TECHNICAL MEMORANDUM

Evaluation of the Environmental Fate of Residual Nitrate from an Advance (Class A) Treated Wastewater Infiltration Facility, Mill City, Oregon

To: Mary Camarata, Department of Environmental Quality

From: Matt Kohlbecker, RG, GSI Water Solutions, Inc.
Ailco Wolf, PG, CHG, GSI Water Solutions, Inc.

CC: Olivier Jamin, Davis Wright Tremaine, LLP
Peter Olsen, PE, Keller Associates, Inc.
Dallin Stephens, PE, Keller Associates, Inc.
Pamela Villarreal, PE, Keller Associates, Inc.
Kevin Stewart, EI, Keller Associates, Inc.
Jason Keller, RG, GeoSystems Analysis, Inc.
Chris Einmo, PE, Marion County

Attachments: Figures 1 through 4
Attachment A. Technical Documentation for Numerical Modeling.

Date: November 26, 2024

Executive Summary

The communities of Gates and Mill City, Oregon, have partnered to develop a modern wastewater treatment facility that will treat wastewater to Class A standards and infiltrate it at a series of Rapid Infiltration Basins (RIBs). State and federal regulations require that the environmental fate of residual pollutants in treated wastewater be evaluated to determine the type of permit that will be required to operate the facility.[1]

During the fall of 2023, GSI Water Solutions, Inc. (GSI), conducted a preliminary evaluation of the environmental fate of residual pollutants in treated wastewater using screening-level models developed by regulatory agencies (GSI, 2023a).[2] The evaluation focused on nitrate, toluene, and di(2-ethylhexyl)phthalate (DEHP), which were detected in untreated wastewater samples from Mill City's existing wastewater treatment facility (GSI, 2023b).

This technical memorandum (TM) documents a final evaluation of the environmental fate of residual nitrate in treated wastewater that: (1) is based on a modeling code (i.e., MODFLOW) that overcomes nitrate-specific limitations of the screening-level models used during the preliminary evaluation, (2) incorporates new site-

[1] The permits include a Water Pollution Control Facilities (WPCF) permit or a National Pollutant Discharge Elimination System (NPDES) permit.
[2] The Large Onsite Septic System (LOSS) model was developed by the Washington State Department of Ecology and the BIOSCREEN model was developed by the U.S. Environmental Protection Agency.

specific data collected in 2024, after the preliminary evaluation was conducted, and (3) incorporates comments on the preliminary evaluation from the Oregon Department of Environmental Quality (DEQ) (DEQ, 2024a). A final evaluation of the environmental fate of residual toluene and DEHP in treated wastewater will be documented in a separate report (GSA, in press).

1. Background

This section presents the project background (Section 1.1), conceptual model for pollutant fate and transport during treated wastewater infiltration (Section 1.2), purpose and objectives of the fate and transport evaluation (Section 1.3), and TM organization (Section 1.4).

1.1 Project Background

The communities of Gates and Mill City have partnered to develop a modern wastewater treatment facility that will treat wastewater to Class A standards and infiltrate it at a series of RIBs. Currently, wastewater in Gates is infiltrated at individual septic systems, and wastewater in Mill City is infiltrated using an over 30-year-old drainfield located adjacent to the Santiam River. Mill City's drainfield is at the end of its usable life and cannot be expanded under current rules. Figure 1 shows the existing and proposed wastewater treatment facilities.

The proposed wastewater treatment facility will significantly improve water quality in the scenic Santiam Canyon because:

- Nitrate has been detected at concentrations up to about 8 milligrams per liter (mg/L) in seeps discharging to the Santiam River near the existing wastewater treatment facility (GSI, 2024a), and nitrate concentrations in wastewater discharges from the existing treatment facility generally range from 20 to 50 mg/L (GSI, 2024b). The proposed RIB facility will treat total nitrogen in wastewater to 2 mg/L or less (corresponding with a nitrate concentration of 2 mg/L assuming all nitrogen is converted to nitrate),[3] which is a significant improvement to wastewater quality under current management practices.
- Individual septic systems and recreational vehicle (RV) park waste systems that currently manage wastewater in Gates may discharge wastewater with a total nitrogen concentration ranging from 30 to over 500 mg/L (DOH, 2021).[4] The new RIB facility's treatment of total nitrogen to a concentration of 2 mg/L represents a significant improvement.
- The RIB facility will be located further from the Santiam River (i.e., the shortest distance between an infiltration basin and the Santiam River along the groundwater flowpath will be about 1,900 feet, as compared to Mill City's existing infiltration facility that is located adjacent to the river). The increased horizontal separation results in an increased travel time between infiltrated wastewater and the river, which in turn results in increased attenuation of residual pollutants in wastewater.

During the spring and summer of 2023, a subsurface characterization was conducted at multiple sites in Mill City to evaluate infiltration feasibility and select a site for the proposed RIBs. Based the results of the characterization, only one site was determined to be capable of infiltrating the 2045 wastewater volume from Gates and Mill City (called Site GM1). Figure 1 shows the monitoring wells, location of a pilot infiltration test basin, and planned RIBs at Site GM1. The preliminary model for the environmental fate of residual pollutants in treated wastewater was based on the data collected during the spring and summer of 2023.

[3] The total nitrogen in treated wastewater consists of 1 mg/L nitrate and 1 mg/L ammonia.
[4] According to the Washington State Department of Health, residential strength effluent is characterized by a total nitrogen concentration ranging from 30 to 100 mg/L. High strength effluent (e.g., RV waste) is characterized by a total nitrogen concentration of more than 500 mg/L (DOH, 2021).

The following data were collected after the summer of 2023 and are incorporated into the model documented in this TM:

- **Subsurface Data from Additional Monitoring Wells.** Two additional monitoring wells—GM1-MW4 and GM1-MW5—were constructed at Site GM1 in March 2024. Soil permeability and groundwater flow directions were updated based on the new wells [results documented in GSI (in press)].
- **Hydrograph Analysis.** Groundwater levels at monitoring wells GM1-MW1 through GM1-MW3 were monitored continuously from September 2023 to April 2024, and aquifer recharge was calculated using the water level fluctuation method [results documented in GSI (2024c)].
- **Nitrate Sampling.** Additional groundwater quality samples were collected from monitoring wells at Site GM1 to further characterize background nitrate concentrations in groundwater [results documented in GSI (2024a)].
- **Pilot Infiltration Test.** An infiltration basin pilot test was conducted during the summer of 2024, and consisted of discharging potable water into a 50 feet by 50 feet temporary basin at a rate of about 50 to 100 gallons per minute.

1.2 Conceptual Model for Treated Wastewater Infiltration

Figure 2 shows a conceptual model for the infiltration of treated wastewater. The treated wastewater will be infiltrated at RIBs, and will be transported downward through unsaturated soils until reaching the groundwater table. After reaching the groundwater table, the water will be transported horizontally by groundwater flow. During transport through unsaturated soils and groundwater, the concentrations of residual nitrate in treated wastewater are attenuated (reduced) by the processes of denitrification, dilution, and dispersion:

- **Denitrification.** Denitrification is a microbial-mediated process in which nitrate and nitrite are reduced to nitrogen gas.
- **Dilution.** Residual nitrate in treated wastewater is diluted by precipitation falling over the infiltration basin footprint and groundwater entering the project site from upgradient. Residual nitrate is further diluted downgradient of the RIBs by precipitation falling over the property that infiltrates through soil and recharges the groundwater system.
- **Dispersion.** Dispersion is attenuation caused by spreading of the residual nitrate (i.e., some nitrate travels slower than the average groundwater velocity and other nitrate travels faster than the average groundwater velocity, thereby reducing nitrate concentrations).

The amount of nitrate attenuation caused by these processes can be evaluated with a pollutant fate and transport model. Table 1 shows site-specific properties, which are input to the model or represented using literature values. Collectively, these properties determine the nitrate concentration after transport through porous media.

Table 1. Site-Specific Soil and Site Properties that Affect Pollutant Attenuation

Attenuation Process	Site-Specific Properties Affecting Attenuation
Denitrification	Organic matter, soil water content, soil oxygen supply, soil temperature, soil pH
Dilution	Precipitation, aquifer thickness, infiltration facility footprint, groundwater velocity, wastewater volume
Dispersion	Distance between the infiltration site and the compliance point and pollutant velocity (a function of sorption, hydraulic conductivity, horizontal hydraulic gradient, and effective porosity)

1.3 Purpose and Objectives of the Fate and Transport Evaluation

The purpose of the modeling summarized in this TM is to inform an analysis of the factors established by DEQ (2024b) for whether the new wastewater treatment facility at Site GM1 is the functional equivalent of a direct discharge to the surface water. The objectives of the model are:

- Develop aquifer parameters and facility operational parameters that can be input into a model to simulate the attenuation of nitrate due to denitrification in soil, dilution, and dispersion during operation of the wastewater treatment facility.
- Develop a calibrated groundwater flow model using the U.S. Geological Survey (USGS) modeling code MODFLOW.
- Use MT3D to simulate nitrate in groundwater adjacent to the Santiam River from 2025 to 2045, and MODPATH to determine the travel time between the RIB facility and the Santiam River. MODPATH simulates nitrate transport due to advective groundwater flow; MT3D simulates nitrate transport due to advective groundwater flow and dispersion[5].

