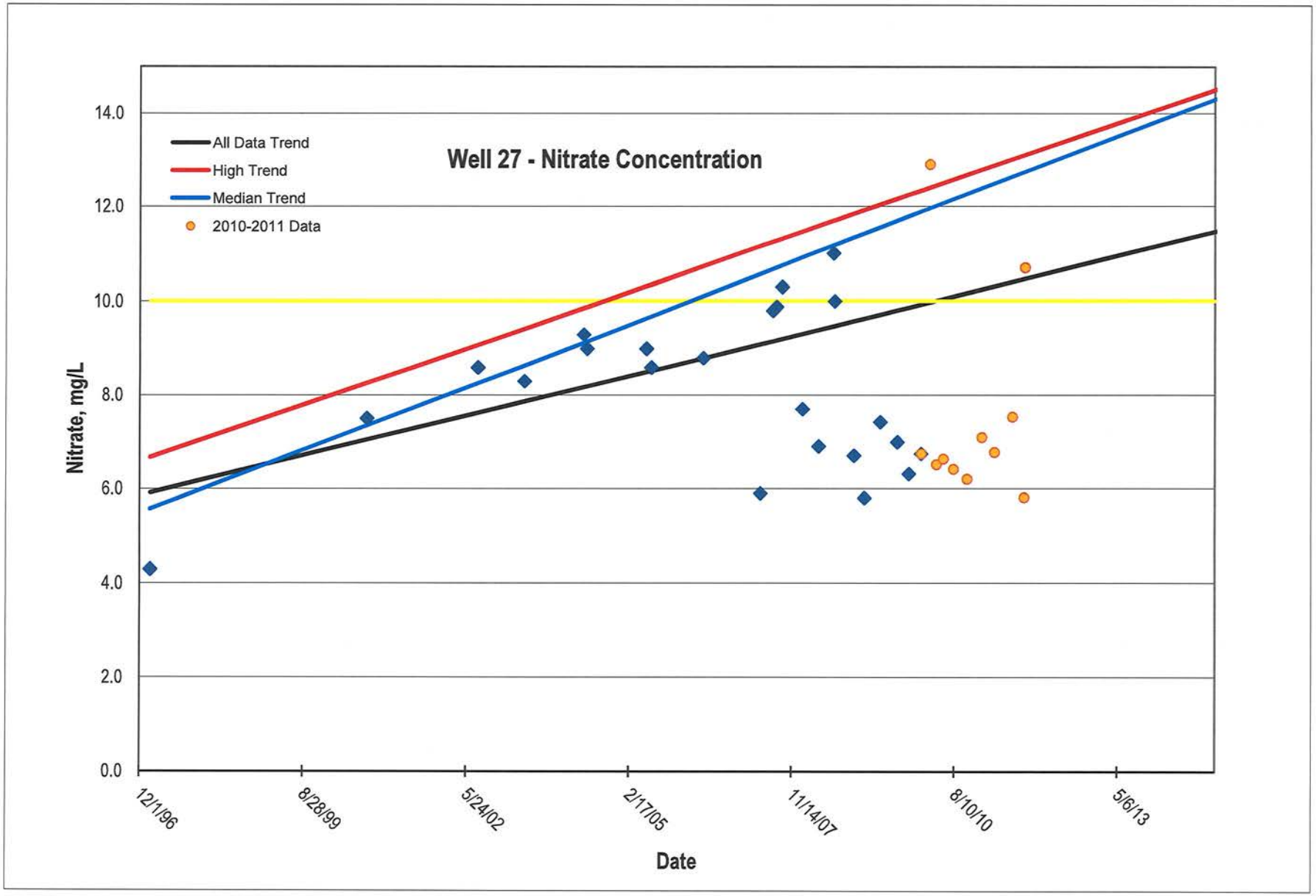

Well 22 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1/27/90
10/23/92
7/20/95
4/15/98
1/9/01
10/6/03
7/2/06
3/28/09
12/23/11
9/18/14
6/14/17
3/10/20
12/5/22
8/31/25
5/27/28
2/21/31
11/17/33
8/13/36
Date

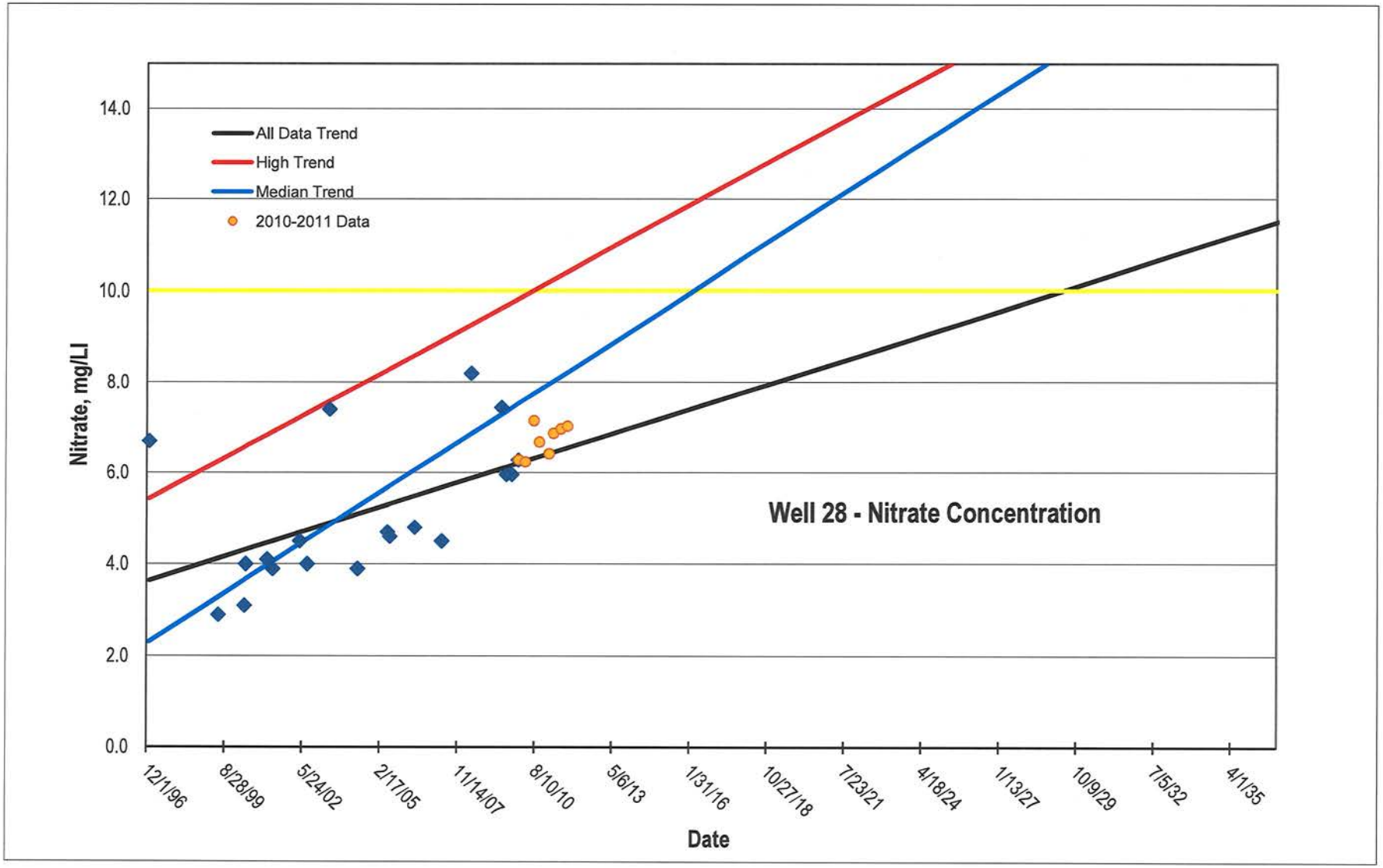

Well 23 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
3/3/91
11/27/93
8/23/96
5/20/99
2/13/02
11/9/04
8/6/07
5/2/10
1/26/13
10/23/15
7/19/18
4/14/21
1/9/24
Date

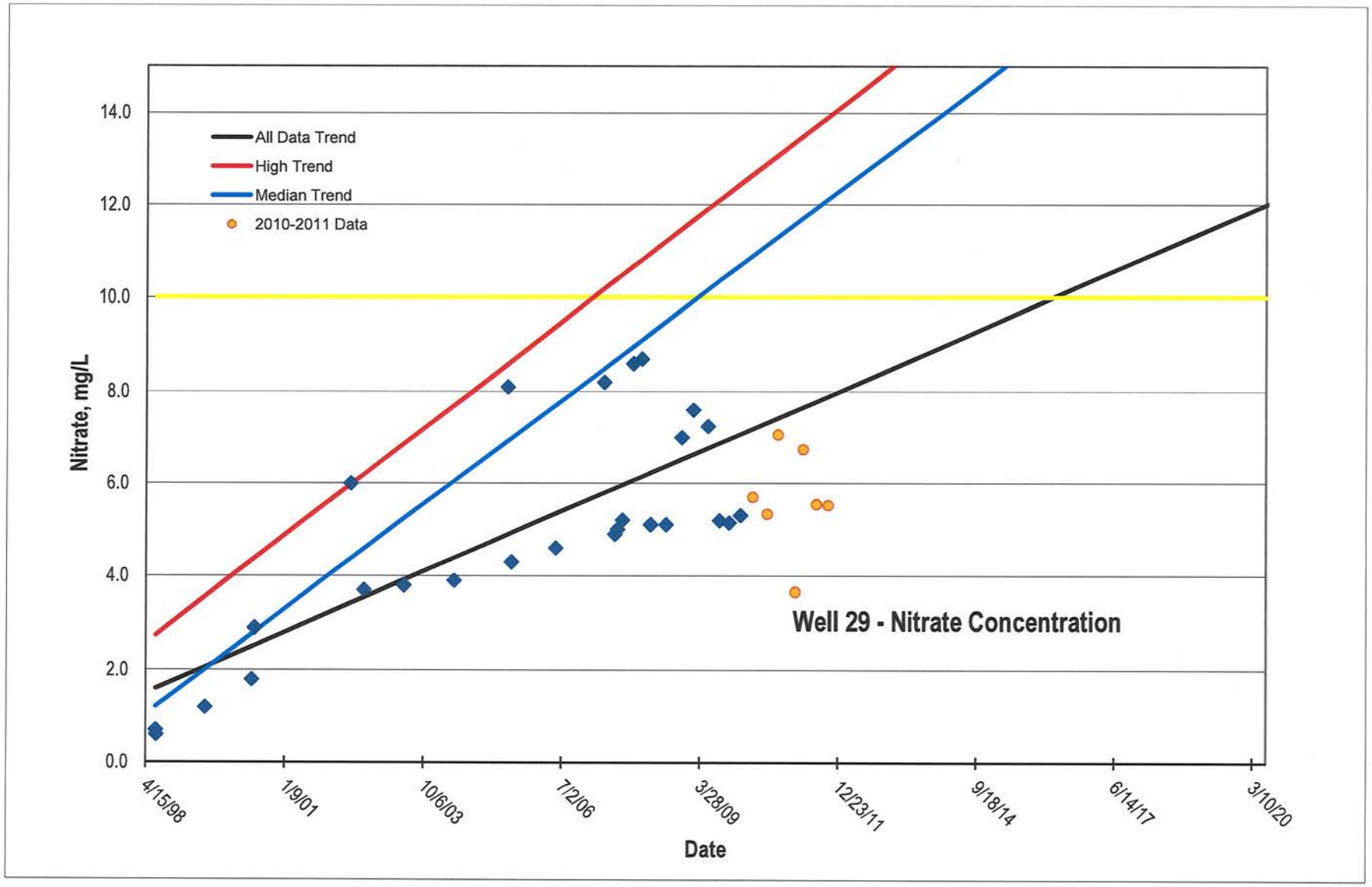

Well 24 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/6/92
1/1/95
9/27/97
6/23/00
3/20/03
12/14/05
9/9/08
6/6/11
3/2/14
11/26/16
8/23/19
5/19/22
2/12/25
11/9/27
8/5/30
5/1/33
1/26/36
Date

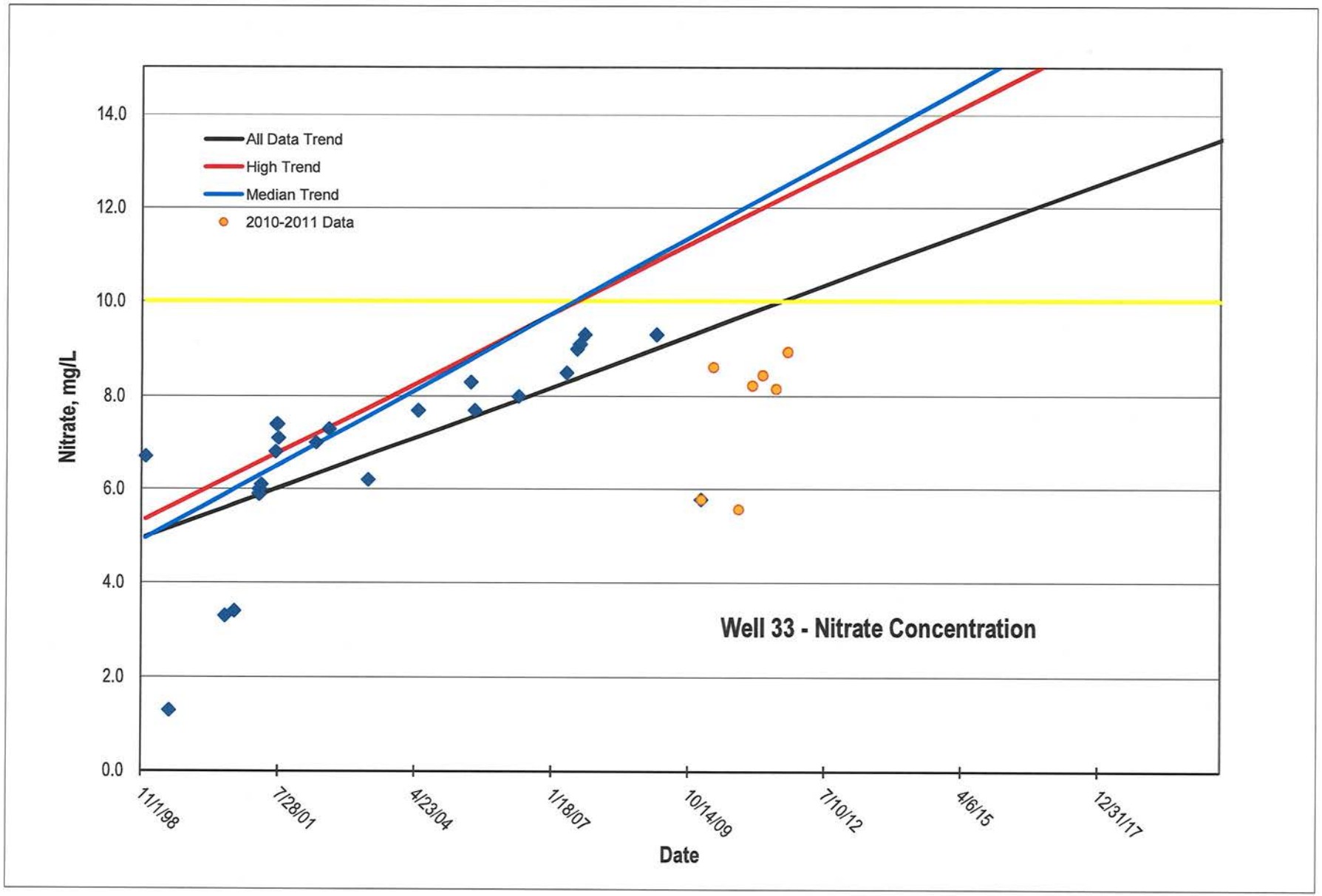

Well 25 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/11/95
1/5/98
10/1/00
6/28/03
3/24/06
12/18/08
9/14/11
6/10/14
3/6/17
12/1/19
8/27/22
5/23/25
Date