1.4 Technical Memorandum Organization

The remainder of this TM is organized as follows:

- Section 2: Fate and Transport Modeling Methods
- Section 3: Fate and Transport Modeling Results
- Section 4: Conclusions
- Section 5: Statement of Limitations
- Section 6: References

The main text of this TM provides an overview of the modeling methods and results. Attachment A contains detailed technical documentation.

2. Fate and Transport Modeling Methods

This section provides an overview of the methods that were used to model nitrate attenuation. Attachment A contains detailed documentation of modeling methods.

2.1 Modeled Time Period, Rapid Infiltration Basin Discharge Rates, and Nitrate Concentration

The fate and transport of nitrate was modeled over a 20-year time period, from 2025 to 2045. During this time, the RIBs were conservatively assumed to discharge at the projected 2045 average dry weather flow (0.209 million gallons per day [MGD], from June to November of each year) and the 2045 average wet weather flow (0.237 MGD, from December to May of each year).

The nitrate concentration in treated wastewater entering groundwater was assumed to be 1.8 mg/L, based on the assumptions that total nitrogen in treated wastewater is initially 2.0 mg/L,[6] all ammonia in wastewater converts to nitrate shortly after infiltration, and nitrate concentrations are reduced by 10 percent

[5] Advection is solute transport with average linear groundwater velocity; dispersion is solute transport that accounts for deviation from the average linear groundwater velocity (i.e., some solute moves faster than the average groundwater flow velocity, other solute moves slower that the average groundwater flow velocity).
[6] Consisting of 1 mg/L nitrate and 1 mg/L ammonia.

in the unsaturated zone by denitrification. The background concentration of nitrate in groundwater was assumed to be 0.56 mg/L based on averaging results of groundwater quality samples collected from Site GM1 monitoring wells.

Attachment A provides detailed documentation of the modeled time period, RIB discharge rates, and nitrate concentrations.

2.2 Model Code and Setup

Groundwater flow was simulated using the USGS modeling code MODFLOW. The Santiam River was simulated with the Streamflow Routing package, RIBs were simulated with the Well Package, and recharge from precipitation was simulated using the Recharge Package. Nitrate fate and transport was simulated using MT3D. Aquifer properties and nitrate properties were assigned in the model based on: (1) slug testing, monitoring well drilling, and groundwater quality sampling conducted as a part of the subsurface characterizations (hydraulic conductivity, background nitrate concentration in groundwater), (2) literature values (dispersivity, denitrification in soil, anisotropy, specific yield), or (3) facility design parameters (residual nitrogen in treated wastewater, treated wastewater discharge rate). Attachment A provides detailed documentation of the model code and setup.

2.3 Model Calibration

The groundwater flow model was calibrated by setting up a transient model to simulate groundwater flow from 2013 to 2014. Calibration was achieved by adjusting streamflow routing package parameters (i.e., conductance and stream bottom elevation), recharge from precipitation, aquifer parameters (i.e., hydraulic conductivity and specific yield), and general head boundary package parameters (i.e., conductance) to improve the match between observed and simulated groundwater elevations. Attachment A provides a detailed discussion of model calibration.

2.4 Sensitivity Analyses

DEQ requested that Marion County evaluate the sensitivity of the modeled nitrate concentration in groundwater adjacent to the Santiam River on aquifer hydraulic conductivity, nitrate concentration in wastewater discharges, and effluent generation volume. Table 2 summarizes the parameters GSI used to conduct a sensitivity analysis.

Table 2. Sensitivity Analysis Scenarios

Parameter	Base Case	Sensitivity Analyses	Rationale
Hydraulic Conductivity	95 feet /day	37 feet/day	Low end: lowest average hydraulic conductivity (GM1, MW3)
		3,818 feet/day	High end: highest average hydraulic conductivity (GM1-MW5)
Nitrate Concentration in Wastewater Discharge	1.8 mg/L	6 mg/L	Reflects higher nitrate associated with treatment by SBR alone (no tertiary denitrification)
		35 mg/L	Reflects current conditions at existing facility
Effluent Generation Volume	0.209 MGD (Summer) 0.237 MGD (Winter)	0.262 MGD	Projected 2045 Maximum Month Wet Weather Flow

Notes

mg/L = milligrams per liter MGD = million gallons per day SBR = sequencing batch reactor

2.5 Model Conservatism

This modeling approach is highly conservative for the following reasons, many of which represent simplifying assumptions:

(1) The modeling approach assumes that, except for denitrification, no pollutant attenuation occurs by dispersion in unsaturated soils.

(2) Treated wastewater discharge rates during the 20-year operational period were conservatively set to be at the 2045 projected rates.

(3) Conservative values of fate and transport parameters are used. For example, dispersion is estimated using the Xu and Eckstein (1995) equation instead of the Gelhar et al. (1991) equation, which results in lower values of dispersivity and, therefore, less pollutant attenuation.

3. Fate and Transport Modeling Results

The model-simulated operation of the proposed infiltration facility from 2025 to 2045 indicates that:

- Nitrate concentrations in the groundwater adjacent to the Santiam River stabilize after about 22 months of infiltration facility operation, and fluctuate seasonally between 1.31 and 1.47 mg/L.
- A sensitivity analysis was conducted to evaluate the sensitivity of the predicted nitrate concentration in groundwater adjacent to the Santiam River on hydraulic conductivity, residual nitrate concentration in wastewater discharge, and facility discharge rate. Table 3 summarizes the results of the sensitivity analysis. The results indicate that:
  - The predicted nitrate concentration is not sensitive to hydraulic conductivity over the range of observed hydraulic conductivity values at Site GM1 (i.e., 37 feet per day to 3,818 feet per day), nor is it sensitive to the facility discharge rate over the range of discharge rates for which the facility is being designed to operate.
  - The proposed treatment facility will significantly improve water quality in the Santiam Canyon, resulting in nitrate in groundwater adjacent to the Santiam River ranging from 1.31 to 1.47 mg/L with the residual nitrate in wastewater treated to 2 mg/L. Nitrate in groundwater adjacent to the Santiam River ranges from 3.87 to 4.55 mg/L with the residual nitrate in wastewater treated to 6 mg/L, and ranged from 21.5 to 25.9 mg/L with the residual nitrate in wastewater treated to 35 mg/L.

Table 3. Sensitivity Analysis Results

Value	Nitrate Concentration in Groundwater Adjacent to the Santiam River	Steady State Nitrate Concentration Reached (months after discharge begins)
Hydraulic Conductivity		
37 feet/day	1.40 to 1.49 mg/L	22 months
95 feet/day (Base Case)	1.31 to 1.47 mg/L	22 months
3,818 feet/day	0.82 to 0.84 mg/L	11 months
Residual Nitrogen Concentration		
2 mg/L (Proposed facility)	1.31 to 1.47 mg/L	22 months
6 mg/L (SBR-only treatment)	3.87 to 4.55 mg/L	25 months
35 mg/L (Existing treatment)	21.5 to 25.9 mg/L	21 months
Facility Discharge Rate		
0.209 MGD / 0.237 MGD (Base Case)	1.31 to 1.47 mg/L	22 months
0.262 MGD	1.33 to 1.49 mg/L	23 months

Notes

mg/L = milligrams per liter MGD = million gallons per day SBR = sequencing batch reactor

4. Conclusions

GSI makes the following conclusions based on the model simulations documented in this TM:

- The new wastewater treatment facility will improve water quality in the Santiam Canyon, because the future predicted nitrate concentration in groundwater adjacent to the river is 1.25 to 1.50 mg/L as compared to at least 8 mg/L (based on sampling of seeps adjacent to the existing facility documented in GSI [2024a]).

- The model results can be used to evaluate whether discharges at the RIBs are functionally equivalent to a direct discharge to surface water. The following analysis is based on DEQ (2024b), which identifies seven factors a determination of functional equivalency is based upon. The nitrate transport model addresses five of these factors.

  - **Factor 1: transit time.** DEQ guidance states that "(t)ransit time is the amount of time a discharge takes to reach the navigable water from the point of discharge from the point source" (DEQ, 2024b, pg. 7). The guidance establishes the following thresholds for using transit time to evaluate functional equivalency:

    - A transit time of less than 90 days strongly indicates that the discharge is a functionally equivalent discharge.

    - A transit time of 90 days to 18 months indicates that the discharge is likely a functionally equivalent discharge, but the determination will include other factors.

    - A transit time of greater than 18 months will rely more on other factors to determine whether the discharge is functionally equivalent.

    <u>Based on the MODPATH simulation, the nitrate transit time from the closest point of an infiltration basin to the Santiam River is approximately 455 days (about 15 months), indicating</u>

<u>that the discharge is likely a functionally equivalent discharge, but the determination will include other factors.</u>

- **Factor 4: the extent to which the pollutant is diluted or chemically changed as it travels.** DEQ guidance states that "(o)nce the effluent reaches groundwater, it can be diluted or chemically changed by the groundwater, aquifer material, or aquifer sediments" (DEQ, 2024b, pg. 9). The guidance does not establish thresholds for evaluating the extent of pollutant dilution. However, the guidance states that ". . . the permit writer, in consult with a DEQ hydrogeologist, should consider the extent to which the pollutants in question are diluted or chemically changed as they travel, however this factor will not, on its own, support a finding of a functional equivalent of a direct discharge" (DEQ, 2024b, pg. 9).

  The nitrate attenuation model predicts that nitrate concentration in groundwater adjacent to the Santiam River will be 1.25 mg/L to 1.50 mg/L. The initial concentration of nitrate at the point of discharge is 2.0 mg/L. <u>Therefore, nitrate experiences a reduction in concentration ranging from 25.0 to 37.5 percent of the initial effluent concentration. This is a significant dilution in the pollutant concentration.</u>

- **Factor 5: the amount of pollutant entering the navigable waters relative to the amount of the pollutant that leaves the point source.** DEQ guidance states that "(d)etermining the amount of pollutant entering the navigable waters will require knowledge of how much effluent is leaving the facility and how much pollutant is entering the navigable waters, as well as knowledge of whether the navigable water is a gaining or losing reach" (DEQ, 2024b, pg. 10).

  As indicated by many seeps along the riverbank and groundwater elevation contour maps, the Santiam River at Mill City is a gaining reach. GSI estimates that 90 percent of the nitrate discharged from the facility reaches the Santiam River, based on a denitrification in soil of 10 percent of initial nitrate.

- **Factor 6: the manner by or area in which the pollutant enters the navigable waters.** DEQ guidance states that "(t)he more discrete an area in which the pollutant enters a navigable water, the more likely it is to be a functional equivalent of a direct discharge" (DEQ, 2024b, pg. 10). The guidance does not establish thresholds for evaluating the manner by or area in which the pollutant enters the navigable waters. The guidance states that the permittee should ". . . (c)onsult with a DEQ hydrogeologist to determine the manner/area in which a pollutant enters the navigable waters" (DEQ, 2024b, pg. 10).

  <u>As shown in Figure 3, the nitrate attenuation model indicates that nitrate will be diffuse, with concentrations of nitrate above background occurring along a 3,500-foot-long section of riverbank. Therefore, the nitrate will be less discrete than a direct discharge from an outfall, or a discharge along the groundwater pathway from a rock fracture.</u>

- **Factor 7: the degree to which the pollution (at that point) has maintained its specific identity.** DEQ guidance states that "(f)actor 7 considers all the pollutants from the effluent in aggregate and requires a determination of how close the discharge into the navigable water is in composition to the original effluent from the point source" (DEQ, 2024b, pg. 10). The guidance does not establish thresholds for evaluating the degree to which pollutants have maintained their specific identity. The guidance states that "(t)he permit writer will want to consider all the relevant pollutants that are part of the effluent and therefore will want data fully characterizing the effluent, groundwater, discharge at the navigable water, and ambient for those pollutants. Once this data(sic) is in hand then the permit writer can determine which pollutants are found in the discharge to the navigable water and how much they have changed using a Piper Diagram or other graphing technique. Consult with a DEQ hydrologist to determine the degree to which a pollutant maintains its identity" (DEQ, 2024b, pg. 11).

With respect to nitrate, the initial concentration in wastewater discharge is 2.0 mg/L, and the concentration in groundwater discharging to the river is predicted to be 1.25 to 1.50 mg/L. The reduction in nitrate concentration is related to dispersion and dilution (both non-destructive mechanisms of pollutant attenuation) and denitrification in soil (a destructive mechanism of pollutant attenuation).

Table 4 summarizes the seven factors established by DEQ (2024b), and how the factors are addressed by the nitrate transport model. Note that the transport model does not address Factors 2 or 3. This table applies DEQ's guidance related to the U.S. Supreme Court's "functional equivalence test" in the *County of Maui v. Hawaii Wildlife Fund* decision. We make no opinion as to DEQ's guidance's consistency with that decision or related EPA guidance.

Table 4. Functional Equivalency Factors Addressed by the Nitrate Transport Model

Factor	Description	Nitrate Model Result	Factor Classification
1	Transit Time of NO_3	455 days (15 months)	Ambiguous Factor
2	Travel Distance of NO_3	—	—
3	Nature of Material	—	—
4	Chemical Change of NO_3	25.0% to 37.5% reduction	Unlikely Factor
5	Amount NO_3 Entering Navigable Water	90% of initial concentration	Likely Factor
6	Manner or Area of NO_3 Discharge	Diffuse (3,500 feet-wide)	Unlikely Factor
7	Identity of NO_3 at Discharge Point	25.0% to 37.5% reduction	Unlikely Factor

Notes

— = not applicable, nitrate model does not provide information about the factor

NO_3 = nitrate

5. Statement of Limitations

This TM documents the work performed by GSI at the request and direction of Keller Associates in accordance with our proposal dated March 14, 2024. The findings, opinions, and conclusions included herein are for the exclusive use of Keller Associates and Marion County. Reliance shall not be provided to any other person or entity without Keller Associates and GSI's written consent. Reliance on this document for any use or by parties, other than those specifically identified, is prohibited without the expressed written consent of GSI and client, and such use is at the sole risk of the user.

6. References

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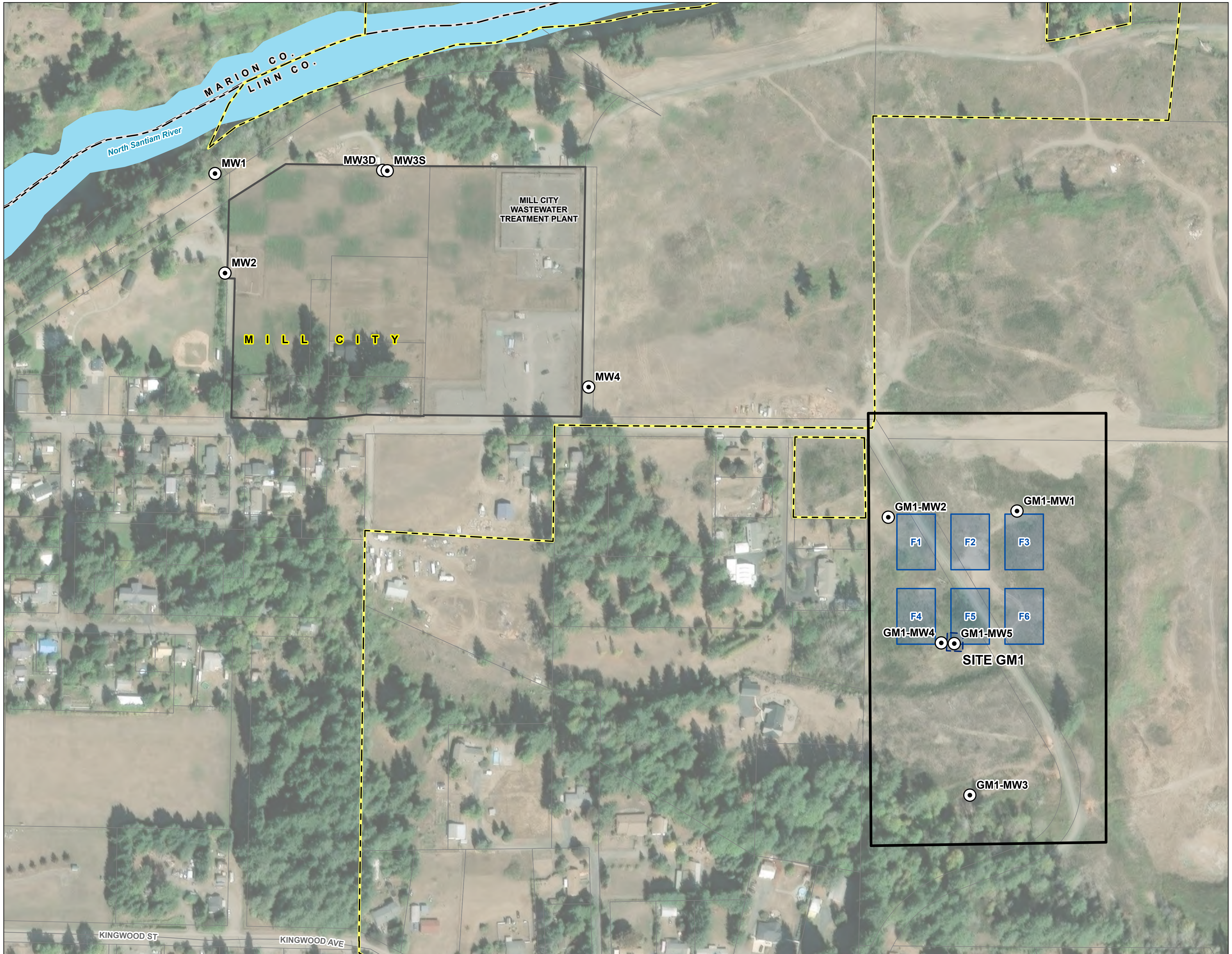

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FIGURE 1
Site Map
Nitrate Fate and Transport Evaluation

LEGEND

- Monitoring Well
- PIT Basin
- Rapid Infiltration Basin
- Existing Wastewater Disposal Facility
- Candidate Site