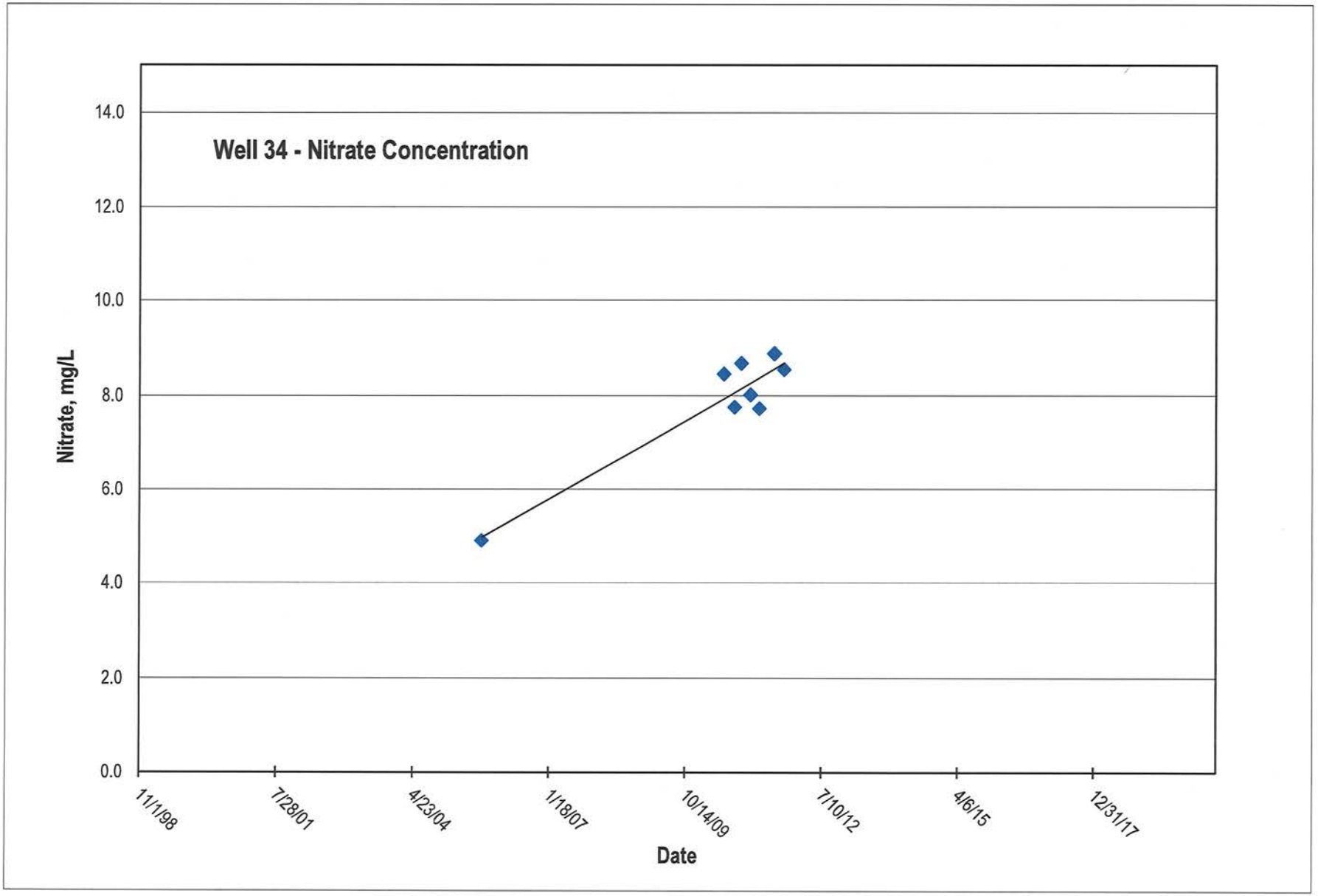

Well 26 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
4/11/95
1/5/98
10/1/00
6/28/03
3/24/06
12/18/08
9/14/11
6/10/14
3/6/17
12/1/19
8/27/22
5/23/25
Date

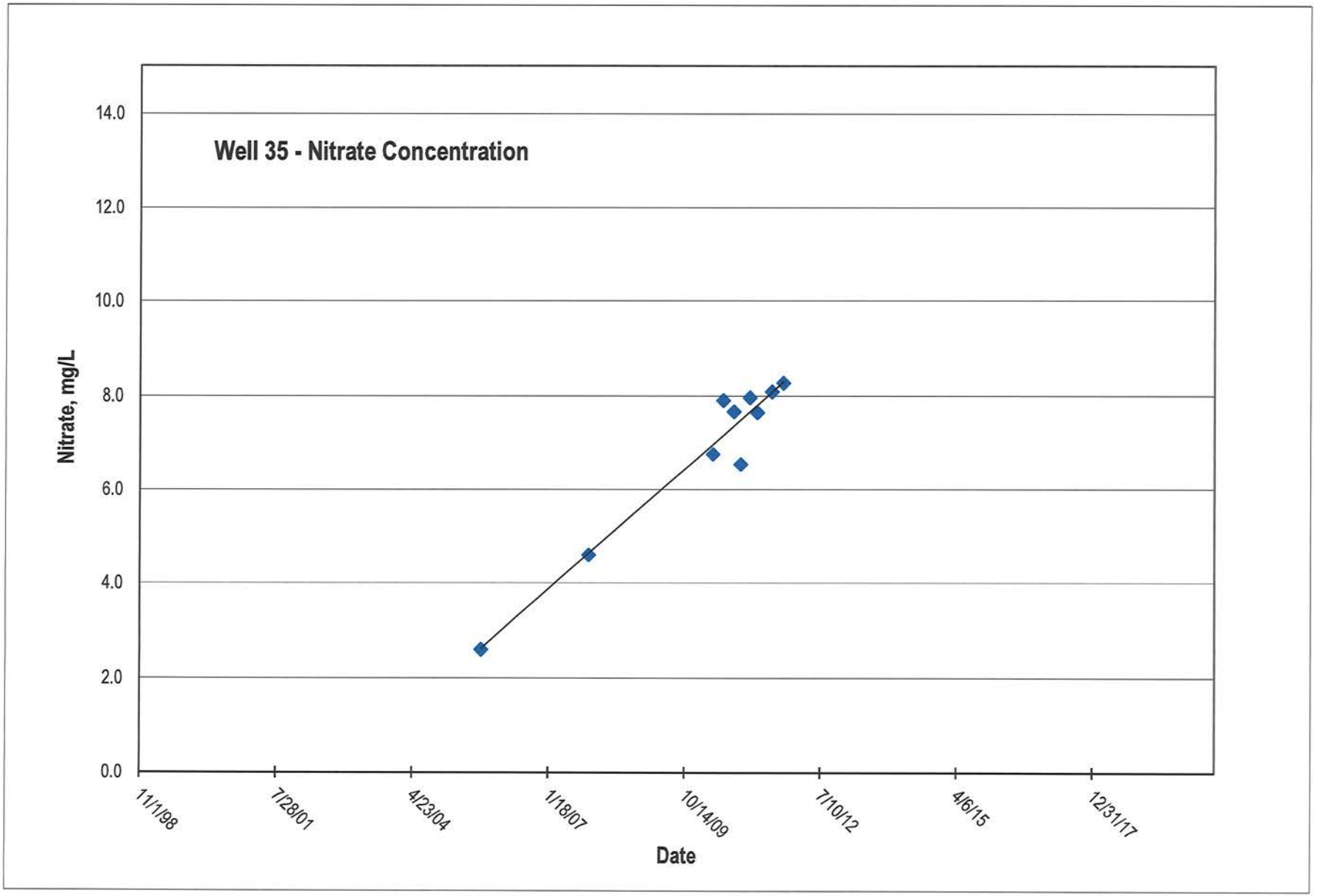

Well 27 - Nitrate Concentration
All Data Trend
High Trend
Median Trend
2010-2011 Data
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
12/1/96
8/28/99
5/24/02
2/17/05
11/14/07
8/10/10
5/6/13
Date


All Data Trend
High Trend
Median Trend
2010-2011 Data
Well 28 - Nitrate Concentration
Nitrate, mg/Ll
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
12/1/96
8/28/99
5/24/02
2/17/05
11/14/07
8/10/10
5/6/13
1/31/16
10/27/18
7/23/21
4/18/24
1/13/27
10/9/29
7/5/32
4/1/35
Date


All Data Trend
High Trend
Median Trend
2010-2011 Data
Well 29 - Nitrate Concentration
Nitrate, mg/L
Date
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
4/15/98
1/9/01
10/6/03
7/2/06
3/28/09
12/23/11
9/18/14
6/14/17
3/10/20


All Data Trend
High Trend
Median Trend
2010-2011 Data
Well 33 - Nitrate Concentration
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
11/1/98
7/28/01
4/23/04
1/18/07
10/14/09
7/10/12
4/6/15
12/31/17
Date


Well 34 - Nitrate Concentration
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
11/1/98
7/28/01
4/23/04
1/18/07
10/14/09
7/10/12
4/6/15
12/31/17
Date


Well 35 - Nitrate Concentration
Nitrate, mg/L
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
11/1/98
7/28/01
4/23/04
1/18/07
10/14/09
7/10/12
4/6/15
12/31/17
Date

HASTINGS UTILITIES WELL BASED NITRATE MANAGEMENT APPROACH TECHNICAL MEMORANDUM

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0.0 INTRODUCTION

In 2010, Hastings Utilities (HU) hired HDR to develop a 20-Year Facility Implementation Plan (Plan) for potable water supply that included treatment options, residual waste stream treatment and disposal requirements, opinion of probable construction costs, and the best alternative for primary treatment and residual waste stream treatment and disposal. In October 2010, HDR presented the proposed Plan to the HU Board. Due to the high cost associated with full-scale nitrate treatment proposed in the Plan, the HU Board decided they would like to pursue other avenues aimed at delaying full-scale treatment as long as possible. As a result, Phase 2 of the Plan, which focuses on further evaluation of groundwater quality, identification of additional water supply sources, and evaluation of alternative well management approaches was initiated in early 2011.

An evaluation of groundwater quality data obtained in 2010 and 2011 is summarized in the *HU 2010 and 2011 Water Quality Summary Technical Memorandum (*hereafter referred to as the *Water Quality Summary TM).* This data was evaluated to identify additional water supply sources around the City of Hastings (City). Based on an initial review of nitrate levels and the existing distribution configuration, three areas surrounding the City were identified for further evaluation.

Nitrate Skimming and Aquifer Storage Recovery (ASR) were identified as two well management approaches to potentially improve water quality. With Nitrate Skimming, nitrate, which is typically present in a higher concentration at the groundwater surface, is skimmed off with a submersible pump and then either sent to waste or treated.

ASR, where water is stored underground and then recovered when it is needed, is becoming a common method of water resource management in the United States. Although the City has an abundance of groundwater, most of this water is contaminated with nitrate to some extent. As such, a form of ASR called 'Pump-Treat-Recharge' was selected for further evaluation. With 'Pump-Treat-Recharge', wells with high levels of nitrate would be pumped extensively, the resultant water would then be treated to a lower nitrate level, and then pumped into several recharge wells. This recharged treated water could then serve as a barrier for other wells to prevent further nitrate contamination.

The HU Groundwater Model was used to evaluate the Nitrate Skimming and 'Pump-Treat-Recharge' concepts for the City. The objective of this technical memorandum (TM) is to discuss this evaluation and the evaluation of additional water supply sources based on water quality data. Groundwater Model results as well as preliminary treatment comparison and evaluation, preliminary management approach, and preliminary opinion of probable construction costs are discussed.

1.0 BACKGROUND

Key components of the Plan and other items relevant to this TM including future water demand, water quality parameters of concern, the Groundwater Model, treatment and residual evaluation, and the proposed Westbrook WTP are discussed below.

1.1 Future Water Demands

The service population for the HU water supply system is expected to increase gradually, from the current population of about 25,100 to a future population of 27,900 in the year 2030 or at a rate of 0.5% a year. Projected average day, maximum day, peak hour demands in million gallons per day (MGD), and corresponding populations are shown in Table 1.1.

TABLE 1.1 – CITY OF HASTINGS FUTURE WATER DEMANDS (MGD)

Year	Service Population[1]	Average Day Total[2]	Maximum Day Total[3]	Peak Hour Total[4]
2009 (Actual)	25,100	6.35	15.50	Unavailable
2010	25,226	7.46	24.69	31.71
2015	25,862	7.71	25.53	32.79
2020	26,516	7.97	26.38	33.87
2025	27,185	8.22	27.22	34.95
2030	27,872	8.48	28.06	36.03

Note: Out-City Users are assumed to be included in trend line projections

[1] Includes residential population outside City limits

[2] Based on Trend Line projections

[3] Maximum Day/Average Day = 3.31

[4] Peak Hour/Average Day = 4.25

1.2 Water Quality Parameters of Concern

Key water quality parameters of concern identified in the Plan are shown in Table 1.2. As shown, arsenic, gross alpha, lead, and atrazine were identified as primary contaminants of concern. Blended nitrate, the primary contaminant of concern, is projected to increase to between 12.7 mg/L and 15.4 mg/L by 2030 depending on wells used to meet water demands. This exceeds the current Safe Drinking Water Act (SDWA) Maximum Contaminant Level (MCL) of 10 mg/L. Arsenic was also identified as a parameter of concern. Based on limited data available, the arsenic MCL could be exceeded in several wells by 2030. Total dissolved solids (TDS) was identified as a secondary contaminant of concern. Hardness, although not regulated, was included due to the high level and potential effect of scaling on kitchen and bathroom fixtures. Although Synthetic Organic Chemicals (SOCs) such as atrazine and other herbicides and pesticides are not listed in Table 1.2, these were also mentioned in the Plan as they could potentially become parameters of concern in the future.

During the summer of 2011, 42 wells were sampled and analyzed for uranium. Uranium levels in these wells ranged from 1.22 to 74.8 µg/L. Six wells located primarily north of Well 33 had uranium levels above the MCL of 30 µg/L (41.9, 45.3, 54.2, 57.7, 62.0, and 74.8 µg/L). As a result of this analysis, uranium was added to the list of water quality parameters of concern.

TABLE 1.2 – WATER QUALITY PARAMETERS OF CONCERN

Parameter	2007 Study Blended	2030 Projected Blended	MCL	Comments
Nitrate (mg/L as N)	10.5	12.7-15.4	10	
Arsenic (µg/L)	1.9	9.6	10	•If true linear relationship, MCL exceeded in Well 22 by 2025 and Wells 1, 4, 8, 19, 24, and 28 by 2030.
				•Limited arsenic data.
Gross Alpha (pCi/L)	6.2	6.8	15	•MCL exceeded in Wells 1 and 35 in 2009.
				•Based on limited data, general increase over time.
				•More data needed.
Lead (µg/L)	1.2	1.3	15	•Occasional spikes over MCL – attributed to sample fixtures.
				•Levels reduced after newer sampling fixtures added.
Total Dissolved Solids (mg/L)	343	378	Secondary-500	•Fluctuating but overall increase.
				•Several wells could approach 500 mg/L by 2030.
Hardness (mg/L as $CaCO_3$)	224	364	None	•General increase over time.
				•If true linear relationship, hardness could go as high 575 mg/L as $CaCO_3$ in Well 33.
Uranium (µg/L)	NIA	NIA	30	•Identified as contaminant of concern in 2011. Need to collect more data.

1.3 Treatment and Residual Evaluation

Both ion exchange (IX) and reverse osmosis (RO) were determined to be viable primary treatment technologies for nitrate removal in the Plan. RO was identified as a more versatile technology, capable of removing a wider range of contaminants and requiring less operator attention than IX. IX with anion exchange resin was identified as the best treatment approach if nitrate is the only contaminant of concern. Overall treatment processes, pre-and post-treatment requirements, residual wastewater quantity and quality, and capital costs for both treatment technologies are included in the Plan.

As uranium was identified as a water quality parameter of concern after the development of the Plan, the ability of treatment technologies to remove uranium was not evaluated prior to this TM. This evaluation is summarized in Section 5.0 of this TM.

1.3.1 Residual Water Quality

Direct discharge to surface water, indirect discharge to surface water via the Hastings Water Pollution Control Center (WPCC), evaporation ponds, and blending for agricultural or irrigation reuse were evaluated in the Plan. Based on preliminary evaluations, it is anticipated that some residual waste may be sent to the WPCC and some may be used for irrigation purposes. However, these disposal options are limited. It is estimated that approximately 0.21 to 0.66 MGD RO residual waste (limited by selenium)

and 0.025 to 0.052 MGD IX residual waste (limited by chloride) could potentially be disposed of at the WPCC. However, this disposal option requires further evaluation based on WPCC operations and future nitrate standards that may eliminate this disposal option completely.

The primary recommendation made in the Plan was to send the residual waste to an evaporation pond with disposal to the WPCC and irrigation purposes as allowed.

As mentioned above, uranium was identified as a water quality parameter of concern after the development of the Plan. As uranium above certain concentrations is classified as hazardous, disposal of concentrate or brine will require further evaluation. A general disposal discussion is presented in Section 6.0.

1.4 Groundwater Model

As part of the Plan, HDR developed a groundwater flow and solute transport (nitrate) model as a tool to estimate the future nitrate concentrations in individual production wells. The groundwater and solute transport model is presented in the *HU Groundwater Modeling Study TM Phase II (2011)*. The purpose of the model was to evaluate the impact of changes in the pumping distribution on nitrate concentrations in individual wells and to evaluate several well field management alternatives.

A critical component of the modeling process involved interpretation of approximately 500 groundwater samples collected during the summer of 2010 for analysis of nitrate in groundwater. The groundwater samples were collected from irrigation, domestic, and municipal wells located within HU's well head protection area (WHPA). The results of the nitrate sampling effort were interpreted by HDR to develop an isoconcentration map for nitrate. The isoconcentration map represents the nitrate concentrations in the Pleistocene aquifer as measured in July and August 2010. These data were used to represent the initial conditions in the solute transport model. The Groundwater Model was constructed to reflect the conservative nature of nitrate transport in groundwater.