All Other Features

- City Boundary
- County Boundary
- Tax Lot
- Watercourse

N

0 125 250 375
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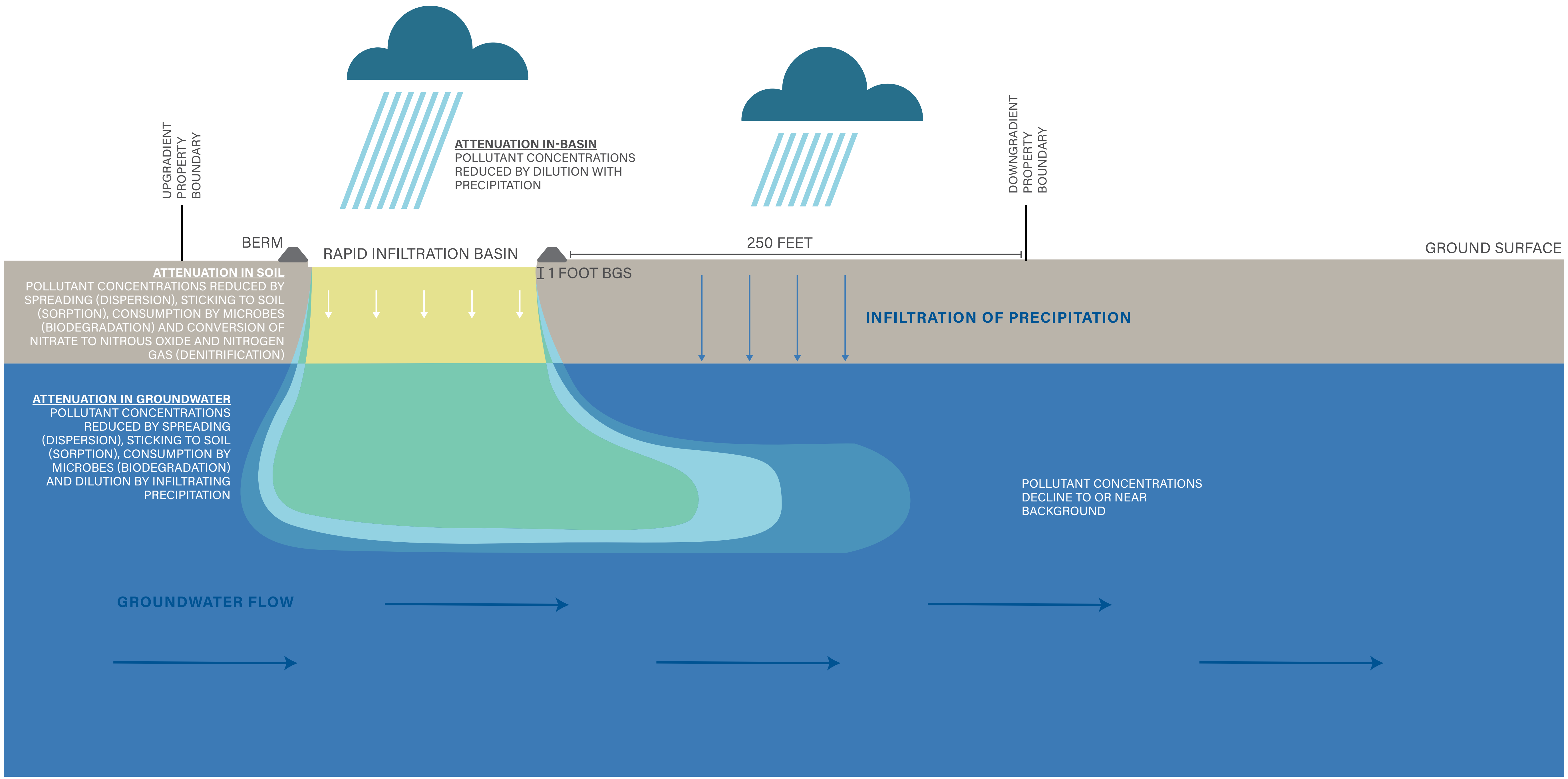
Date: October 15, 2024
Data Sources: BLM, ESRI, ODOT, USGS, Imagery (2022)

GSI Water Solutions, Inc.



LEGEND

Concentrations

- Highest
- Medium
- Low
- At or Near Background

FIGURE 2

Conceptual Model for Pollutant Attenuation During Treated Wastewater Infiltration

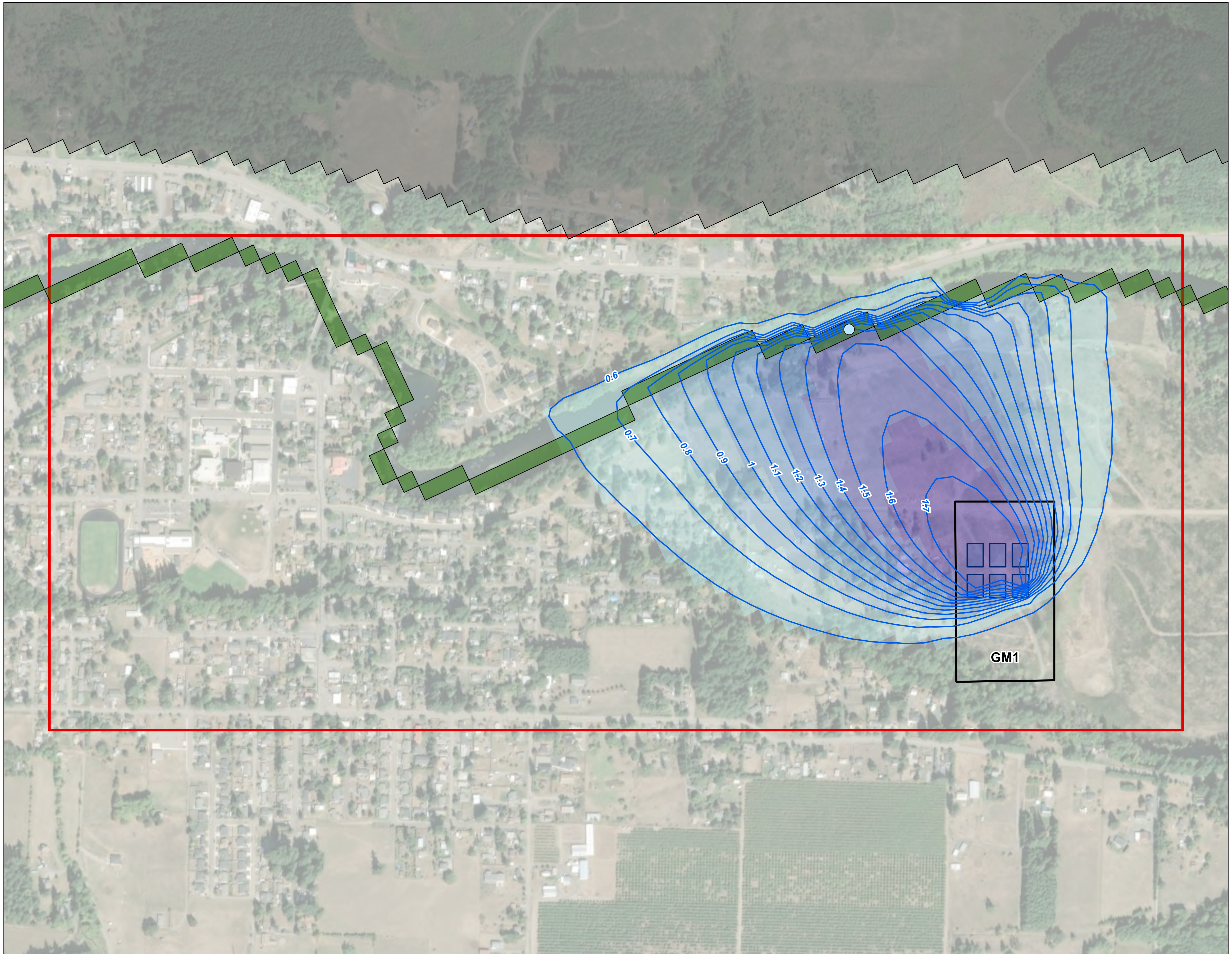
Nitrate Fate and Transport Evaluation

GSI Water Solutions, Inc.

FIGURE 3

Future Model Nitrate Concentration

Nitrate Fate and Transport Evaluation



LEGEND

- Nitrate Concentration Target
- Nitrate Concentration Contour (0.1 mg/L interval)
- Rapid Infiltration Basin
- Stream Cell
- No Flow Cell
- GM1 Site
- Area of Interest

Nitrate Concentration

- 0.6 - 0.8 mg/L
- 0.8 - 1.0 mg/L
- 1.0 - 1.2 mg/L
- 1.2 - 1.4 mg/L
- 1.4 - 1.6 mg/L
- 1.6 - 1.8 mg/L

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0 300 600 900
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Date: October 15, 2024
Data Sources: BLM, ESRI, ODOT, USGS, Imagery (2022)

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ATTACHMENT A

Technical Documentation for Application of MODFLOW-2005 for Fate and Transport Evaluation of Nitrate in Groundwater

1. Background

The proposed wastewater treatment facility at Site GM1 is being designed to reduce the total nitrogen concentration in wastewater to about 2 milligrams per liter (mg/L) and infiltrate the wastewater at Rapid Infiltration Basins (RIBs). The nitrogen in treated wastewater will initially consist of about 1 mg/L nitrate and 1 mg/L ammonia. All ammonia is expected to convert to nitrate shortly after infiltration. Therefore, the nitrate concentrations in infiltrated wastewater are expected to be about 2 mg/L nitrate.[1] The nitrate in infiltrated wastewater will migrate downwards through unsaturated soil, enter groundwater, and be transported towards the Santiam River. This attachment provides technical documentation for an evaluation of the fate and transport of nitrate in groundwater using a numerical groundwater fate and transport model.

The purpose of the model is to predict nitrate concentrations in groundwater along the groundwater flowpath and travel time between the RIB facility and the Santiam River. The simulations are based on nitrate attenuation only by denitrification and dispersion because nitrate is not attenuated by other processes (e.g., sorption). MODFLOW-2005 was used to simulate groundwater flow, and the MT3D-USGS model was used to simulate nitrate transport by advection and dispersion. MODFLOW-2005 is a numerical groundwater flow modeling code developed by the U.S. Geological Survey (USGS).

2. Groundwater Modeling Methods

The methods that were used to simulate the fate and transport of nitrate in groundwater include:

(1) Build and calibrate a model that simulates groundwater flow in Mill City, Oregon, from 2013 through 2024. The model is calibrated to 2013 through 2024 groundwater elevations, and is called the historical Mill City Flow Model (MCFM) in this attachment.

(2) Convert the historical MCFM to a predictive fate and transport model that simulates RIB operation and nitrate transport from 2025 through 2045. The predictive model is called the predictive Mill City Fate and Transport Model (MCF&TM) in this attachment.

(3) Conduct a sensitivity analysis using the predictive MCF&TM to determine the sensitivity of model results to aquifer parameter hydraulic conductivity, the concentration of residual nitrate in treated wastewater discharge, and the volume of infiltrated wastewater.

This section summarizes the methods that were used to simulate groundwater flow and nitrate fate and transport, including development of the model domain, simulation duration, and time discretization (Section 2.1), model boundary conditions (Section 2.2), initial aquifer and pollutant properties (Section 2.3), and model calibration and final model input parameters (Section 2.4).

[1] Email from D. Stephens (Keller Associates) to M. Kohlbecker (GSI Water Solutions) RE: Water Quality Bullets. September 10, 2024.

2.1 Model Domain, Simulation Duration, and Time Discretization

This section documents the model domain (Section 2.1.1) and simulation duration and time discretization (Section 2.1.2).

2.1.1 Model Domain

The model domain was designed to simulate groundwater flow in shallow sands and gravels above a low permeability silt/clay layer that appears to be continuous in the vicinity of Site GM1 and the existing wastewater treatment facility. The bottom of the model domain corresponds with the silt/clay layer, which was delineated based on a boring at Site GM1 [about 45 feet below ground surface (bgs)],[2] a boring at the existing wastewater treatment plant (about 35 feet bgs),[3] and water well driller logs available from the Oregon Water Resources Department Online Well Report Query (OWRD, 2024). Figure A.1 is a contour map showing the elevation of the silt/clay layer and well data used to develop the contour map. Figure A.2 is a geologic cross section showing the relationship between the silt/clay layer, sand and gravel layers, and bedrock.

Figure A.3 is the model domain. A model grid was established inside of the domain consisting of 165 rows, 170 columns, and single layer of evenly spaced grid cells measuring 100 by 100 feet. The model is rotated by 25 degrees counterclockwise to align the model cells perpendicular to the general groundwater flow direction toward the Santiam River. The importance of the model rotation is to reduce the potential mass balance errors in the numerical solution of the nitrate transport using MT3D-USGS. The lateral extent of the model domain corresponds with the following features:

- West and east model boundaries are general head boundaries that simulate the underflow in and out of the model domain that were set at sufficient distance as to not influence flow in the area of interest (AOI) between Site GM1 and the Santiam River.
- The southern model boundary is a no flow boundary that corresponds with the southern extent of the sand/gravel. South of the contact, silt/clay appears to be present from ground surface to the top of bedrock based on water well driller logs (Figures A.1 and A.2).[4]
- The northern model boundary is a no flow boundary that corresponds with the northern extent of the sand/gravel. Specifically, the sand/gravel pinches out against low permeability tuffaceous sedimentary rocks and basalt flows north of the Santiam River (Figure A.2, cross section A to A').

2.1.2 Simulation Duration and Time Discretization

The historical MCFM uses monthly stress periods to vary model fluxes (i.e., treated wastewater discharges, aquifer recharge from precipitation, and flow in the Santiam River based on historical data from stream gages). The historical MCFM simulates the period from January 2013 to June 2024 using 138 stress periods for the 11.5 year model period.

The predictive MCF&TM simulates facility operation and nitrate fate and transport for 20 years (i.e., from 2025 to 2045 or 249 stress periods), to reflect that the facility design is based on projected wastewater flows in 2045. The predictive model assumes that the hydrologic drivers (recharge from precipitation and Santiam River flows) for the historical period from October 2013 through September 2023 will repeat starting in October 2025. MODPATH was used to calculate the travel time for groundwater by advection from the RIB facility to the Santiam River, by placing a particle in the northwest corner of RIB Basin F1 (the closest point in the RIB facility to the river).

[2] See temporary boring GM1-TB2 in GSI (2023a).
[3] See the boring for monitoring well MW-3d in EMCON (1989).
[4] LINN 3510, LINN 3511, and LINN 58086

2.2 Model Boundary Conditions

A boundary condition is an external influence that adds or removes water from the groundwater system. This section provides technical details about boundary conditions used to simulate groundwater flow, including the Streamflow Routing Package (Section 2.2.1), the Well Package (Section 2.2.2), the Recharge Package (Section 2.2.3), and the General Head Boundary Package (Section 2.2.4).

2.2.1 Streamflow Routing [SFR] Package

The Streamflow Routing Package (SFR) represents the head-dependent boundary condition that computes surface water/groundwater exchanges between the aquifer and the Santiam River at the locations shown in Figure A.3. Each SFR cell in the model has a specified bottom elevation representing the river thalweg (based on Light Detection and Ranging [LiDAR] data) and simulates river/aquifer seepage depending on the head difference between the river and the groundwater system and the streambed hydraulic conductivity. The flow in the SFR cells is routed downstream using the Manning's Equation. The surface water inflows into the model domain at the most upstream reach of the river is estimated based on linear interpolation between the observed monthly flows of the USGS Niagara and Mehama gages. The Niagara gage is located about ten miles upstream of the existing wastewater treatment facility, and the Mehama gage is located about nine miles downstream of the existing wastewater treatment facility. Table A.1 summarizes SFR input parameters.

Table A.1. SFR Package Input Parameters

Parameter	Santiam River
River Bottom Elevation	767 – 852 feet
Manning's Roughness Coefficient	0.03
Streambed Hydraulic Conductivity	10 feet/day

SFR package parameters conductance (which is a function of hydraulic conductivity, flow path length, and cell area) and stream bottom elevation were adjusted during the model calibration process to better match the observed groundwater elevations near the Santiam River. In the historical MCFM, an of average 375 acre-feet per month of groundwater flow is exchanged to the gaining Santiam River.

The calibrated SFR parameters from the historical MCFM were incorporated into the predictive MCF&TM. Specifically, the estimated Santiam River inflows from October 2013 to September 2023 in the historical MCFM were repeated for 20-year predictive MCF&TM period from 2025 to 2045.

2.2.2 Well [WEL] Package

The Well Package simulates flow in a specified model cell that withdraws water from or injects water into the aquifer at a constant rate during a stress period. For the historical MCFM and predictive MCF&TM, the Well Package is used to simulate the recharge from treated wastewater infiltration. Groundwater pumping from domestic and irrigation wells were not included in the model because irrigation/municipal wells pump groundwater from below the silt/clay layer, and domestic well pumping is considered to be de minimus.

The historical MCFM incorporates the existing Mill City wastewater treatment plant infiltration using Well Package cells, as shown in Figure A.3. The infiltration volumes are estimated from 2022 historical data provided by Mill City.

For the predictive MCF&TM, the RIB discharges were set based on projected design flows from Gates and Mill City for 2045. The 2045 Average Dry Weather Flow rate (0.209 million gallons per day [MGD]) was used for June through November, and the 2045 Average Wet Weather Flow (0.237 MGD) was used for December to May.[5] RIBs discharges were simulated with the Well Package using nine cells to represent the approximately 2 acres of recharge basins within Site GM1.

2.2.3 Recharge [RCH] Package

Natural recharge in the model domain consists of two components: (1) areal recharge from precipitation and (2) localized recharge from small tributaries to the Santiam River that are located distal from Site GM1 (see Rock Creek, Turnridge Creek, Deford Creek, and other unnamed creeks in Figure A.3).

Aerial recharge of precipitation represents precipitation that passes through the root zone and percolates to the groundwater system. The Recharge Package simulates areal recharge to groundwater across the entire model domain based on user-specified recharge values for each model grid cell. The recharge rate for the historical MCFM is based on USGS reports by Lee and Risley (2002),[6] Conlon et al. (2005)[7], and Herrera et al. (2014)[8] which estimated that the average recharge rates in the model domain ranged between 15 to 30 inches per year. The annual average recharge rate implemented in the historical MCFM is 20 inches per year and is spatially distributed based on the Parameter-elevation Regression on Independent Slope Model (PRISM) 30-year precipitation isoheytal map. The modeled recharge is equal to an approximate annual average recharge of 3,600 acre-feet. This 20 inches per year recharge value was later changed to about 24 inches per year in the calibrated model.

Runoff originating in watersheds north and south of the model domain contributes flows and therefore recharge in the smaller ungauged tributary areas inside the historical MCFM (Figure A.3). To estimate these ungauged flows, the following method was implemented. At the most downstream reach of the SFR Package, the Santiam River outflow from the model domain was estimated based on linear interpolation between the observed monthly flows of the USGS Niagara and Mehama gages, similarly to what was done to estimate the Santiam River inflow into the model domain (Section 2.2.1). A fraction of the differences between the estimated Santiam River model inflows and outflows represents the estimate of the recharge from ungauged tributaries streambed percolation inside the model domain. The final ungauged tributary recharge in the historical MCFM is a calibrated value of 862 acre-feet per year. The 862 acre-feet per year of recharge was spatial distributed near the tributaries flow paths in the Recharge Package.