1.5 Westbrook Water Treatment Plant

In 2008, nitrate levels at a key well (Well 33) for HU began to approach the SDWA MCL. As a result, a RO treatment plant was designed for the well site. The Westbrook Water Treatment Plant (WTP) construction was planned for the near future to remove nitrate from Well 33 raw water. The plant was designed to treat an adjustable portion of the well flow with a raw water nitrate level as high as 15 mg/L as N (nitrate references hereafter shown as 'mg/L' instead of 'mg/L as N') to achieve a finished blended water nitrate level between 6 and 8 mg/L as N. The plant was anticipated to be built in two phases. The first phase of the Westbrook WTP would provide approximately 1.4 million gallons per day (MGD) or 1,000 gallons per minute (gpm) of water treatment based on the feed water capacity. The total final finished water capacity of the Westbrook WTP was designed for approximately 3.5 MGD (2,450 gpm).

As a result of the October 2010 HU Board Meeting, Westbrook WTP construction was postponed until the nitrate management concepts could be further studied. With the evaluation of new nitrate management approaches, the need and location of the Westbrook WTP is uncertain. In addition, the need for RO treatment compared to other nitrate removal technologies is uncertain.

2.0 NITRATE SKIMMING

2.1 Overview

In 2009, HU experimented with changing the pump suction setting depth in Well 33 as an attempt to manage nitrate concentrations in this well. The results of this study, which consisted of a down-hole spinner flow meter survey and depth specific interval sampling, are summarized in a letter report developed by Layne Christensen (Layne, 2009). The results of the study indicated that 40 to 50 percent of the total well flow rate entered through the top 10 feet of the screen interval. Well 33 is screened near the bottom of the aquifer, from 205 to 235 feet below ground surface (bgs). The results of the study indicate that the concentration of nitrate entering the well screen varied by depth, as summarized in the Table 2.1.

TABLE 2.1 – WELL 33 DEPTH SPECIFIC NITRATE SAMPLE RESULTS

Depth of Water Quality Sample (feet below top of pump pedestal)	Nitrate Concentration (mg/L)
205	13.9
207	13.8
220	4.1
234	2.0
Well Discharge (February 5, 2009)	**6.1**

Given the observations from the pilot study, HU implemented a second pilot scale project (nitrate skimming pilot) in early 2011. The nitrate skimming pilot test consisted of the installation of a small diameter submersible pump to capture the high concentration of nitrate entering Well 33 near the top of the well screen. The objective of the nitrate skimming pilot test was to evaluate if this pumping modification would significantly reduce the nitrate concentration of the well discharge by pumping out the higher nitrate concentrations at the top of the screen.

2.2 Methodology

Prior to implementing the nitrate skimming pilot test, HDR and HU submitted plans and specifications to the Nebraska Department of Health and Human Services (NDHHS) to

modify the intake system of Well 33. The pilot program began operation in February 2011 upon receipt of NDHHS approval of plans and specifications.

Modifications to Well 33 included installation of a 2-inch diameter submersible pump, located adjacent to the 12-inch diameter drop pipe of the existing line shaft turbine pump. The submersible pump was installed with the suction intake located near the top of the well screen, approximately 205 to 207 feet below the top of the pump pedestal. During the pilot program, the submersible pump intake depth was periodically adjusted to evaluate the impact of depth on the concentration of nitrate removed by the pump. The submersible pump delivered approximately 60 gpm at the installed head conditions. The flow rate of Well 33 varied from 600 to 1,300 gpm during the testing program. The discharge piping of the submersible pump was routed through an existing access hole in the pump base and was routed to a sanitary sewer.

Water samples were collected on a regular basis throughout the length of the nitrate skimming pilot test. Nitrate concentrations for both the submersible pump and the discharge of Well 33 were monitored. During the initial months of the pilot, water samples were collected on a daily basis. Sample collection frequency decreased to a weekly interval during the final three months of the pilot program (June through August).

2.3 Results

The results of the nitrate skimming pilot test are shown on Figures 2.1 and 2.2. As shown on Figure 2.1, the highest concentration of nitrates removed by the submersible pump was observed when the intake of the submersible pump was set near the top of the well screen, between 205 and 207 feet below the top of the pump pedestal. At this depth, the influent nitrate concentrations in the submersible pump remained fairly constant at 16 to 17 mg/L and the nitrate concentration in the discharge of Well 33 ranged between 8.4 and 8.8 mg/L. When the submersible pump was lowered to a depth of 210.5 feet below the top of the pump pedestal, the nitrate concentrations in the submersible pump immediately declined to approximately 12 mg/L, and the concentration in the discharge of Well 33 slowly increased to over 9.0 mg/L. Based on these results, it was determined that the best location for nitrate skimming was 207 feet below the top of the pump pedestal.

During a period from mid June to the end of August, HU adjusted the pumping rate in Well 33 to evaluate the impact of pumping rate on nitrate concentrations in the well. Figure 2.2 illustrates that the pumping rate of Well 33 did not have much impact on the influent concentrations of either Well 33 or the submersible pump. These data suggest that the influent nitrate concentrations are not impacted by the pumping rate of Well 33, or the corresponding change in size of the cone of depression of the well. This suggests that the highest nitrate concentrations are located in a fairly narrow horizontal band within the aquifer, and are moving in the direction of Well 33.

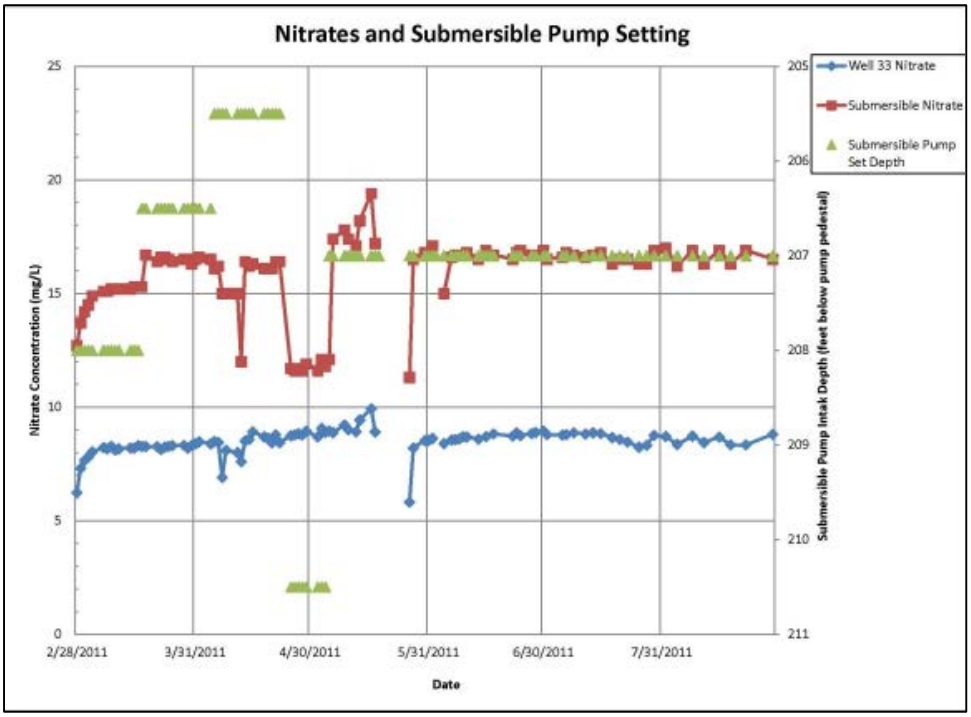

FIGURE 2.1 – NITRATE CONCENTRATIONS AND SUBMERSIBLE PUMP SETTING DEPTH

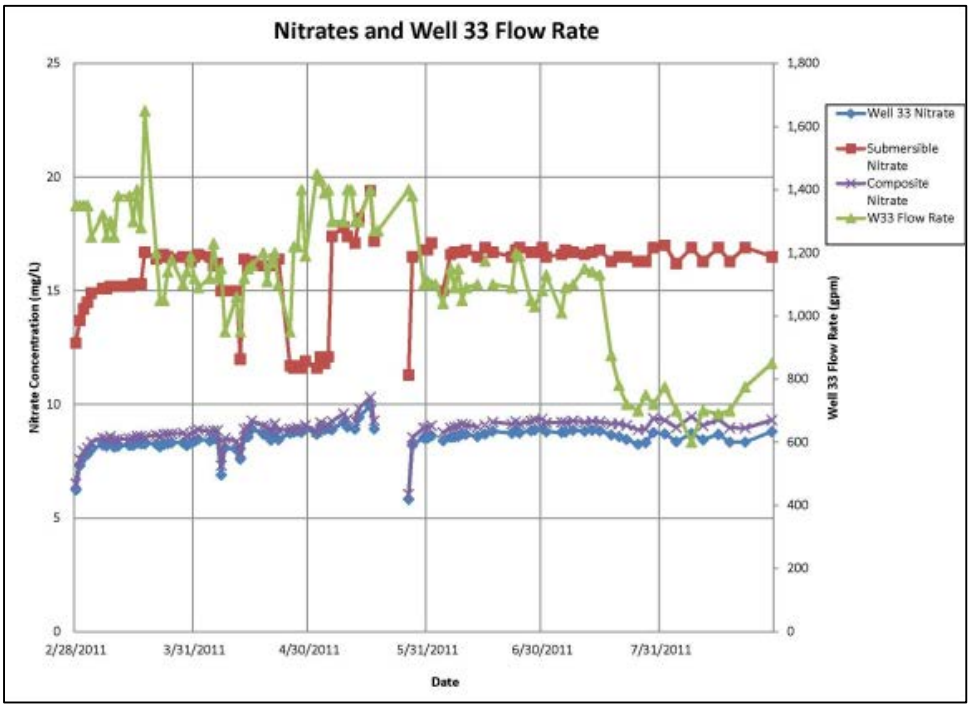

FIGURE 2.2 – NITRATE CONCENTRATIONS AND WELL 33 FLOW RATE

The largest reduction in the composite nitrate concentration of Well 33 occurred during the period from mid July through early September when the flow rate of Well 33 was reduced to between 600 and 800 gpm, while the pumping rate in the submersible pump remained at 60 gpm. During this period, the average concentration of the Well 33 discharge was approximately 8.5 mg/L while the average discharge concentration from the submersible pump was approximately 16.6 mg/L. Using the ratio of the pumping rates and concentrations over that period, the calculated equivalent concentration in the Well 33 discharge (assuming no submersible pump) was 9.1 mg/L, meaning the use of the nitrate-skimming pump reduced the effluent concentration in the well by 0.6 mg/L. For Well 33, decreasing the flow rate of the primary well pump did not result in a significant change in the nitrate concentration observed in the primary well pump. Therefore, the reduction in the composite nitrate concentration of the well occurred because the same concentration of nitrate, observed in the primary well pump, was produced at a lower flow rate.

2.4 Summary

The nitrate skimming pilot test successfully demonstrated that a low volume/high concentration stream of raw water can be intercepted by a second pump installed in a municipal well. This concept can be applied in the design of future wells or in the modification of existing wells. Based on the data collected from the Well 33 pilot test, it appears that the largest reduction in the composite nitrate concentration of the well was achieved when the pumping rate in the municipal well was reduced. The results of the pilot study show that the use of nitrate skimming is a viable alternative that can be used to reduce the volume of water that must be treated. This reduction in treated water requirement will reduce capital improvements costs, and thus operation and maintenance costs. The extent of this savings has not yet been quantified.

3.0 PUMP-TREAT-RECHARGE

3.1 Overview

The updated HU Phase II Groundwater Model was used to evaluate the feasibility of implementing the Pump-Treat-Recharge concept. The general concepts associated with the alternative are summarized below:

1. Select wells located along the upgradient (groundwater) side of Hastings would be used to intercept large quantities of nitrate-impacted water. The upgradient wells would consist of Well 33 and a new well or capture well, which would be strategically located to intercept an area of high nitrate concentration groundwater.
2. The raw groundwater would be treated to reduce nitrate concentrations to 2 or 5 mg/L.
3. Most or all of the treated water would be returned to the aquifer downgradient of the two pumping wells through several recharge wells. The recharged water

would migrate downgradient towards the other HU water supply wells, at the natural rate of groundwater flow. The recharged water would be recaptured by several HU water supply wells.

The primary benefit of the Pump-Treat Recharge concept is the development of a zone of treated water in the aquifer (recharge bubble) that forms over the first few years of system operation. In this concept, the aquifer provides a vast storage source for treated water. The treated water is then removed when needed by existing HU water supply wells.

With this well management option, water would need to be pumped from Well 33 and the capture well 365 days per year, 24 hours per day. This water would then need to be treated and injected continuously. This has the further benefit of only treating for average day demands, using the aquifer for storage and operating wells in the summer months as required to meet maximum day conditions.

Several irrigation wells are located within the area where the treated recharge bubble will develop. The removal of these irrigation wells may be necessary to ensure that the treated groundwater is only removed by HU wells. Removal of irrigation wells as a result of this project may require HU to provide an alternative water source to replace the irrigation water. This alternative source could include a variety of replacement sources, including untreated water pumped from the upgradient pumping wells.

3.2 Methodology

The purpose of the Pump-Treat-Recharge model simulations was to evaluate the feasibility of this well field management strategy to protect and improve the water quality of existing HU wells. The model simulations were developed to conceptually demonstrate viability only and do not represent system final design. If adopted, a final Pump-Treat-Recharge system could be a scaled up or scaled down version of what is presented below.

The Pump-Treat-Recharge option was developed assuming Well 33 and a new well (Capture Well) would be used to intercept the high nitrate groundwater. Model simulations were performed using a 1,500 gpm (2.16 MGD) flow rate for Well 33 and a 2,000 gpm (2.88 MGD) flow rate for the Capture Well. As the purpose of these two wells would be to intercept as much nitrate impacted water as possible, the wells were assumed to operate 24 hours per day, 7 days per week, at a high well yield.

Model simulations were performed assuming treated effluent levels of 2 and 5 mg/L. The treated water was recharged into the aquifer using seven (7) wells, each with a recharge rate of 500 gpm. The seven (7) recharge wells to two (2) pumping wells ratio was selected for the model simulations based on aquifer storage and recovery (ASR) rules of thumb that indicate the recharge capacity of a well is typically between three (3) to four (4) times less than the pumping capacity of a well (Pyne, 1995). For the purposes of this study, it was assumed that 100 percent of the pumped water would be treated and

returned to the aquifer through the recharge wells. This assumption does not account for treatment system recovery (i.e. not all water will be recovered after treatment). Upon selection of a water treatment technology, the Pump-Treat-Recharge model will be updated to reflect the actual pumped and recharge volumes, which will account for the reject water of the selected treatment technology. The location of the recharge wells, and the results of the recharge particle tracking simulations are shown on Figure 3.1.

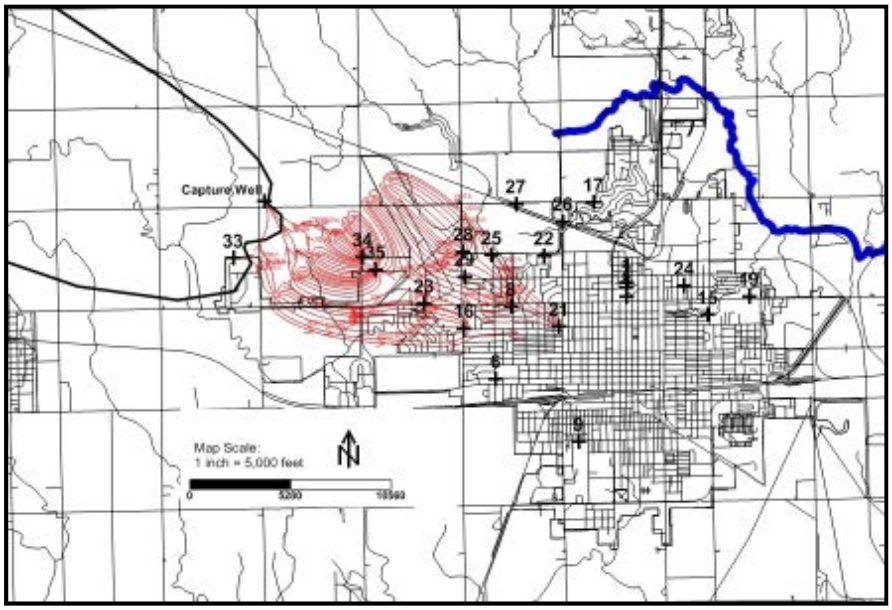

FIGURE 3.1 – MODEL PREDICTED RECHARGE PARTICLE TRACKING RESULTS - 20-YEAR TIME

The recharge wells, shown on Figure 3.1, were located to achieve the maximum benefit for existing HU wells, which are located downgradient of two pumping wells. Under the modeled scenario, the treated water would be recaptured by HU wells 8, 16, 21, 23, 25, 28, 29, 34, and 35 during the 20-year planning cycle. The model predicted time for treated water to first reach the downgradient HU wells is summarized in Table 3.1.

TABLE 3.1 – TIME FOR TREATED RECHARGE WATER TO REACH DOWNGRADIENT WELL

Well Number	Time for Treated Recharge Water to
8	9 years
16	11 years
21	13 years
23	9 years
25	7 years
28	4 years
29	6 years
34	1 year
35	2 years

The model predicted future nitrate concentrations at each HU well were tracked by the groundwater model for both the 2 mg/L and 5 mg/L Pump-Treat-Recharge scenarios. The results of these analyses are shown on Figures 3.2 and 3.3. Although it would take several years for the treated water to reach the downgradient HU water supply wells, the benefit of the Pump-Treat-Recharge option is predicted to occur very quickly due to the addition of the Capture Well. The Capture Well is located downgradient of the highest nitrate concentrations. Operation of both the Capture Well and Well 33 effectively protects the other existing HU wells from the zone of high nitrate concentration groundwater that is located upgradient of these two wells (Figure 3.4).

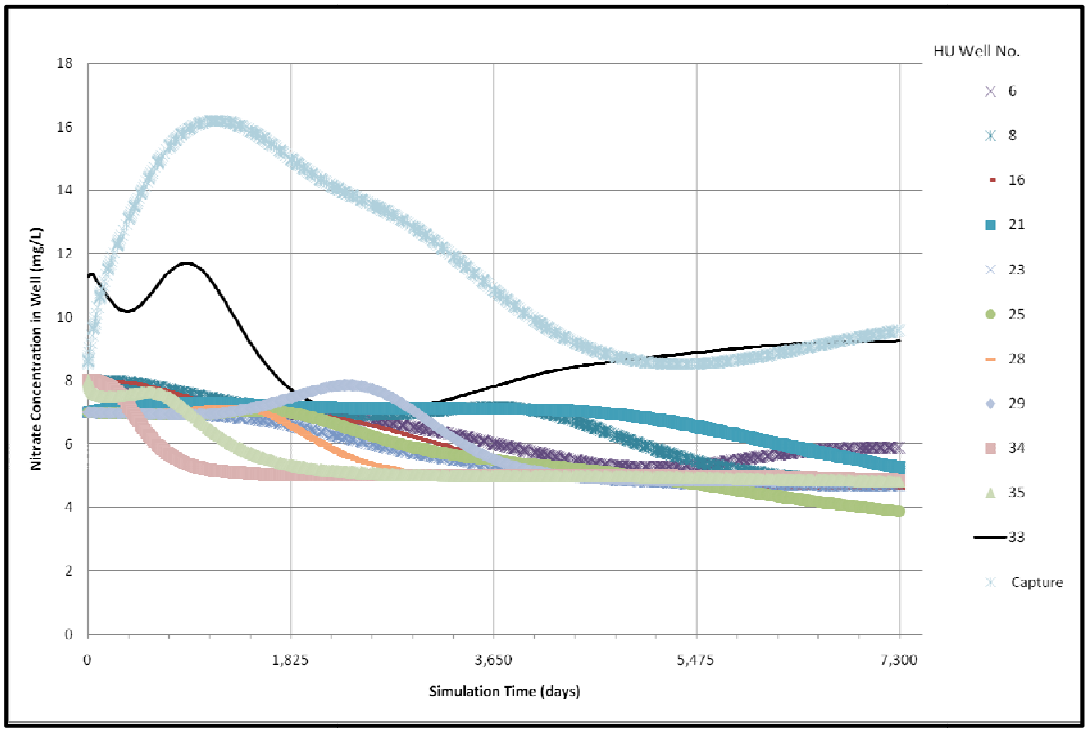

FIGURE 3.2 – MODEL PREDICTED NITRATE CONCENTRATIONS IN DOWNGRADIENT RECOVERY WELLS FOR 5 MG/L RECHARGE SIMULATION

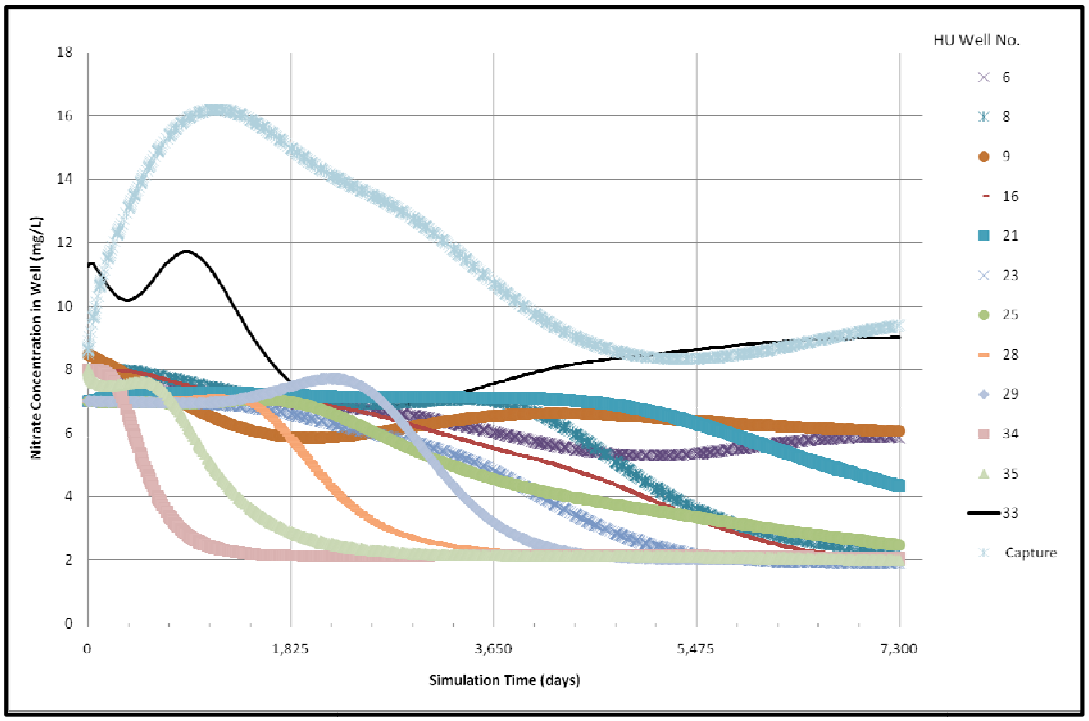

FIGURE 3.3 – MODEL PREDICTED NITRATE CONCENTRATIONS IN DOWNGRADIENT RECOVERY WELLS FOR 2 MG/L RECHARGE SIMULATION

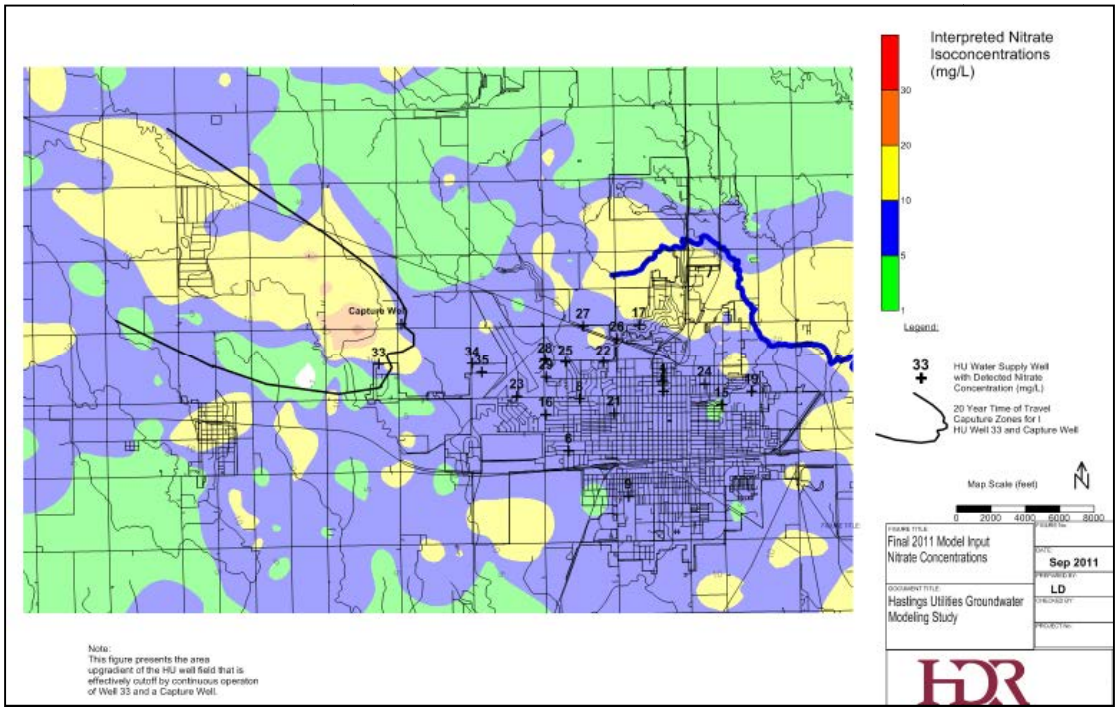

FIGURE 3.4 – CAPTURE ZONES FOR WELL 33 AND CAPTURE WELL

3.3 Groundwater Model Run Results

As mentioned, the Groundwater Model was used to predict nitrate concentrations in HU wells over a 20-year period. Four different scenarios were evaluated and are described in Table 3.2. In Scenario 1, all currently active wells were evaluated assuming a treated injected water nitrate concentration of 5 mg/L. In Scenario 2, Wells 31 and 32 were added. Although these wells are currently out of service, they are located in the Lochland area and sampling data obtained in 2010 showed lower nitrate levels in this area. Wells used for Scenario 1 and 2 analysis were also used for Scenarios 3 and 4, respectively. However, in Scenarios 3 and 4, a treated injected water nitrate concentration of 2 mg/L was assumed.

All projections presented in this section are based on the assumption that no additional nitrates are being added to the aquifer. Although this assumption is not realistic, it is believed that the rate of new contamination can be lowered through water conservation and best management practices. These concentrations will need to monitored and adjustments made if nitrate levels approach or exceed the MCL.

TABLE 3.2 – MODEL EVALUATION RESULT SCENARIOS

Scenario	Wells Included	Treated Injected Water Nitrate Concentration (mg/L as N)
1	1,2,4,6,8,9,15,16,17,19,21,22,23 ,24,25,26,27,28,29,34,35	5
2	Same as Scenario 1 + 31 & 32	5
3	Same as Scenario 1	2
4	Same as Scenario 1 + 31 & 32	2

The projected nitrate levels were then used to determine total well capacity available for potable water use if wells with nitrate levels greater than 8 mg/L are eliminated on a yearly basis. This total well capacity available for potable water use was then compared to peak hour demand to determine whether ground storage and high service pumping would be required to meet these needs.

During the development of this report, 2011 sampling data revealed that nitrate levels in the Lochland area were much higher than those obtained during 2010 sampling. As the projected peak capacity of Wells 31 and 32 is lower than other HU wells, Scenarios 2 and 4 were eliminated from further consideration and are not discussed below. Modeled data for these eliminated scenarios can be found in Appendix A.

3.3.1 Well 33 and Capture Well

Projected nitrate levels in Well 33 and the Capture Well from 2012 to 2031 are shown in Table 3.3. As shown, the maximum projected nitrate level is 11.7 mg/L for Well 33 and 16.2 mg/L for the Capture Well regardless of treated and injected nitrate level. The minimum nitrate level in Well 33 is decreased from 7.1 to 6.9 mg/L when the treated and

injected nitrate level is reduced from 5 to 2 mg/L. Similarly, the minimum nitrate level in the Capture Well is decreased from 8.6 to 8.4 mg/L when the treated and injected nitrate level is reduced from 5 to 2 mg/L.

TABLE 3.3 – WELL 33 AND CAPTURE WELL NITRATE LEVELS IN MG/L (TREAT AND INJECT AT 5 MG/L VERSUS 2 MG/L)

	Treat and Inject at 5 mg/L		Treat and Inject at 2 mg/L	
Year	Well 33	Capture Well	Well 33	Capture Well
2012	11.4	12.9	11.4	12.9
2013	11.4	15.3	11.4	15.3
2014	11.7	16.2	11.7	16.2
2015	11.2	16.2	11.2	16.2
2016	9.2	15.9	9.1	15.9
2017	7.7	15.0	7.6	15.0
2018	7.1	14.2	7.0	14.1
2019	7.2	13.6	6.9	13.5
2020	7.4	12.9	7.2	12.8
2021	7.8	11.9	7.5	11.8
2022	8.2	10.9	7.9	10.7
2023	8.4	9.9	8.2	9.8
2024	8.6	9.2	8.3	9.0
2025	8.7	8.8	8.5	8.6
2026	8.9	8.6	8.6	8.4
2027	9.0	8.6	8.8	8.5
2028	9.1	8.9	8.9	8.7
2029	9.2	9.1	8.9	8.9
2030	9.2	9.4	9.0	9.2
2031	9.2	9.6	9.0	9.4
Minimum:	**7.1**	**8.6**	**6.9**	**8.4**
Maximum:	**11.7**	**16.2**	**11.7**	**16.2**

3.3.2 Scenario 1 Results

Projected nitrate levels by well for Scenario 1, where water is treated to 5 mg/L and then reinjected, are summarized in Table 3.4. Nitrate levels greater than 8 and 10 mg/L are highlighted in yellow and red, respectively. Maximum, minimum, average, and blended nitrate for all wells (excluding Well 33 and the Capture Well) are also shown in the table. Key findings are summarized below.

- The projected maximum nitrate level ranges between 9.4 and 12.9 mg/L. The projected minimum nitrate level starts at 7.0 in 2012 and steadily decreases to 2.6 mg/L in 2031. Similarly, the projected average nitrate level starts at 7.6 mg/L and steadily decreases to 6.0 mg/L in 2031.
- If wells with nitrate levels greater than 8 mg/L are eliminated on a yearly basis and no blending is conducted, the total well capacity is projected to range between 30 MGD (2013, 2014, and 2016) and 36.2 MGD (2031) or average 32.1 MGD over the 18-year period. This is below the 2030 projected peak hour demand of 36 MGD. Thus, storage and high service pumping would be required to meet this demand.

- When all wells are blended, regardless of the nitrate level, the nitrate level starts at 7.6 mg/L in 2012 and decreases to 5.8 mg/L in 2031. Total well capacity for all wells is 41.5 MGD.

3.3.3 Scenario 3 Results

Projected nitrate levels by well for Scenario 3, where water is treated to 2 mg/L and then reinjected, are summarized in Table 3.5. Key findings are summarized below.

- The projected maximum nitrate level ranges between 9.9 and 12.9 mg/L.
- The projected minimum nitrate level does not steadily decrease with this Scenario. Instead, it decreases for 4 years, increases for 5 years, and then steadily decreases until 2031 when the end result is 1.9 mg/L.
- If wells with nitrate levels greater than 8 mg/L are eliminated on a yearly basis and no blending is conducted, the total well capacity is projected to range between 30.5 MGD (2013 and 2014) and 37.4 MGD (2031) or average 33.2 MGD over the future time period. As this capacity is below the 2030 projected peak hour demand of 36 MGD, storage and high service pumping would be required to meet this demand.
- When all wells are blended, regardless of the nitrate level, the nitrate level starts at 7.7 mg/L in 2012 and decreases to 5.7 mg/L in 2031. As mentioned in Scenario 1, the total well capacity for all wells is 41.5 MGD.