2.2.4 General Head Boundary [GHB] Package

A GHB was assigned to portions of the groundwater model where the sand/gravel aquifer above the low permeability silt/clay layer extends beyond the western and eastern bounds of the modeled area. The GHB Package was used to simulate the underflow of groundwater along the eastern and western boundary of the model domain (Figure A.3). A GHB allows water to enter/exit the groundwater model based on the difference between assigned boundary head (groundwater elevation) and model-calculated head. A conductance term incorporates the hydraulic conductivity and geometry of materials between the model cell and boundary feature, which determines the magnitude of flows across the boundary.

The GHB conditions were set at sufficient distance from the AOI as to not influence flow characteristics between Site GM1 and the Santiam River (Figure A.3). For the historical MCFM, the transient GHB heads are calibrated due to the historical water level observations in nearby wells. The calibrated GHB conductance ranged from 5,000 to 10,000 square feet per day (ft^2/day).

The calibration of the GHB is evaluated based on the simulated values for observed static water levels at wells LINN 64376 and MARI 70819 near eastern and western GHB, respectively (Figure A.3). Wells LINN

[5] Email from K. Stewart (Keller Associates) to M. Kohlbecker (GSI Water Solutions) RE: Modeling Data Needs Discussion. May 28, 2024.
[6] 15 to 20 inches per year in the model domain
[7] 21 to 30 inches per year in the model domain
[8] 20 to 25 inches per year in the model domain

64376 and MARI 70819 are not in the AOI, but they do provide an indication that the overall groundwater gradient from east to west along the Santiam River is reasonable with a residual error of 1.85 feet and 2.23 feet, respectively.

2.3 Initial Aquifer and Pollutant Properties

Table A.2 summarizes aquifer properties and pollutant properties. If "initial" is written before a property, the property was potentially changed or evaluated during model calibration (see Section 2.4). The following sections describe the methods that were used to develop the initial aquifer and pollutant properties.

Table A.2. Aquifer and Nitrate Properties

Property	Symbol	Value	Units	Subsection in the Text
Aquifer Properties				
Initial Hydraulic Conductivity	K	189.5	feet/day	Subsection 2.3.1
Anisotropy	K_H:K_V	10:1	dimensionless	Subsection 2.3.2
Initial Specific Yield	S_y	0.24	dimensionless	Subsection 2.3.3
Dispersivity	α_L α_T α_V	31.7 (Longitudinal) 10.5 (Transverse) 1.6 (Vertical)	feet feet feet	Subsection 2.3.4
Nitrate Properties				
Retardation Factor	R	1.0	dimensionless	Subsection 2.3.5
Half Life	h	∞	days	Subsection 2.3.6
Initial Concentration in Treated Wastewater	C_0	2.0	mg/L	Subsection 2.3.7
Background Concentration in Groundwater	C_{GW}	0.556	mg/L	Subsection 2.3.8

Note

mg/L = milligrams per liter

2.3.1 Initial Hydraulic Conductivity (*K*)

Hydraulic conductivity is a proportionality constant that describes the ease of fluid movement through soil or rock. Table A.3 summarizes values of hydraulic conductivity for the shallow sands and gravels at Site GM1. The initial hydraulic conductivity value of 189.5 feet per day is the geometric mean of the values in Table A.3.

Table A.3. Initial Hydraulic Conductivity

Test Location ID	Source	Type of Analysis	Number of Tests	Geometric Mean Hydraulic Conductivity
GM1-MW1	GSI (2023a)	Slug Test	2	163.3 feet/day
GM1-MW2	GSI (2023a)	Slug Test	3	113.6 feet/day
GM1-MW3	GSI (2023a)	Slug Test	3	37.0 feet/day
GM1-MW4	GSI (in press)	Slug Test	3	93.4 feet/day
GM1-MW5	GSI (in press)	Slug Test	3	3,817 feet/day

2.3.2 Anisotropy (K_H:K_V)

The vertical hydraulic conductivity, K_v, was set as one tenth the horizontal K_h. However, in a single-layer MODFLOW model, the vertical hydraulic conductivity K_v generally has limited influence on flow characteristics because there is no vertical flow between layers.

2.3.3 Initial Specific Yield (S_y)

Specific yield is the ratio of the volume of water that saturated media yields to gravity drainage to the total volume of the media. Initially, the specific yield of 0.24 was used in the groundwater model, which was taken from Morris and Johnson (1967) for a "gravel, medium."

2.3.4 Dispersivity (α_L, α_T, α_V)

Dispersivity is a three-dimensional, scale-dependent variable that describes the amount of pollutant spreading (i.e., dispersion) that occurs during pollutant transport. Dispersivity in the direction of flow is called longitudinal dispersivity. Longitudinal Dispersivity was calculated using the Xu and Eckstein (1995) equation:

$$\alpha_L = 0.83\left[log\left(L_p\right)\right]^{2.414} \tag{A.1}$$

Where:

α_L is longitudinal dispersivity (meters)

L_p is the length of the pollutant plume (meters)

The shortest distance between an infiltration basin and the downgradient property boundary along the groundwater flow path is about 1,900 feet. Using the shortest distance is conservative because it will result in the smallest value for dispersivity and, therefore, least amount of dispersion. Based on a pollutant plume length of 579 meters (1,900 feet) (the distance from the northwest corner of RIB F1 to the Santiam River along the groundwater flowpath) the longitudinal dispersivity is 9.65 meters (31.7 feet) according to Equation (A.1).

According to ASTM (1995), transverse dispersivity can be assumed to be 33 percent of longitudinal dispersivity (i.e., 3.2 meters or 10.5 feet), and vertical dispersivity can be assumed to be 5 percent of longitudinal dispersivity (i.e., 0.48 meters or 1.6 feet)

2.3.5 Retardation Factor

The retardation factor for nitrate is 1.0, indicating that nitrate does not sorb to soil. Therefore, nitrate travels at the same velocity as groundwater.

2.3.6 Half Life (h) and First Order Decay Constant (λ)

Nitrate does not degrade under aerobic conditions. Therefore, the half life for nitrate is infinite and the first order decay coefficient for nitrate is zero.

2.3.7 Nitrate Concentration in Treated Wastewater (C_0)

The new RIB system will treat total nitrogen in wastewater to 2 mg/L or less. The total nitrogen in treated wastewater will initially consist of 1 mg/L nitrate and 1 mg/L ammonia. It is assumed that all ammonia will convert to nitrate shortly after discharge (i.e., 2 mg/L nitrate concentration in the unsaturated zone) and that denitrification in the unsaturated zone will reduce nitrate concentration by 10 percent (i.e., 1.8 mg/L nitrate concentration entering groundwater). The 10 percent denitrification assumption is the default value in the Washington Department of Health Large Onsite Sewage System (LOSS) model (DOH, 2021), which has been adopted by the Oregon Department of Environmental Quality (DEQ) to evaluate whether onsite systems meet

Oregon's groundwater protection requirements.[9] Table A.4 summarizes the nitrate concentrations in treated wastewater and groundwater.

Table A.4. Nitrate Concentration in Treated Wastewater

Total Nitrogen Concentration in Treated Wastewater Discharge [1]	Nitrate Concentration Reduction Due to Denitrification in Soil	Nitrate Concentration Entering Groundwater
2 mg/L	10%	1.8 mg/L

Notes

[1] Initially 1 mg/L ammonia and 1 mg/L nitrate. The "concentration in treated wastewater discharge" assumes all ammonia is converted to nitrate shortly after discharge.

mg/L = milligrams per liter

SBR = sequencing batch reactor

2.3.8 Background Nitrate Concentration in Groundwater (C_{GW})

Groundwater in the sand/gravel at Site GM1 contains nitrate. Table A.5 summarizes nitrate concentrations in groundwater samples collected from monitoring wells at GM1. The background nitrate concentration in the MODFLOW model was 0.556 mg/L, which is the geometric mean concentration based on water quality samples collected from monitoring wells at Site GM1.

Table A.5. Nitrate in Groundwater

Monitoring Well	Sampling Date	Nitrate Concentration	Geometric Mean Nitrate Concentration
GM1-MW1	5/28/2023	1.1 mg/L	0.963 mg/L
	7/25/2023	0.843 mg/L	
GM1-MW2	4/25/2024	0.308 mg/L	0.308 mg/L
GM1-MW4	4/25/2024	0.699 mg/L	0.699 mg/L
GM1-MW5	5/30/2024	0.460 mg/L	0.460 mg/L
		Geometric Mean Nitrate Concentration	0.556 mg/L

Note

mg/L = milligrams per liter

2.4 Model Calibration and Final Model Input Parameters

Calibration of the historical MCFM was achieved by adjustments of aquifer parameters, boundary conditions, and model stresses so that simulated groundwater elevations match observed groundwater elevations within a predetermined range of error. The groundwater model is evaluated primarily on the statistical parameters of residuals (observed minus simulated groundwater elevations) in target wells across the model domain. The primary calibration goal is to achieve a relative error of less than 10 percent (ESI, 2000-2020; Spitz and Moreno, 1996).

Manual trial-and-error calibration was conducted based on hydrologic expertise and conceptual knowledge of the groundwater basin. The historical MCFM was calibrated by adjustments to boundary condition parameters of streambed conductance, streambed elevation, general head conductance and adjustments to the spatial and temporal distribution of recharge fluxes as discussed in Section 2.2. Additionally, the model was calibrated by adjusting Santiam River stream bottom elevation and conductance; aquifer parameter hydraulic conductivity; and aquifer parameter specific yield aquifer parameters to minimize the difference

[9] Oregon Administrative Rule 340 – 040

between simulated and observed water levels. Table A.6 summarizes the final calibrated aquifer parameters ranges that were used in the model.