TABLE 3.4 – SCENARIO 1 (ACTIVE WELLS NOT INCLUDING 31 AND 32, 5 MG/L INJECTION)

Well	Nominal Flow Rate (gpm)	Nominal Flow Rate (MGD)	Nitrate Level (mg/L as N)																			
			2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
1	750	1.1	7.0	6.5	6.5	6.6	6.8	7.1	7.5	7.9	8.2	8.5	8.9	9.2	9.4	9.4	9.4	9.2	8.8	8.4	7.9	7.4
2	1200	1.7	7.0	6.5	6.4	6.5	6.6	6.9	7.2	7.6	7.9	8.1	8.4	8.7	9.0	9.1	9.1	9.0	8.8	8.5	8.1	7.6
4	1100	1.6	7.0	6.5	6.4	6.4	6.5	6.6	6.7	7.0	7.2	7.5	7.7	7.9	8.2	8.4	8.5	8.5	8.5	8.4	8.2	7.9
6	1000	1.4	8.0	7.8	7.5	7.2	7.1	7.0	6.9	6.7	6.5	6.3	6.0	5.7	5.5	5.3	5.3	5.5	5.7	5.8	5.9	5.9
8	2000	2.9	8.0	8.0	7.7	7.5	7.2	7.0	6.9	7.0	7.1	7.2	7.2	7.1	6.7	6.3	5.8	5.5	5.2	5.0	4.9	4.8
9	1000	1.4	8.5	7.8	7.1	6.5	6.1	5.9	6.0	6.2	6.4	6.5	6.6	6.6	6.6	6.6	6.5	6.4	6.3	6.2	6.2	6.1
15	900	1.3	7.0	6.5	6.5	6.6	6.7	6.9	7.1	7.2	7.3	7.3	7.4	7.5	7.6	7.8	8.1	8.4	8.8	9.2	9.5	9.8
16	1000	1.4	8.0	7.9	7.6	7.3	7.1	7.0	6.8	6.6	6.2	5.9	5.5	5.2	5.0	4.9	4.7	4.7	4.6	4.6	4.6	4.6
17	1000	1.4	9.4	10.8	11.4	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.8	9.1	8.7	8.3	7.8	7.3	6.7	6.1	5.4	4.9
19	1000	1.4	8.0	8.8	9.6	10.1	10.2	10.2	9.8	9.3	9.0	9.2	9.6	10.1	10.6	11.2	11.8	12.3	12.6	12.8	12.9	12.9
21	1000	1.4	7.2	7.3	7.3	7.3	7.2	7.2	7.1	7.1	7.1	7.1	7.1	7.1	7.0	6.9	6.8	6.6	6.3	6.0	5.7	5.5
22	1750	2.5	7.5	8.1	8.3	8.3	8.1	7.9	8.0	8.0	8.0	7.8	7.5	7.1	6.7	6.4	6.0	5.5	5.1	4.6	4.2	3.8
23	1800	2.6	7.0	7.0	6.9	6.9	6.8	6.6	6.3	6.0	5.7	5.5	5.3	5.1	5.0	4.9	4.8	4.8	4.7	4.7	4.7	4.7
24	1800	2.6	8.1	8.4	8.4	8.4	8.4	8.3	8.3	8.4	8.7	9.2	9.9	10.6	11.2	11.7	11.9	12.0	11.9	11.7	11.4	10.9
25	1250	1.8	7.0	7.0	7.0	7.0	7.1	7.0	6.7	6.3	5.9	5.7	5.5	5.4	5.2	5.1	4.9	4.7	4.5	4.4	4.2	4.0
26	1250	1.8	8.3	8.5	8.4	8.0	8.5	9.0	9.3	9.3	9.3	9.0	8.6	8.2	7.7	7.2	6.6	6.0	5.3	4.7	4.1	3.6
27	1250	1.8	7.7	8.6	9.2	9.3	9.2	8.8	8.3	7.9	7.4	7.0	6.4	5.9	5.3	4.6	4.1	3.6	3.2	3.0	2.8	2.6
28	1750	2.5	7.0	7.1	7.2	7.2	7.1	6.6	5.9	5.4	5.1	5.0	5.0	5.0	4.9	4.9	4.9	4.9	4.8	4.8	4.8	4.8
29	1750	2.5	7.0	7.0	6.9	7.1	7.4	7.8	7.9	7.7	7.1	6.2	5.5	5.1	5.0	4.9	4.9	4.9	4.8	4.8	4.8	4.8
34	2150	3.1	8.0	7.2	5.7	5.2	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.9
35	2150	3.1	8.0	7.6	7.5	6.5	5.7	5.3	5.1	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.9	4.9	4.9	4.8
31	400	0.6	11.5	10.0	8.5	7.2	6.2	5.5	5.2	5.4	5.4	5.4	5.3	5.0	4.5	4.0	3.5	3.0	2.6	2.2	2.0	1.9
32	400	0.6	4.1	3.7	3.2	3.0	3.6	4.4	4.9	5.1	5.1	4.8	4.3	3.7	3.0	2.5	2.1	1.7	1.5	1.6	1.9	2.5
33			11.4	11.4	11.7	11.2	9.2	7.7	7.1	7.2	7.4	7.8	8.2	8.4	8.6	8.7	8.9	9.0	9.1	9.2	9.2	9.2
Capture Well			12.9	15.3	16.2	16.2	15.9	15.0	14.2	13.6	12.9	11.9	10.9	9.9	9.2	8.8	8.6	8.6	8.9	9.1	9.4	9.6
Maximum Nitrate, All Wells:			9.4	10.8	11.4	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.9	10.6	11.2	11.7	11.9	12.3	12.6	12.8	12.9	12.9
Minimum Nitrate, All Wells :			7.0	6.5	5.7	5.2	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.6	4.1	3.6	3.2	3.0	2.8	2.6
Average Nitrate, All Wells:			7.6	7.7	7.6	7.5	7.5	7.4	7.4	7.3	7.2	7.1	7.0	7.0	6.9	6.8	6.8	6.6	6.5	6.4	6.2	6.0
Blended Nitrate, All Wells:			7.6	7.6	7.5	7.4	7.3	7.3	7.2	7.1	7.0	6.9	6.8	6.8	6.7	6.6	6.5	6.4	6.3	6.1	6.0	5.8
Well Capacity (Wells with Nitrate < 8 mg/L, MGD):			34.3	30.0	30.0	31.8	30.0	32.5	32.5	34.3	33.2	31.5	31.5	31.5	31.7	31.7	31.8	31.8	31.8	31.8	32.9	36.2

TABLE 3.5 – SCENARIO 3 (ACTIVE WELLS NOT INCLUDING 31 AND 32, 2 MG/L INJECTION)

Well	Nominal Flow Rate (gpm)	Nominal Flow Rate (MGD)	Nitrate Level (mg/L as N)																		
			2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
1	750	1.1	7.0	6.5	6.5	6.6	6.8	7.1	7.5	7.9	8.2	8.5	8.9	9.2	9.4	9.4	9.4	9.2	8.8	8.4	7.9	7.4
2	1200	1.7	7.0	6.5	6.4	6.5	6.6	6.9	7.2	7.6	7.9	8.1	8.4	8.7	9.0	9.1	9.1	9.0	8.8	8.5	8.1	7.6
4	1100	1.6	7.0	6.5	6.4	6.4	6.5	6.6	6.7	7.0	7.2	7.5	7.7	7.9	8.2	8.4	8.5	8.5	8.5	8.4	8.2	7.9
6	1000	1.4	8.0	7.8	7.5	7.2	7.1	7.0	6.9	6.7	6.5	6.3	6.0	5.7	5.5	5.3	5.3	5.5	5.7	5.8	5.9	5.9
8	2000	2.9	8.0	8.0	7.7	7.5	7.2	7.0	6.9	7.0	7.1	7.2	7.2	7.1	6.7	6.3	5.8	5.5	5.2	5.0	4.9	4.8
9	1000	1.4	8.5	7.8	7.1	6.5	6.1	5.9	6.0	6.2	6.4	6.5	6.6	6.6	6.6	6.6	6.5	6.4	6.3	6.2	6.2	6.1
15	900	1.3	7.0	6.5	6.5	6.6	6.7	6.9	7.1	7.2	7.3	7.3	7.4	7.5	7.6	7.8	8.1	8.4	8.8	9.2	9.5	9.8
16	1000	1.4	8.0	7.9	7.6	7.3	7.1	7.0	6.8	6.6	6.2	5.9	5.5	5.2	5.0	4.9	4.7	4.7	4.6	4.6	4.6	4.6
17	1000	1.4	9.4	10.8	11.4	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.8	9.1	8.7	8.3	7.8	7.3	6.7	6.1	5.4	4.9
19	1000	1.4	8.0	8.8	9.6	10.1	10.2	10.2	9.8	9.3	9.0	9.2	9.6	10.1	10.6	11.2	11.8	12.3	12.6	12.8	12.9	12.9
21	1000	1.4	7.2	7.3	7.3	7.3	7.2	7.2	7.1	7.1	7.1	7.1	7.1	7.1	7.0	6.9	6.8	6.6	6.3	6.0	5.7	5.5
22	1750	2.5	7.5	8.1	8.3	8.3	8.1	7.9	8.0	8.0	8.0	7.8	7.5	7.1	6.7	6.4	6.0	5.5	5.1	4.6	4.2	3.8
23	1800	2.6	7.0	7.0	6.9	6.9	6.8	6.6	6.3	6.0	5.7	5.5	5.3	5.1	5.0	4.9	4.8	4.8	4.7	4.7	4.7	4.7
24	1800	2.6	8.1	8.4	8.4	8.4	8.4	8.3	8.3	8.4	8.7	9.2	9.9	10.6	11.2	11.7	11.9	12.0	11.9	11.7	11.4	10.9
25	1250	1.8	7.0	7.0	7.0	7.0	7.1	7.0	6.7	6.3	5.9	5.7	5.5	5.4	5.2	5.1	4.9	4.7	4.5	4.4	4.2	4.0
26	1250	1.8	8.3	8.5	8.4	8.0	8.5	9.0	9.3	9.3	9.3	9.0	8.6	8.2	7.7	7.2	6.6	6.0	5.3	4.7	4.1	3.6
27	1250	1.8	7.7	8.6	9.2	9.3	9.2	8.8	8.3	7.9	7.4	7.0	6.4	5.9	5.3	4.6	4.1	3.6	3.2	3.0	2.8	2.6
28	1750	2.5	7.0	7.1	7.2	7.2	7.1	6.6	5.9	5.4	5.1	5.0	5.0	5.0	4.9	4.9	4.9	4.9	4.8	4.8	4.8	4.8
29	1750	2.5	7.0	7.0	6.9	7.1	7.4	7.8	7.9	7.7	7.1	6.2	5.5	5.1	5.0	4.9	4.9	4.9	4.8	4.8	4.8	4.8
31	400	0.6	11.5	10.0	8.5	7.2	6.2	5.5	5.2	5.4	5.4	5.4	5.3	5.0	4.5	4.0	3.5	3.0	2.6	2.2	2.0	1.9
32	400	0.6	4.1	3.7	3.2	3.0	3.6	4.4	4.9	5.1	5.1	4.8	4.3	3.7	3.0	2.5	2.1	1.7	1.5	1.6	1.9	2.5
34	2150	3.1	8.0	7.2	5.7	5.2	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.9
35	2150	3.1	8.0	7.6	7.5	6.5	5.7	5.3	5.1	5.1	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.9	4.9	4.9	4.8
33			11.4	11.4	11.7	11.2	9.2	7.7	7.1	7.2	7.4	7.8	8.2	8.4	8.6	8.7	8.9	9.0	9.1	9.2	9.2	9.2
Capture Well			12.9	15.3	16.2	16.2	15.9	15.0	14.2	13.6	12.9	11.9	10.9	9.9	9.2	8.8	8.6	8.6	8.9	9.1	9.4	9.6
Maximum Nitrate, All Wells:			11.5	10.8	11.4	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.9	10.6	11.2	11.7	11.9	12.3	12.6	12.8	12.9	12.9
Minimum Nitrate, All Wells :			4.1	3.7	3.2	3.0	3.6	4.4	4.9	5.0	5.0	4.8	4.3	3.7	3.0	2.5	2.1	1.7	1.5	1.6	1.9	1.9
Average Nitrate, All Wells:			7.7	7.6	7.4	7.3	7.2	7.2	7.2	7.1	7.0	7.0	6.8	6.8	6.6	6.5	6.4	6.3	6.1	6.0	5.8	5.7
Blended Nitrate, All Wells:			7.7	7.6	7.5	7.3	7.3	7.2	7.1	7.0	7.0	6.9	6.8	6.7	6.6	6.5	6.4	6.3	6.1	6.0	5.8	5.7
Well Capacity (Wells with Nitrate < 8 mg/L, MGD):			34.8	30.5	30.5	32.9	31.1	33.6	33.6	35.4	34.3	32.6	32.6	32.6	32.8	32.8	33.0	33.0	33.0	33.0	34.1	37.4

3.3.4 Scenario 1 Versus Scenario 3 (Treated Injected Water of 5 Versus 2 mg/L)

Maximum, minimum, and average nitrate levels for Scenarios 1 and 3 are graphically depicted in Figure 3.5. Key findings are summarized below.

- The maximum nitrate levels for both scenarios are basically the same (lines overlap one another on Figure 3.5).
- As would be expected, the minimum levels are higher for Scenario 1, where water is treated and reinjected at 5 mg/L.
- The average levels for both Scenarios 1 and 3 are approximately the same for 5 years but then are slightly higher for Scenario 1.

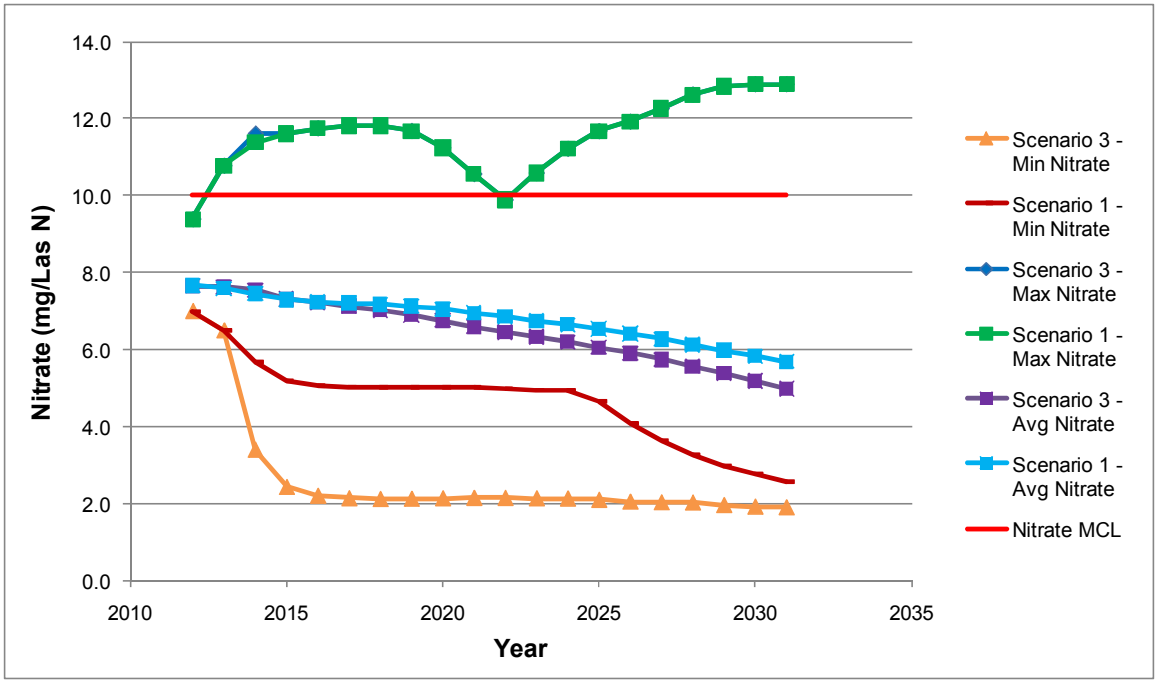

FIGURE 3.5 – SCENARIO 1 VERSUS 3 – MAXIMUM, MINIMUM, AND AVERAGE PROJECTED NITRATE

Projected 2030 peak hour demand, total capacity when all wells are in operation, and total capacity for Scenarios 1 and 3 wells with nitrate less than or equal to 8 mg/L are depicted in Figure 3.6. In Figure 3.7, blended nitrate levels for all wells and for wells with nitrate less than or equal to 8 mg/L are shown for both Scenarios 1 and 3. Key findings are summarized below.

- For both scenarios, the total available capacity when wells with nitrate concentration less than or equal to 8 mg/L are included is less that the projected 2030 peak hour demand (36 MGD). Thus, in order to meet this demand, storage and high service pumping would be needed.
- The curves for Scenario 1 and 3 are basically the same, suggesting that treating and reinjecting the water at 2 mg/L instead of 5 mg/L does not have any added benefit

with respect to capacity. Thus, the additional costs to treat the water to 2 mg/L is not justified.

- When all wells are in operation and are blended, a total of 41.5 MGD is available. As shown on Figure 3.7, when all wells are blended, the nitrate level is initially below 8 mg/L and continues to decrease over time.

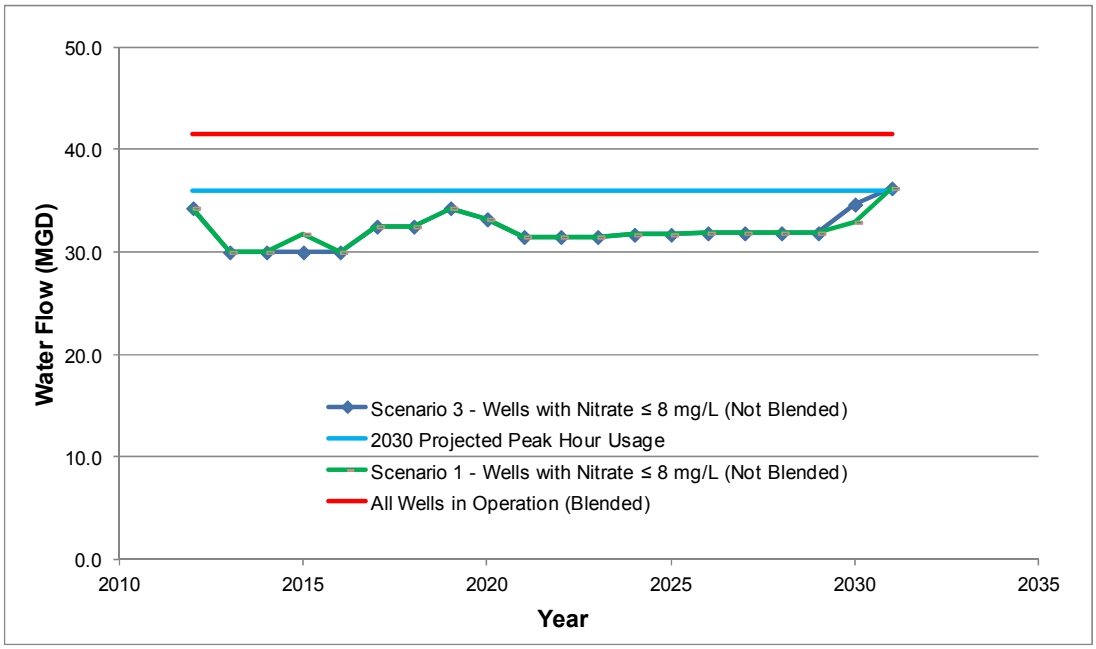

FIGURE 3.6 – SCENARIO 1 VERSUS 3 – PROJECTED WATER DEMAND AND TOTAL WELL CAPACITY

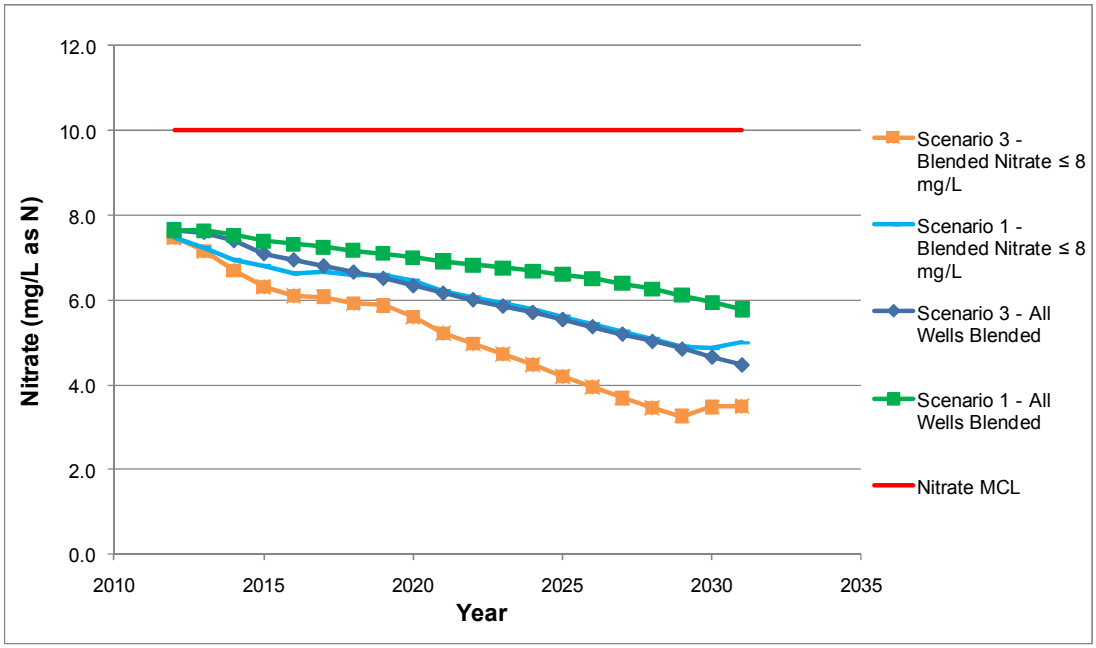

FIGURE 3.7 – SCENARIO 1 VERSUS – PROJECTED BLENDED NITRATE

3.4 Summary

Based on modeled data over a 20-year period, the Pump-Treat-Recharge well management approach could potentially be a viable alternative to protect HU wells from further nitrate contamination. However, the total available capacity when wells with nitrate concentration less than or equal to 8 mg/L are included is less that the projected 2030 peak hour demand (36 MGD). Thus, in order to meet this demand, storage and high service pumping would be required. With storage and high service pumping, all wells, regardless of nitrate concentration, could be blended and still produce water with nitrate less than 8 mg/L. Treating and reinjecting the water at 2 mg/L instead of 5 mg/L does not have any added benefit with respect to capacity.

It is recommended that additional modeling be performed to optimize the use of existing wells and/or the addition of new wells for nitrate capture. HU has expressed a desire to work with the local well owners and agricultural production facilities. It is important that any plan implemented allow for the continued operation of the agricultural facilities. Reuse of nitrate-contaminated waters for agricultural production is a viable treatment and disposal option. This concept combines aquifer management with an irrigation use plan.

4.0 POTENTIAL LOCATIONS FOR NEW GROUNDWATER WELLS

Based on the water quality analysis summarized in the Plan (i.e. prior to 2010), several areas were identified as potential locations for new wells for HU. These areas were initially selected as a result of the presence of lower nitrates based on the water quality data collected to date and/or the presence of existing wells that are not currently in use. These areas identified are summarized below.

- **Lochland** – The Lochland area is generally located north of the City of Hastings and has existing wells in the area which are not currently in use.
- **Trumbull** – Trumbull is located northeast of the City of Hastings. In 2006, HU constructed a transmission main north towards Trumbull to provide additional capacity to this area. The water main, placed into service in 2008, is 12 inches in diameter between Lochland Road and 94th Street and then decreases in size to 8 inches. At 94th Street, ownership of the water main changes from HU to Trumbull. This water main provides a potential to develop wells north of the Lochland area and possibly east towards Trumbull.
- **Juniata** – Juniata is generally located west of the City of Hastings. The area located southwest of Juniata appears to have lower nitrate levels.

In 2010 and 2011, additional water quality data including uranium, iron, and manganese was obtained. This data is summarized in the *Water Quality Summary TM*. Nitrate, uranium, and iron levels that are above 80-percent of their corresponding MCLs as of 2011 are depicted on Figure 4.1. As shown, nitrate and uranium levels above 80-percent of their corresponding MCLs were obtained in the Lochland area. Although nitrate levels

in the Trumbull area are lower than 8 mg/L (80-percent of the MCL), the iron levels are greater than 0.24 mg/L (80-percent of the secondary MCL for iron).

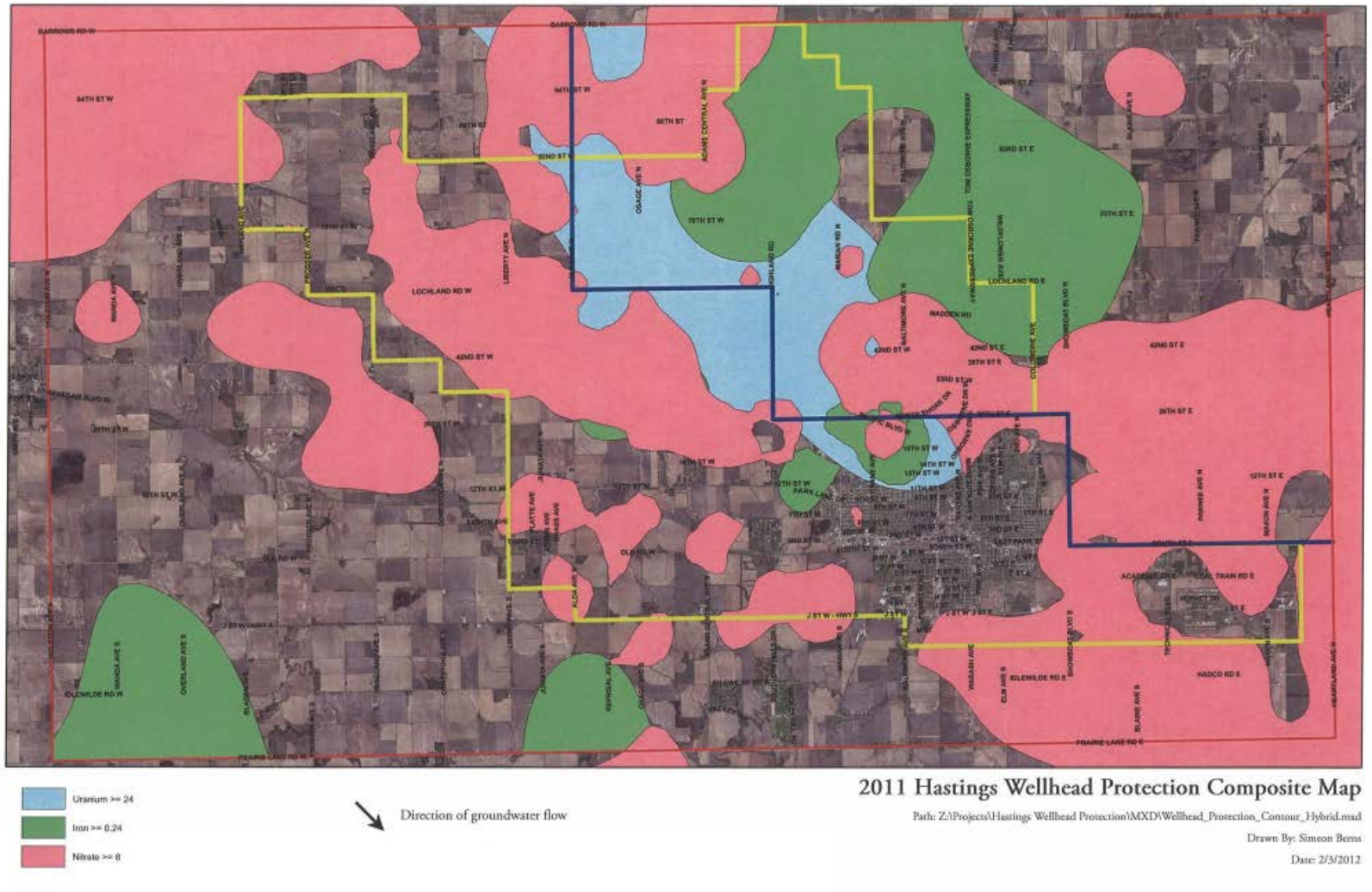

FIGURE 4.1 – 2011 HASTINGS WELLHEAD PROTECTION WATER QUALITY COMPOSITE MAP

Well capacity, piping needs, impact of wells on HU, withdrawal impacts, and treatment requirements associated with each of the aforementioned areas are discussed below. Updated water quality obtained in 2010 and 2011 as it relates to the continued viability of these areas for future well development is also discussed.

4.1 Well Capacity

4.1.1 Lochland

HU maintains two wells, Well 31 and 32, near the Lochland golf course. Well 31 was constructed in 1984 and Well 32 was constructed in 1971. Available well records indicate that these wells were capable of achieving flow rates between 450 and 700 gpm when first constructed. HU maintains the infrastructure associated with these wells and water rights associated with the wells, but does not actively pump the wells into distribution.

The hydrogeology near the Lochland golf course is significantly different from the hydrogeology on the west side of Hastings, near Wells 33, 34, and 35. The depth to the static water level in the aquifer in this area ranges from 110 to 120 ft bgs, while the depth to bedrock near the wells ranges from 162 and 166 ft bgs. These facts limit the saturated thickness of the aquifer near the Lochland wells to 40 to 50 feet, which is much less than the saturated thickness in the area of Wells 33, 34, and 35, which is approximately 120 feet. The decrease in the saturated thickness of the aquifer decreases the potential yield of a well as less saturated thickness reduces the transmissivity of the aquifer, and less saturated thickness reduces the available drawdown in the pumping well. Given the low transmissivity values and the limited available drawdown, it is estimated that the maximum pumping rate for a municipal well constructed in this area would be between 400 and 500 gpm.

4.1.2 Trumbull

With the recent construction of a water main north towards the Trumbull area, there is a potential for HU to construct additional wells north of the Lochland wells. The aquifer in the Trumbull area, north and east of the Lochland wells, has a slightly greater saturated thickness than the Lochland area. As a result, it is believed that wells in this area could be developed with a maximum pumping rate of approximately 700 gpm to 800 gpm.

4.1.3 Juniata

The hydrogeology west of Hastings, near Juniata, appears capable of sustaining well sites that can produce higher yields than Wells 33, 34, and 35. The saturated thickness of the aquifer near Juniata ranges between 120 to over 150 feet. This increase in saturated thickness, relative to the Well 33 area, results in an increase in the aquifer transmissivity, which is estimated to be between 150,000 to 200,000 gallons per day per foot (gpd/ft). This increase in both the saturated thickness and transmissivity of the aquifer should result in well sites that could produce higher pumping yields than those at Well 33.

Based on these observations, it is estimated that the maximum pumping rate for a municipal well constructed in this area would be between 1,500 and 2,000 gpm.

4.2 Piping and Hydraulics

With each of the alternative well locations, piping from the well(s) to the existing HU distribution system will be required. A preliminary evaluation of the piping needs for connection to the HU distribution system was conducted and is summarized below. If any of the alternatives are determined to be viable solutions further analysis of the hydraulic impacts to the system and the associated pump and piping requirements will need to be conducted.

4.2.1 Lochland

Connecting wells located in the Lochland area could be accomplished through the use of the existing water mains between County Road 81 (42nd Street) and County Road 82. The piping in this area consists of a looped piping system of 12-inch and 16-inch water mains which should be of adequate capacity to convey any water from the wells to the distribution system.

4.2.2 Trumbull

Currently there is a 12-inch water main that extends north from the City of Hastings along County Road 9-5W to the intersection of County Road 85 with an existing connection to the Trumbull system. If wells were developed closer to the Trumbull area, the existing lines and connection points between the Trumbull system and HU's system could potentially be used with the wells providing supply to both Trumbull and HU as needed.

4.2.3 Juniata

Connecting wells located southwest of Juniata to the HU distribution system would require extending a new water main from the wells east toward the existing HU distribution system. The existing HU distribution system hydraulic model was used to conduct a preliminary evaluation of required piping sizes and connections points. Based on this analysis, it was determined that to maintain a well pump head of approximately 130 psi and to best maintain system pressure in HU's distribution system, the following piping is required:

- New 24-inch water main from the proposed new wells southwest of Juniata running east along Highway 6 to the intersection of Highway 6 and South Osage Avenue.
- New 16-inch water main running north from the 24-inch water main on Highway 6 to the existing 16-inch water main on W 12th Street.
- New 16-inch water main from the intersection of Highway 6 and South Osage Avenue that runs east along Highway 6 to the existing 16-inch water main at the intersection of Highway 6 and South Marian Road.

This pipeline configuration will provide a looped system from the area of Well 33 to the southern portion of the distribution system while allowing the connection of the proposed new wells southwest of Juniata without increasing pressure in the distribution system.

4.3 Withdrawal Impacts

Another consideration associated with the construction and operation of new wells located in the areas surrounding the City of Hastings is the potential impacts on groundwater quality associated with the operation of these new wells. In some instances, the operation of these new wells may result in decreased water quality over time. The pumping or withdrawals from these wells may tend to draw areas of lesser water quality towards the wells, potentially increasing the chance for deteriorated water quality in the wells.

4.3.1 Lochland

In the Phase II Groundwater Modeling Report, some discussion of the impacts of pumpage of wells in the area of Lochland was provided. In general, the Lochland area currently has nitrate levels that exceed the MCL. Based on the groundwater modeling efforts for this area, it is believed that the nitrate levels would, at minimum, exceed the MCL for the first several years. The nitrate levels beyond this timeframe could potentially begin to decline if there is not a continued source of nitrate in the area. However, because the existing levels of nitrate in this area currently exceed the MCL, further development of wells in this area is not recommended.

4.3.2 Trumbull

Based on the information provided in the aforementioned modeling TM , the area around Trumbull appears to have moderate nitrate levels (5 mg/L to 8 mg/L). The sampling frequency for this area was less dense than other areas within the HU WHPA, and the nitrate levels in the area may be higher that indicated. There appears to be an area of higher nitrates northeast of Trumbull that could ultimately impact the long term viability of wells in this area. The areas of higher nitrates around the Trumbull area along with the limitations of well capacity in this area may limit the feasibility of well development in this area.

4.3.3 Juniata

The proposed wells located southwest of Juniata are in an area that currently has lower nitrate levels (< 5 mg/L). As the higher nitrate areas appear to be downstream of these wells, the impacts of pumpage from these wells to the wells themselves and other wells in the area should be minimized.

As discussed in the aforementioned modeling TM, the area near Juniata was not sampled at the same density as the area inside of the HU WHPA. As a result, prior to proceeding further with the assessment of well development southwest of Juniata, obtaining more water quality samples in the area is recommended. A higher sampling frequency may

determine that there are areas near or around these proposed well locations that would limit the feasibility of well operation in this area now or in the future.

4.4 Treatment Requirements

For the potential wells located southwest of Juniata and in the Trumbull area, water quality samples taken to date indicate higher iron concentrations. This data is summarized in the *Water Quality Summary TM* and is depicted graphically in Figure 4.1. These iron levels are in some cases near or above the secondary MCL for iron. As such, treatment may be required to remove the iron. In addition, typically where higher iron concentrations are found, there is a potential for higher manganese levels.