Table A.6. Calibrated Aquifer Parameters

Parameter	Minimum Value	Maximum Value	Notes
Hydraulic Conductivity	35 feet/day	150 feet/day	Within the approximate range of observed values (see Table A.3).
Specific Yield	0.20	0.20	Reduced from published value of 0.24 for medium gravel, see Section 2.3.3.
Aquifer Thickness	4 feet	284 feet	Thicknesses in AOI range from 25 feet to 80 feet.

A total of 13 target wells (49 measured values) used for calibration are located at or near the AOI and are calibrated from January 2013 through June 2024. Figure A.3 shows the location and average residual of these target wells. Table A.7 presents relevant statistical results for groundwater calibration.

Table A.7. Groundwater Model Calibration Statistics

Statistic	Calibration Results
Residual Mean	0.01
Residual Std. Deviation	2.26
Residual Sum of Squares	249
RMS Error	2.26
Minimum Residual	-4.69
Maximum Residual	4.45
Range of Observations	64.48
Scaled Res. Std. Dev.	0.035
Number of Observations	49

Figure A.4 presents a scatter plot of simulated groundwater elevations versus observed groundwater elevations. The modeled values plot closely to the 1:1 line and are typically within one standard deviation of the mean. In general, the observed and simulated groundwater elevations compare favorably, and calibration is further supported by scaled residual standard deviation (relative error) of 3.5 percent, well below industry standard of 10 percent. Figures A.5 through A.17 show the hydrographs of 13 target wells showing model-generated compared to observed groundwater elevations.

3. Predictive Model Output and Sensitivity Analysis

The calibrated historical MCFM was converted to a predictive fate and transport model with nitrate transport parameters implemented as described in Sections 2.3.4 and 2.3.7. This section summarizes output from the nitrate transport model (i.e., pollutant concentration in groundwater adjacent to the Santiam River) for nitrate (Section 3.1) and a sensitivity analysis on model results (Section 3.2).

3.1 Nitrate Adjacent to the Santiam River (Base Case Model)

Nitrate concentrations in groundwater adjacent to the Santiam River achieve a steady state conditions 22 months after discharge from the new wastewater infiltration facility, and the nitrate concentrations fluctuate between 1.3 and 1.5 mg/L during wet and dry seasons, respectively. Based on a MODPATH simulation, nitrate from the northwest corner of RIB F1 (the closest point in a RIB to the Santiam River) reaches the Santiam River 455 days (about 15 months) after discharge due to groundwater advection. Nitrate concentrations in groundwater adjacent to the Santiam River are summarized in chemograph Figure A.18 and in Table A.8. Figure A.19 shows the location of the target well from which the chemograph is derived (see "Nitrate Concentration Target"). Figure A.19 also shows a birds-eye-view of the September 2045 modeled nitrate concentrations downgradient of the RIBs.

Table A.8. Nitrate Concentration in Groundwater Adjacent to the Santiam River

Nitrate Concentration Entering Groundwater	Maximum Steady State Nitrate Concentration in Groundwater at the Santiam River	Average Background Nitrate in Groundwater
1.8 mg/L	1.5 mg/L	0.556 mg/L

Note

mg/L = milligrams per liter

3.2 Sensitivity Analysis

DEQ requested that Marion County evaluate the sensitivity of the modeled nitrate concentration in groundwater at the Santiam River on aquifer hydraulic conductivity, nitrate concentration entering groundwater, and effluent generation volume. GSI conducted the sensitivity analysis using the parameters summarized in Table A.9.

Table A.9. Sensitivity Analyses

Parameter	Base Case	Sensitivity Analyses	Rationale
Hydraulic Conductivity	95 feet /day	37 feet/day	Low end: lowest average hydraulic conductivity (GM1, MW3)
		3,818 feet/day	High end: highest average hydraulic conductivity (GM1-MW5)
Nitrate Concentration	1.8 mg/L	6 mg/L	Reflects higher nitrate associated with treatment by SBR
		35 mg/L	Reflects current conditions at existing facility
Effluent Generation Volume	0.209 MGD (Summer) 0.237 MGD (Winter)	0.262 MGD	Projected 2045 Maximum Month Wet Weather Flow

Notes

mg/L = milligrams per liter

MGD = million gallons per day

SBR = sequencing batch reactor

Sensitivity analyses were performed on predictive MCF&TM to assess the parameters that have the greatest effects on nitrate concentrations adjacent to the Santiam River. Parameters in Table A.9 were implemented in the model and the results are summarized in Table A.10.

Table A.10. Sensitivity Parameters and Associated Changes to Predicted Nitrate Concentrations

Run Description	Steady State Nitrate Concentration Reached (months after discharge begins)	Maximum Nitrate Concentration (mg/L)	Minimum Nitrate Concentration (mg/L)
Baseline	22	1.47	1.31
K = 37 feet/day	22	1.49	1.40
K = 3,818 feet/day	11	0.84	0.82
Residual Nitrate Concentration = 6 mg/L	25	4.55	3.87
Residual Nitrate Concentration = 35 mg/L	21	25.9	21.5
Facility Discharge Rate = 0.262 MGD	23	1.49	1.33

Notes

Baseline has AOI K= 95 feet/day, nitrate loading = 1.8 mg/L and effluent seasonal recharge is 0.237 MGD and 0.209 MGD

Maximum and minimum concentration represent seasonal steady state conditions

K = Hydraulic Conductivity

mg/L = milligrams per liter

MGD = million gallons per day

For comparison, the nitrate concentrations at the Santiam River for all sensitivity runs are plotted on a single chemograph (Figure A.20). Due to the large variation on the y-axis in Figure A.20, Figure A.21 shows the same sensitivity runs on a zoomed in y-axis.

4. References

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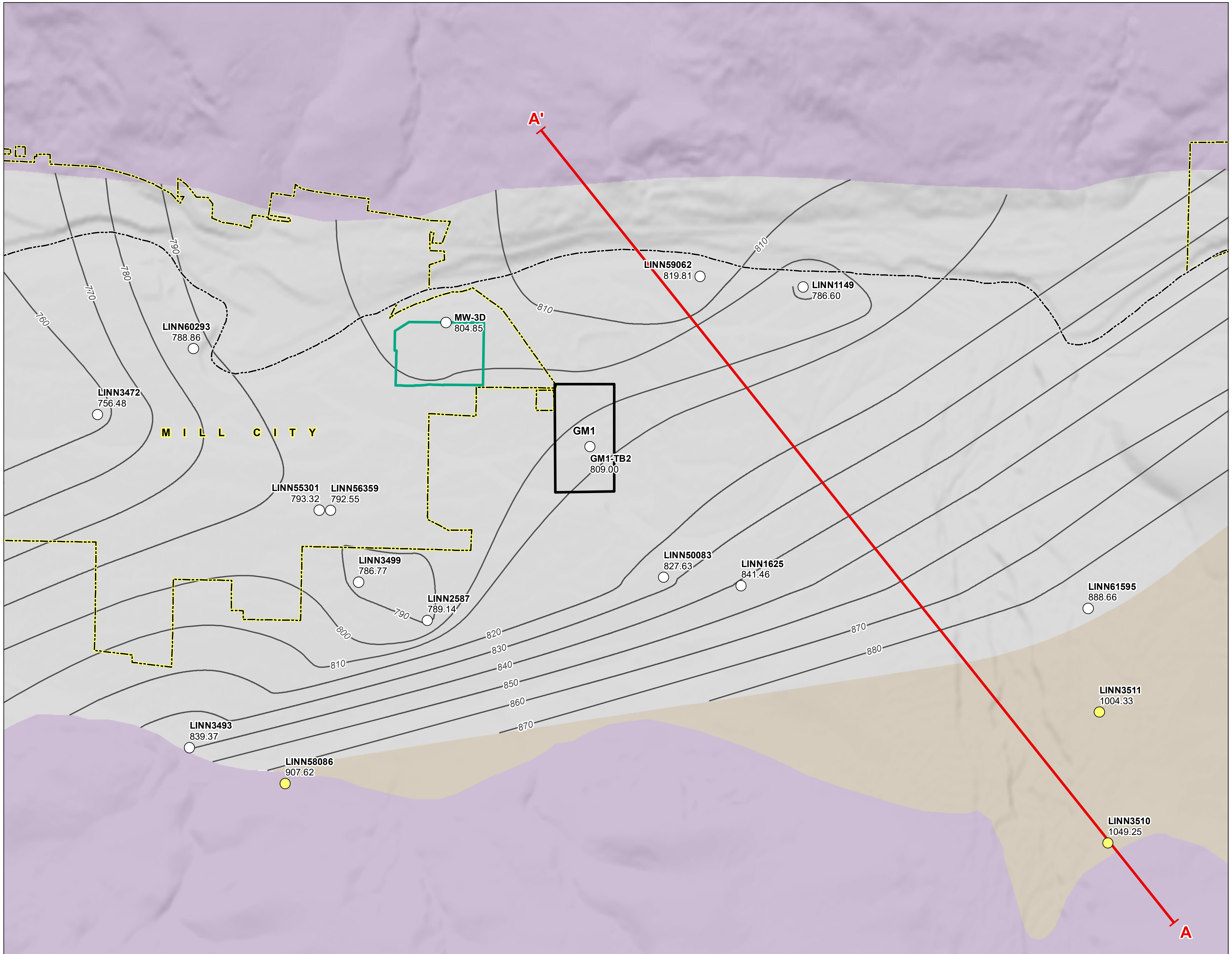
FIGURE A.1

Top of Silt/Clay Layer Elevation Contours

Fate and Transport Evaluation for Nitrate in Groundwater



LEGEND

Top of Silt/Clay Contour, Feet

Site GM1

Mill City Wastewater Treatment Plant

Wells

Well (Elevation of the Start of the Silt/Clay Layer)

Well with Silt/Clay from Ground Surface to Basalt (Elevation of the Start of the Silt/Clay Layer)

Surficial Geology

Bedrock

Sand/Gravel

Silt/Clay

All Other Features

City Boundary

County Boundary

Major Road

Watercourse

Waterbody

NOTE

Elevation data extracted from 2009 Lidar

N

0 500 1,000 1,500

Feet

Date: October 14, 2024

Data Sources: BLM, ESRI, ODOT, USGS, Aerial Photo 2020

GSI Water Solutions, Inc.