Treatment options to remove iron and manganese include:

- Lime Softening and Filtration
- Aeration and Filtration
- Oxidative Processes and Filtration
    - Chlorine Addition
    - Permanganate Addition
    - Ozonation
- Greensand Filtration
- Ion Exchange (Zeolite Softening)

Each of these treatment alternatives have associated advantages and disadvantages. Generally, if lime softening or ion exchange is not being used to remove other water quality parameters, the oxidative processes followed by filtration are typically used for iron and manganese removal. Aeration can also be used but its effectiveness is limited at higher concentrations, and for manganese is dependant on the pH of the water being treated.

Additional water quality from the area southwest of Juniata would be required to further define the full treatment requirements for the proposed wells in this area.

4.5 Well Summary

Due to the low yield of the Lochland wells, and the likelihood of future nitrate contamination, development of wells in this area is not recommended. It may be possible to continue to utilize the wells as an emergency or irrigation source.

While wells in the Trumbull area have a potentially slightly higher yield, the nitrate levels in this area appear to be approaching upwards of 8 mg/L with higher nitrate areas upstream. This water quality could limit the long-term viability of any wells located in this area. In addition, treatment for iron removal may be required for wells in this area.

Juniata could be a potential source of water for HU given the favorable aquifer conditions that should produce high yielding water supply wells. However, less water quality data is available in this area. Therefore, additional water quality testing should be performed.

Specifically, very limited data is available for uranium concentrations near Juniata. This information should be collected prior to performing any additional investigations.

Estimated costs to develop new wells in the Juniata area and associated piping are included in Section 7.0.

5.0 TREATMENT COMPARISON AND EVALUATION

As mentioned previously, RO and IX were evaluated as primary treatment technologies for nitrate removal in the Plan. In the winter of 2010/2011, HU was approached by Shikun & Binui (S&B) regarding Selective Electrodialysis (SED) technology. SED is similar to electrodialysis reversal (EDR) and is able to selectively remove nitrate as well as other contaminants. Per S&B literature,

"The SED process is based on the ability of semi-permeable membranes to let select ions in a solution of ionized salts pass through, while blocking others. Salts are in solution as ionized particles with positive or negative charges (for example sodium chloride as Na+ and Cl-). When a direct current is imposed on the solution, the positive ions migrate to the negative electrode, or cathode. The negative ions migrate to the positive electrode, or anode. A cation permeable membrane allows positive ions to pass, but blocks negative ions. An anion permeable membrane does the opposite – allows negative ions to pass, but blocks positive ions. Electrodialysis does not remove bacteria, colloidal matter, or matter that is not ionized."

As SED technology was considered to be a potentially viable primary treatment technology for nitrate removal, it was evaluated further.

When evaluating treatment technologies, a number of factors must be considered. Two primary considerations include rejection of water quality parameters and overall water recovery. Approximate rejection rates for HU parameters of concern using RO, IX, SED, and EDR are summarized in Table 5.1. Rejection rates shown for SED were obtained from the S&B proposal to HU in July 2011. Rejection rates for EDR were obtained from GE Water. As shown, RO is able to remove all parameters of concern at a rate greater than 90 percent. For IX, when both cation and anion exchange resin units are used, all of the parameters of concern can be removed to some extent. However, RO is better than IX at removing gross alpha, lead, and atrazine. With EDR technology, all parameters of concern except atrazine and lead, can be removed to some extent with a one-stage system. Additional removal may be possible with multiple stages. For SED, nitrate, hardness, and TDS removal rates are shown. Although SED technology is similar to EDR with respect to removing charged components, it is unknown whether the selective membrane used in the process can remove arsenic, gross alpha, and uranium or to what extent. More analysis would need to be conducted if this technology is considered further.

TABLE 5.1 – APPROXIMATE REJECTION RATES FOR HU PARAMETERS OF CONCERN

Parameter	RO	IX	EDR[1]	SED[1]
Nitrate (mg/L as N)	> 90%	> 90%	60%	60%
Arsenic (µg/L)	> 90%	> 90%	> 50%[6]	Unknown
Gross Alpha (pCi/L)	> 90%	Some[2]	50%	Unknown
Uranium	> 90%	> 90%	40%	Unknown
Lead (µg/L)	> 90%	Some[3]	0%	0%
Atrazine (µg/L)	> 90%	Some[4]	0%	0%
Total Dissolved Solids (mg/L)	> 90%	> 90%[5]	40%	35%
Hardness (mg/L as $CaCO_3$)	> 90%	> 90%[5]	50%	35%

1 Rejection rate for one stage system. Rate may be higher with additional stages.

2 Cation and anion exchange resin can remove positive and negative gross alpha valences for radium and uranium, respectively. RO is the EPA approved technology to remove gross alpha below MCL.

3 Cation exchange resin unit required to remove. Rejection percentage dependent on resin and conditions.

4 Atrazine and degradation products adsorbed by strong acid cation exchange resin. Resin must be regenerated prior to initial breakthrough of calcium. Source: Advances in Water and Wastewater Treatment, Rao Y. Surampalli, Environmental and Water Resources Institute (U.S.) Environmental and Multi-Media Council.

5 Cation exchange resin unit required to remove.

6 Chlorine needed to change valence state.

If it is assumed that the average nitrate concentration being pumped from Well 33 and the Capture Well is approximately 16 mg/L (maximum modeled nitrate level in capture well was 16.2 mg/L as shown in Table 3.3), then with a 60 percent rejection of nitrate, a one-stage SED or EDR system can only treat to approximately 6.4 mg/L. As such, additional stages would be required to obtain a 5 mg/L nitrate level.

Water recovery rates and corresponding total feed water, bypass, treatment feed water, and concentrate water rates for RO and IX required to provide 5 MGD of finished water at 5 mg/L nitrate are summarized in Table 5.2. As shown, approximately 4.77 MGD of water would require treatment with RO to achieve a final nitrate level of 5 mg/L after bypass water is blended. For IX technology, the amount of water that would require treatment to achieve a 5 mg/L nitrate level would be 3.86 MGD.

TABLE 5.2 – ESTIMATED FEED AND RESIDUAL PROCESS FLOW STREAMS FOR VARIOUS TECHNOLOGIES AT 5 AND 2 MG/L TREATED INJECTED WATER (16 MG/L RAW NITRATE)

Treatment Technology	Typical Recovery (%)	Typical Nitrate Rejection (%)	Total Feed Water (MGD)	Bypass (MGD)	Treatment Feed Water (MGD)	Permeate Water (MGD)	Concentrate Water (MGD)	Finished Water (MGD)
RO	80%	90%	5.95	1.18	4.77	3.82	0.95	5.00
IX	99%	90%	5.04	1.18	3.86	3.82	0.04	5.00

As discussed in the Plan, residual management is a key component in technology evaluation. As shown in Table 5.2, the residuals associated with a RO system designed to provide 5 MGD of 5 mg/L nitrate water, assuming no additional residual treatment, is 0.95 MGD (660 gpm). The residual quantity associated with IX is decreased to 0.04 MGD (28 gpm).

As mentioned in Section 1.3.1, it is estimated that approximately 0.21 to 0.66 MGD RO residual waste (limited by selenium) and 0.025 to 0.052 MGD IX residual waste (limited by chloride) could potentially be disposed of at the WPCC. Residual quantities for IX shown in Table 5.2 are within the range of potential quantities that could be disposed of at the WPCC. Although RO residual quantities shown in Table 5.2 are above the range of potential range of quantities that could be disposed of at the WPCC, these quantities are based on a primary RO system. If a secondary RO system is used to treat primary RO concentrate, the volume would be reduced to within the WPCC range. Regardless, this disposal option requires further evaluation based on WPCC operations and future nitrate standards.

6.0 RESIDUAL EVALUATION FOR URANIUM

As mentioned above, direct discharge to surface water, indirect discharge to surface water via the Hastings Water Pollution Control Center (WPCC), evaporation ponds, and blending for agricultural or irrigation reuse were evaluated in the Plan. However, as uranium was not considered a parameter of concern at that time, residual concentrations of uranium were not factored into this evaluation.

Based on a RO recovery rate of 80-percent and a raw water uranium level of 56 µg/L, the approximate concentration of uranium in the residual stream would be 280 µg/L. If the maximum uranium concentration encountered to date is assumed, the uranium concentration in the residual stream would be approximately 374 µg/L. The effect of this concentration on disposal options will need to be investigated further.

7.0 PRELIMINARY OPINION OF PROBABLE CONSTRUCTION COSTS

Preliminary opinion of probable construction costs (OPCC) for the following options are discussed in this section:

- Option 1 – Development of Additional Wells in Juniata Area
- Option 2 – Nitrate Skimming
- Option 3 – Pump-Treat-Recharge

For cost estimating purposes, RO was used for treatment as it is the most conservative technology with respect to removal. Costs will need to be updated based on the selected treatment technology.

7.1 Option 1 – Development of Additional Wells in Juniata Area

As mentioned in Section 4.0, Juniata could be a potential source of water for HU given the favorable aquifer conditions that should produce high yielding water supply wells. OPCC of corresponding components for this option are summarized in Table 7.1. As shown, costs are included to develop three (3) wells in the Juniata area. Assuming a pumping rate of approximately 1,500 gpm per well, this option would produce approximately 6.5 MGD (4,500 gpm) of water. Treatment is not included in the costs. Additional water quality from the area southwest of Juniata would be required to further define the full treatment requirements for the proposed wells in this area.

TABLE 7.1 – OPCC FOR OPTION 1-WELL DEVELOPMENT IN JUNIATA AREA (APPROXIMATELY 6.5 MGD)

Component	Units	Unit Cost	Total Cost
New Wells, Pump, and Motor	3	$ 300,000	$ 900,000
20-Inch Piping	29,000 ft	$ 117 per ft	$ 3,393,000
16-Inch Piping to Well 33	13,200 ft	$ 94 per ft	$ 1,241,000
16-Inch Piping Along Highway 6	16,100 ft	$ 94 per ft	$ 1,513,000
Subtotal			**$ 7,047,000**
Electrical/Standby Power		10%	$ 705,000
Subtotal			**$ 7,752,000**
Contractor OH&P		7%	$ 543,000
Contingencies		15%	$ 1,163,000
Subtotal			**$ 9,458,000**
Engineering, Legal, Fiscal		15%	$ 1,419,000
Total Estimated Cost			**$ 10,877,000**

7.2 Option 2 – Nitrate Skimming

As discussed in this TM, with nitrate skimming, nitrate, which is typically present in a higher concentration at the groundwater surface, is skimmed off with a submersible pump and then either sent to waste or treated. To accomplish this, existing wells would need to be modified with an adjacent skimming well or dual pump system in the well casing (most wells are not large enough for two pumps). Each irrigation or municipal well

modification and submersible pump addition is estimated to cost $300,000, which includes well, pump, motor, and well piping. These costs include a $150,000 for the well, $100,000 for the pump and motor, and $50,000 for the down hole well piping.

The nitrate skimming treatment system would need to treat up to 200 gpm per production well where the nitrate skimming approach is used. Budgetary quotes from four manufacturers/suppliers were obtained and are summarized in Table 7.2. As shown, the cost per 100 gallons was calculated and used to develop an average cost for both 200 and 400 gpm systems.

TABLE 7.2 – NITRATE SKIMMING RO SYSTEM BUDGETARY COST (NOT INCLUDING INSTALLATION)

Manufacturer/Supplier	Permeate (gpm)	Total Cost	Cost per 100 gallons
GE Water	400	$ 200,000	$ 500
Harn	300	$ 550,000	$ 1,833
Layne Christensen	200	$ 178,000	$ 890
	400	$ 314,000	$ 785
Wigen[1]	200	$ 270,000	$ 1,350
		Average:	$ 1,072
Costs Based on Average:	200	$ 214,000	
	400	$ 429,000	

1 Antiscalant feed system not included.

The OPCC for nitrate skimming at one well is summarized in Table 7.3. It was assumed that the WTP would be located at the well site. This alternative includes costs for only one skimming well which would not meet the system requirements. Building space is included for an additional RO units, but equipment and piping costs cannot be reasonably developed at this time. For cost estimating purposes, it was assumed that residual treatment waste can be sent to the WPCC. Piping to convey this residual treatment waste to the WPCC is not included in the costs. If treatment of the residuals is required, additional costs will need to be added.

TABLE 7.3 – OPCC FOR OPTION 2-NITRATE SKIMMING (PER WELL)

Component	Units	Unit Cost	Total Cost
Well Components			
Modify Existing Municipal Well	1	$ 100,000	$ 100,000
Well Pump and Motor	1	$ 90,000	$ 90,000
Down Hole Well Piping	1	$ 40,000	$ 40,000
Subtotal			**$ 230,000**
Treatment Components			
Treatment Plant - Installed[1] Equipment Cost (200 gpm RO System)	1	$ 278,000	$ 278,000
Treatment Plant - Building Cost	3,000	$240 per ft	$ 720,000
Subtotal			**$ 998,000**
Mechanical (HVAC/Plumbing)	8%		$ 80,000
Additional Process Piping	16%		$ 160,000
Electrical Standby Power	10%		$ 100,000
Subtotal of Well and Treatment Components			**$ 1,568,000**
Contractor OH&P		7%	$ 110,000
Contingencies		15%	$ 235,000
Subtotal			**$ 1,913,000**
Engineering, Legal, Fiscal		15%	$ 287,000
Estimated Total Cost			**$ 2,200,000**

1 Installation factor of 1.3 used.

7.3 Option 3 – Pump-Treat Recharge

As mentioned above, with this option, select wells located along the upgradient (groundwater) side of the City would be used to intercept large quantities of nitrate-impacted water. The upgradient wells would consist of Well 33 and a new capture well, which would be strategically located to intercept an area of high nitrate concentration groundwater. The raw groundwater would be treated to reduce nitrate concentrations to 5 mg/L. Most or all of the treated water would be returned to the aquifer downgradient of the two pumping wells through several recharge wells. The recharged water would migrate downgradient towards the other HU water supply wells, at the natural rate of groundwater flow. The recharged water would be recaptured by several HU water supply wells.

As mentioned previously, for the purposes of this study, it was assumed that 100 percent of the pumped water would be treated and returned to the aquifer through the recharge wells (approximately 5 MGD). This assumption does not account for treatment system recovery (i.e. not all water will be recovered after treatment). Approximately 4.77 MGD of water would require treatment with RO (3.82 MGD permeate water at 80-percent recovery) to produce 5.0 MGD of 5 mg/L nitrate water after bypass water is blended (refer to Table 5.2). For analysis purposes, Budgetary quotes obtained for systems designed to produce 3.8 MGD of permeate are summarized in Table 7.4. As shown, the cost per one MGD was calculated and used to develop an average system cost.

TABLE 7.4 – PUMP-TREAT-RECHARGE RO SYSTEM BUDGETARY COST (NOT INCLUDING INSTALLATION)

Manufacturer/Supplier	Permeate (MGD)	Total Cost	Cost per MGD
GE Water	3.9	$ 2,000,000	513,000
Ham	3.8	$ 3,250,000	855,000
Layne Christensen	3.8	$ 1,256,600	331,000
Wigen[1]	3.8	$ 1,460,000	384,000
Costs Based on Average:			521,000
	3.8	$ 1,980,000	

1 Antiscalant feed system not included.

During model simulations, the treated water was recharged into the aquifer using seven (7) wells, each with a recharge rate of 500 gpm. The seven (7) recharge wells to two (2) pumping wells ratio was selected for the model simulations based on established aquifer storage and recovery (ASR) rules of thumb that indicate the recharge capacity of a well is typically between three (3) to four (4) times less than the pumping capacity of a well (Pyne, 1995).

The aquifer recharge system would be a gravity system and consist of a recharge (injection) well, control valves, and column piping installed in the well. Assuming the recharge wells are constructed using 18-inch diameter screen and casing, the total cost for a recharge well is estimated to be $150,000 per well system. This includes the well, down hole column pipe, flow control valves, and the above grade well completion.

The OPCC for this option is summarized in Table 7.5. It was assumed that the WTP would be located near Well 33 and the Capture Well. One mile of 24-inch piping was included to convey treated water to the location of the injection wells. For cost estimating purposes, it was assumed that residual treatment waste can be sent to the WPCC. Piping to convey this residual treatment waste to the WPCC is not included in the costs. If treatment of the residuals is required, additional costs will need to be added.

TABLE 7.5 – OPCC FOR OPTION 3-PUMP-TREAT-RECHARGE (PRODUCE 5 MGD OF 5 MG/L NITRATE WATER)

Component	Units	Unit Cost	Total Cost
Well Components			
Injection Well (Includes Control Valves and Column Piping)	7	$ 150,000	$ 1,050,000
Subtotal			**$ 1,050,000**
Treatment Components			
Treatment Plant - Installed[1] Equipment Cost (3.8 MGD RO System)	1	$ 2,574,000	$ 2,574,000
Treatment Plant - Building Cost (Units)	7,500 SF	$ 240 per SF	$ 1,800,000
Subtotal			**$ 4,374,000**
Mechanical (HVAC/Plumbing)	8%		$ 350,000
Additional Process Piping	16%		$ 700,000
Electrical & Standby Power	10%		$ 437,000
Subtotal			**$ 5,861,000**
Piping			
24-Inch Pipe from WTP to Injection Wells	5,280 ft	$ 141 per ft	$ 744,000
Subtotal			**$ 744,000**
Subtotal of Well, Treatment, and Piping			**$ 7,655,000**
Contractor OH&P		7%	$ 536,000
Contingencies		15%	$ 1,148,000
Subtotal			**$ 9,339,000**
Engineering, Legal, Fiscal		15%	$ 1,401,000
Estimated Total Cost			**$ 10,740,000**

1 Installation factor of 1.3 used.

8.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the Phase II Modeling and well field management evaluations discussed in this TM, all concepts appear to be preliminarily feasible at this time and partial treatment of the water supply appears to be a viable alternative to significantly reduce the capital and operating costs associated with SDWA compliance, in particular the nitrate issue. Prior to proceeding further with the assessment of well development southwest of Juniata, obtaining more water quality samples (particularly uranium, iron, and manganese) in the area is recommended. A higher sampling frequency may determine that there are areas near or around these proposed well locations that would limit the feasibility of well operation in this area now or in the future. If it is determined that developing wells in Juniata is a viable alternative from a water quality perspective, the feasibility of obtaining public acceptance, purchasing land, and obtaining easements in the area will need to be evaluated further.

The options presented in Section 7.0 could be implemented individually or in conjunction with one another. However, to determine feasibility beyond modeling, these concepts will require further investigation through piloting. Preliminarily, it is believed that Nitrate Skimming (Dual Pumps) and Pump-Treat Recharge (ASR) would be best combined into a joint project. Nitrate Skimming could be used to help control water disposal costs by using the water for irrigation in the summer and increase the

nitrate concentration in the water to be treated, thus saving hydraulic (treatment) capacity costs.

Future recommendations aimed at refining the well based management approach are summarized below.

1. Continue to sample wells for contaminants of concern. Include contaminants of concern listed on the Unregulated Contaminant Monitoring Regulation (UMCR) 116 list.
2. Continue to update and rerun Groundwater Model with new data.
3. Continue to evaluate nitrate skimming concept through Dual Pump Study.
4. Conduct pilot to demonstration Pump-Treat-Recharge Concept
    a. Meet with Regulatory Agencies to coordinate requirements for pilot program and ASR permitting. Review options and determine need for Underground Injection Control (UIC) permit.
    b. Develop Work Plan to implement ASR Pilot Program.
    c. Perform groundwater modeling to support concept design.
    d. Evaluate need for treatment and define treatment technology.
5. Conduct groundwater modeling for water supply area (separate from Pump-Treat-Recharge and Nitrate Skimming).
    a. Determine best pumping approach to minimize nitrate and uranium.
    b. Determine optimum flow rates for treated and injected water.
    c. Determine impact of irrigation pumping in the water supply area.
6. Evaluate treatment technology alternatives for water treatment requirements and residuals disposal options with respect to uranium and contaminants of concern on the UMCR list.
    a. Determine if WPCC can accommodate residual volumes (smaller quantities for nitrate skimming and pump-treat-recharge) and concentrations of uranium, nitrate, chloride, selenium, etc.
    b. Meet with Regulatory agencies to discuss options for residual management.
7. Based on 2012 water quality data, evaluate areas for development of Pump-Treat-Recharge and potential of developing new wells.
8. Evaluate other well management / watershed approaches (i.e. trading irrigation water approach, etc.)
9. Refine Well Field Management Conceptual Design. Update OPCC costs based on pilot results and updated residual management plan.
10. Continue to work with various agencies to try and reduce and/or eliminate any ‘continuous’ sources of nitrate and uranium.

9.0 REFERENCES

Layne, 2009. Water Supply Well 33 Spinner Flow Meter Survey and Depth Specific Water Sampling. Prepared for Hastings Utilities. February.

Pyne, R.D. 1995. Groundwater Recharge and Wells A Guide to Aquifer Storage and Recovery. Lewis Publishers. New York.

APPENDIX A – GROUNDWATER MODELED DATA FOR SCENARIOS 2 AND 4

Scenario 2 - Active Wells Including Wells 31 and 32, 5 mg/L Injection

Well	Nominal Flow Rate (gpm)	Nominal Flow Rate (MGD)	Nitrate Level (mg/L as N)																			
			2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
1	750	1.1	7.0	6.5	6.6	6.6	6.8	7.1	7.5	7.9	8.2	8.5	8.9	9.2	9.4	9.4	9.4	9.2	8.8	8.4	7.9	7.4
2	1200	1.7	7.0	6.5	6.5	6.5	6.6	6.9	7.2	7.6	7.9	8.1	8.4	8.7	9.0	9.1	9.1	9.0	8.8	8.4	8.0	7.6
4	1100	1.6	7.0	6.5	6.4	6.4	6.5	6.6	6.7	7.0	7.2	7.5	7.7	7.9	8.2	8.4	8.5	8.5	8.5	8.4	8.2	7.9
6	1000	1.4	8.0	7.8	7.5	7.2	7.1	7.0	6.9	6.7	6.5	6.3	6.0	5.7	5.5	5.3	5.3	5.5	5.7	5.8	5.9	5.9
8	2000	2.9	8.0	8.0	7.7	7.5	7.2	7.0	6.9	7.0	7.1	7.1	7.0	6.7	6.0	5.1	4.3	3.6	3.1	2.8	2.5	2.4
9	1000	1.4	8.5	7.8	7.1	6.5	6.1	5.9	6.0	6.2	6.4	6.5	6.6	6.6	6.6	6.6	6.5	6.4	6.3	6.2	6.2	6.1
15	900	1.3	7.0	6.5	6.6	6.6	6.7	6.9	7.1	7.2	7.3	7.3	7.4	7.5	7.6	7.8	8.1	8.4	8.8	9.2	9.5	9.8
16	1000	1.4	8.0	7.9	7.6	7.3	7.1	7.0	6.8	6.6	6.2	5.9	5.5	5.2	4.8	4.3	3.8	3.3	2.8	2.5	2.2	2.1
17	1000	1.4	9.4	10.8	11.6	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.8	9.1	8.7	8.3	7.8	7.3	6.7	6.1	5.4	4.9
19	1000	1.4	8.0	8.8	10.1	10.1	10.2	10.2	9.8	9.3	9.0	9.2	9.6	10.1	10.6	11.2	11.8	12.3	12.6	12.8	12.9	12.9
21	1000	1.4	7.2	7.3	7.3	7.3	7.2	7.2	7.1	7.1	7.1	7.1	7.1	7.1	7.0	6.9	6.6	6.3	5.9	5.5	5.1	4.7
22	1750	2.5	7.5	8.1	8.3	8.3	8.1	7.9	8.0	8.0	8.0	7.8	7.4	7.0	6.5	6.1	5.7	5.3	4.8	4.4	3.9	3.4
23	1800	2.6	7.0	7.0	6.9	6.9	6.8	6.6	6.3	6.0	5.7	5.3	4.8	4.1	3.4	2.8	2.4	2.2	2.0	2.0	1.9	1.9
24	1800	2.6	8.1	8.4	8.4	8.4	8.4	8.3	8.3	8.4	8.7	9.2	9.9	10.6	11.2	11.7	11.9	12.0	11.9	11.7	11.4	10.9
25	1250	1.8	7.0	7.0	7.0	7.0	7.1	7.0	6.6	6.1	5.5	5.0	4.5	4.2	4.0	3.7	3.5	3.3	3.1	3.0	2.8	2.6
26	1250	1.8	8.3	8.5	8.4	8.0	8.5	9.0	9.3	9.3	9.3	9.0	8.6	8.2	7.7	7.2	6.6	6.0	5.3	4.7	4.1	3.6
27	1250	1.8	7.7	8.6	9.3	9.3	9.2	8.8	8.3	7.9	7.4	6.9	6.4	5.8	5.2	4.6	4.1	3.6	3.2	2.9	2.7	2.5
28	1750	2.5	7.0	7.1	7.2	7.2	7.0	5.8	4.3	3.2	2.7	2.4	2.3	2.3	2.2	2.2	2.2	2.2	2.1	2.1	2.1	2.1
29	1750	2.5	7.0	7.0	7.1	7.1	7.4	7.7	7.7	7.2	5.9	4.3	3.2	2.5	2.2	2.1	2.0	2.0	2.0	2.0	2.0	2.0
34	2150	3.1	8.0	6.5	3.4	2.4	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1
35	2150	3.1	8.0	7.6	7.1	5.1	3.6	2.9	2.5	2.3	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.0	2.0
31	400	0.6	11.5	10.0	8.5	7.2	6.2	5.5	5.2	5.4	5.4	5.4	5.3	5.0	4.5	4.0	3.5	3.0	2.6	2.2	2.0	1.9
32	400	0.6	4.1	3.7	3.2	3.0	3.6	4.4	4.9	5.1	5.1	4.8	4.3	3.7	3.0	2.5	2.1	1.7	1.5	1.6	1.9	2.6
33			11.4	11.4	11.7	11.2	9.1	7.6	7.0	6.9	7.2	7.5	7.9	8.2	8.3	8.5	8.6	8.8	8.9	8.9	9.0	9.0
Capture Well			12.9	15.3	16.2	16.2	15.9	15.0	14.1	13.5	12.8	11.8	10.7	9.8	9.0	8.6	8.4	8.5	8.7	8.9	9.2	9.4
Maximum Nitrate, All Wells:			9.4	10.8	11.6	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.9	10.6	11.2	11.7	11.9	12.3	12.6	12.8	12.9	12.9
Minimum Nitrate, All Wells :			7.0	6.5	3.4	2.4	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.0	2.0	2.0	2.0	1.9	1.9
Average Nitrate, All Wells:			7.6	7.6	7.5	7.3	7.2	7.1	7.0	6.9	6.7	6.6	6.5	6.3	6.2	6.1	5.9	5.7	5.6	5.4	5.2	5.0
Blended Nitrate, All Wells:			7.6	7.6	7.4	7.1	6.9	6.8	6.7	6.5	6.3	6.2	6.0	5.9	5.7	5.5	5.4	5.2	5.0	4.9	4.7	4.5
Well Capacity (Wells with Nitrate < 8 mg/L, MGD):			34.3	30.0	30.0	30.0	30.0	32.5	32.5	34.3	33.2	31.5	31.5	31.5	31.7	31.7	31.8	31.8	31.8	31.8	34.6	36.2

Scenario 4 - Active Wells Including Wells 31 and 32, 2 mg/L Injection

Well	Nominal Flow Rate (gpm)	Nominal Flow Rate (MGD)	Nitrate Level (mg/L as N)																			
			2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
1	750	1.1	7.0	6.5	6.6	6.6	6.8	7.1	7.5	7.9	8.2	8.5	8.9	9.2	9.4	9.4	9.4	9.2	8.8	8.4	7.9	7.4
2	1200	1.7	7.0	6.5	6.5	6.5	6.6	6.9	7.2	7.6	7.9	8.1	8.4	8.7	9.0	9.1	9.1	9.0	8.8	8.4	8.0	7.6
4	1100	1.6	7.0	6.5	6.4	6.4	6.5	6.6	6.7	7.0	7.2	7.5	7.7	7.9	8.2	8.4	8.5	8.5	8.5	8.4	8.2	7.9
6	1000	1.4	8.0	7.8	7.5	7.2	7.1	7.0	6.9	6.7	6.5	6.3	6.0	5.7	5.5	5.3	5.3	5.5	5.7	5.8	5.9	5.9
8	2000	2.9	8.0	8.0	7.7	7.5	7.2	7.0	6.9	7.0	7.1	7.1	7.0	6.7	6.0	5.1	4.3	3.6	3.1	2.8	2.5	2.4
9	1000	1.4	8.5	7.8	7.1	6.5	6.1	5.9	6.0	6.2	6.4	6.5	6.6	6.6	6.6	6.6	6.5	6.4	6.3	6.2	6.2	6.1
15	900	1.3	7.0	6.5	6.6	6.6	6.7	6.9	7.1	7.2	7.3	7.3	7.4	7.5	7.6	7.8	8.1	8.4	8.8	9.2	9.5	9.8
16	1000	1.4	8.0	7.9	7.6	7.3	7.1	7.0	6.8	6.6	6.2	5.9	5.5	5.2	4.8	4.3	3.8	3.3	2.8	2.5	2.2	2.1
17	1000	1.4	9.4	10.8	11.6	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.8	9.1	8.7	8.3	7.8	7.3	6.7	6.1	5.4	4.9
19	1000	1.4	8.0	8.8	10.1	10.1	10.2	10.2	9.8	9.3	9.0	9.2	9.6	10.1	10.6	11.2	11.8	12.3	12.6	12.8	12.9	12.9
21	1000	1.4	7.2	7.3	7.3	7.3	7.2	7.2	7.1	7.1	7.1	7.1	7.1	7.1	7.0	6.9	6.6	6.3	5.9	5.5	5.1	4.7
22	1750	2.5	7.5	8.1	8.3	8.3	8.1	7.9	8.0	8.0	8.0	7.8	7.4	7.0	6.5	6.1	5.7	5.3	4.8	4.4	3.9	3.4
23	1800	2.6	7.0	7.0	6.9	6.9	6.8	6.6	6.3	6.0	5.7	5.3	4.8	4.1	3.4	2.8	2.4	2.2	2.0	2.0	1.9	1.9
24	1800	2.6	8.1	8.4	8.4	8.4	8.4	8.3	8.3	8.4	8.7	9.2	9.9	10.6	11.2	11.7	11.9	12.0	11.9	11.7	11.4	10.9
25	1250	1.8	7.0	7.0	7.0	7.0	7.1	7.0	6.6	6.1	5.5	5.0	4.5	4.2	4.0	3.7	3.5	3.3	3.1	3.0	2.8	2.6
26	1250	1.8	8.3	8.5	8.4	8.0	8.5	9.0	9.3	9.3	9.3	9.0	8.6	8.2	7.7	7.2	6.6	6.0	5.3	4.7	4.1	3.6
27	1250	1.8	7.7	8.6	9.3	9.3	9.2	8.8	8.3	7.9	7.4	6.9	6.4	5.8	5.2	4.6	4.1	3.6	3.2	2.9	2.7	2.5
28	1750	2.5	7.0	7.1	7.2	7.2	7.0	5.8	4.3	3.2	2.7	2.4	2.3	2.3	2.2	2.2	2.2	2.2	2.1	2.1	2.1	2.1
29	1750	2.5	7.0	7.0	7.1	7.1	7.4	7.7	7.7	7.2	5.9	4.3	3.2	2.5	2.2	2.1	2.0	2.0	2.0	2.0	2.0	2.0
31	400	0.6	11.5	10.0	8.5	7.2	6.2	5.5	5.2	5.4	5.4	5.4	5.3	5.0	4.5	4.0	3.5	3.0	2.6	2.2	2.0	1.9
32	400	0.6	4.1	3.7	3.2	3.0	3.6	4.4	4.9	5.1	5.1	4.8	4.3	3.7	3.0	2.5	2.1	1.7	1.5	1.6	1.9	2.6
34	2150	3.1	8.0	6.5	3.4	2.4	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1
35	2150	3.1	8.0	7.6	7.1	5.1	3.6	2.9	2.5	2.3	2.2	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.0	2.0
33			11.4	11.4	11.7	11.2	9.1	7.6	7.0	6.9	7.2	7.5	7.9	8.2	8.3	8.5	8.6	8.8	8.9	8.9	9.0	9.0
Capture Well			12.9	15.3	16.2	16.2	15.9	15.0	14.1	13.5	12.8	11.8	10.7	9.8	9.0	8.6	8.4	8.5	8.7	8.9	9.2	9.4
Maximum Nitrate, All Wells:			11.5	10.8	11.6	11.6	11.7	11.8	11.8	11.7	11.2	10.6	9.9	10.6	11.2	11.7	11.9	12.3	12.6	12.8	12.9	12.9
Minimum Nitrate, All Wells :			4.1	3.7	3.2	2.4	2.2	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.0	1.7	1.5	1.6	1.9	1.9
Average Nitrate, All Wells:			7.7	7.6	7.4	7.1	7.0	6.9	6.9	6.8	6.6	6.5	6.3	6.1	6.0	5.8	5.6	5.4	5.3	5.1	4.9	4.7
Blended Nitrate, All Wells:			7.7	7.6	7.3	7.0	6.9	6.8	6.6	6.5	6.3	6.1	6.0	5.8	5.7	5.5	5.3	5.1	4.9	4.8	4.6	4.4
Well Capacity (Wells with Nitrate < 8 mg/L, MGD):			34.8	30.5	30.5	31.1	31.1	33.6	33.6	35.4	34.3	32.6	32.6	32.6	32.8	32.8	33.0	33.0	33.0	33.0	35.8	37.4