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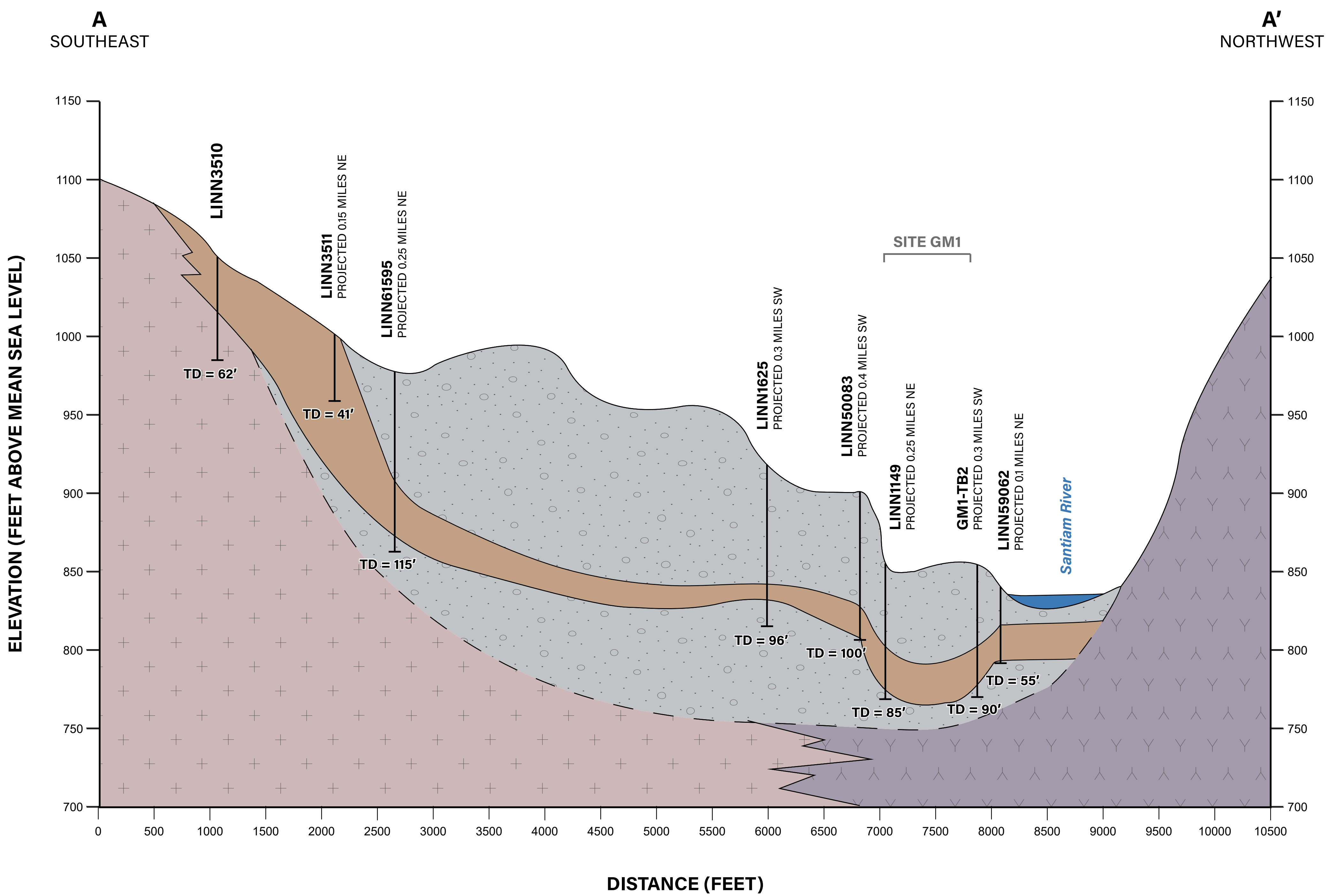
FIGURE A.2

Geologic Cross Section A

Fate and Transport Evaluation
for Nitrate in Groundwater



LEGEND

Alluvium

- Silt/Clay
- Sand/Gravel

Bedrock

- Little Butte Volcanics (Tolb)
- Tuffaceous Sedimentary Rocks, Basalt Flows and Tuffs (Tu)

NOTE

Total depth is feet below ground surface
Bedrock geology from DOGAMI

GSI Water Solutions, Inc.

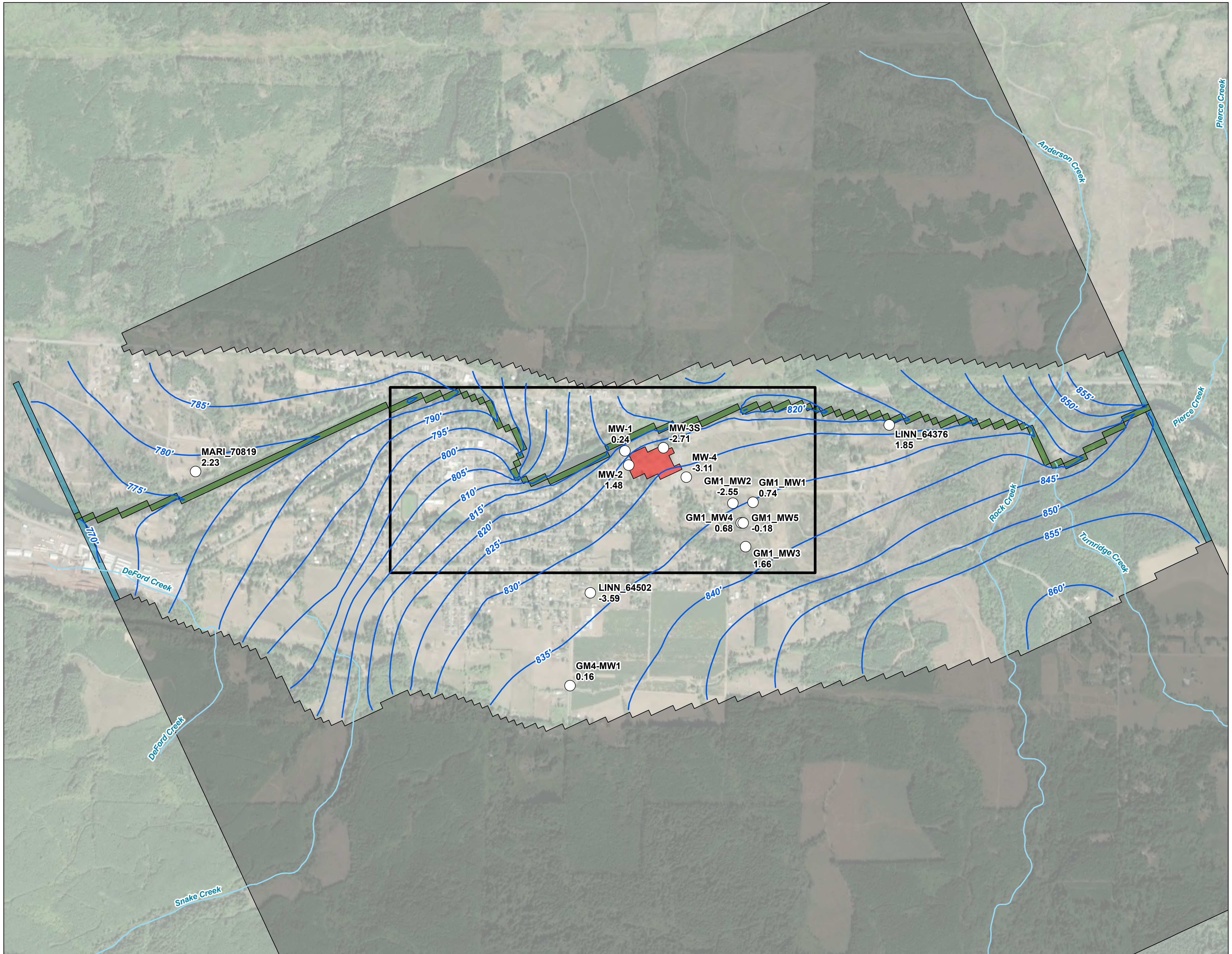


FIGURE A.3

Model Domain

Fate and Transport Evaluation for Nitrate in Groundwater

LEGEND

- Water Level Elevation Target and Residual
- Modeled Water Level Elevation Contour, June 2024 (5-foot interval)
- Existing Treated Wastewater Infiltration Facility Cell
- General Head Boundary Cell
- Stream Cell
- No Flow Cell
- Area of Interest
- Watercourse

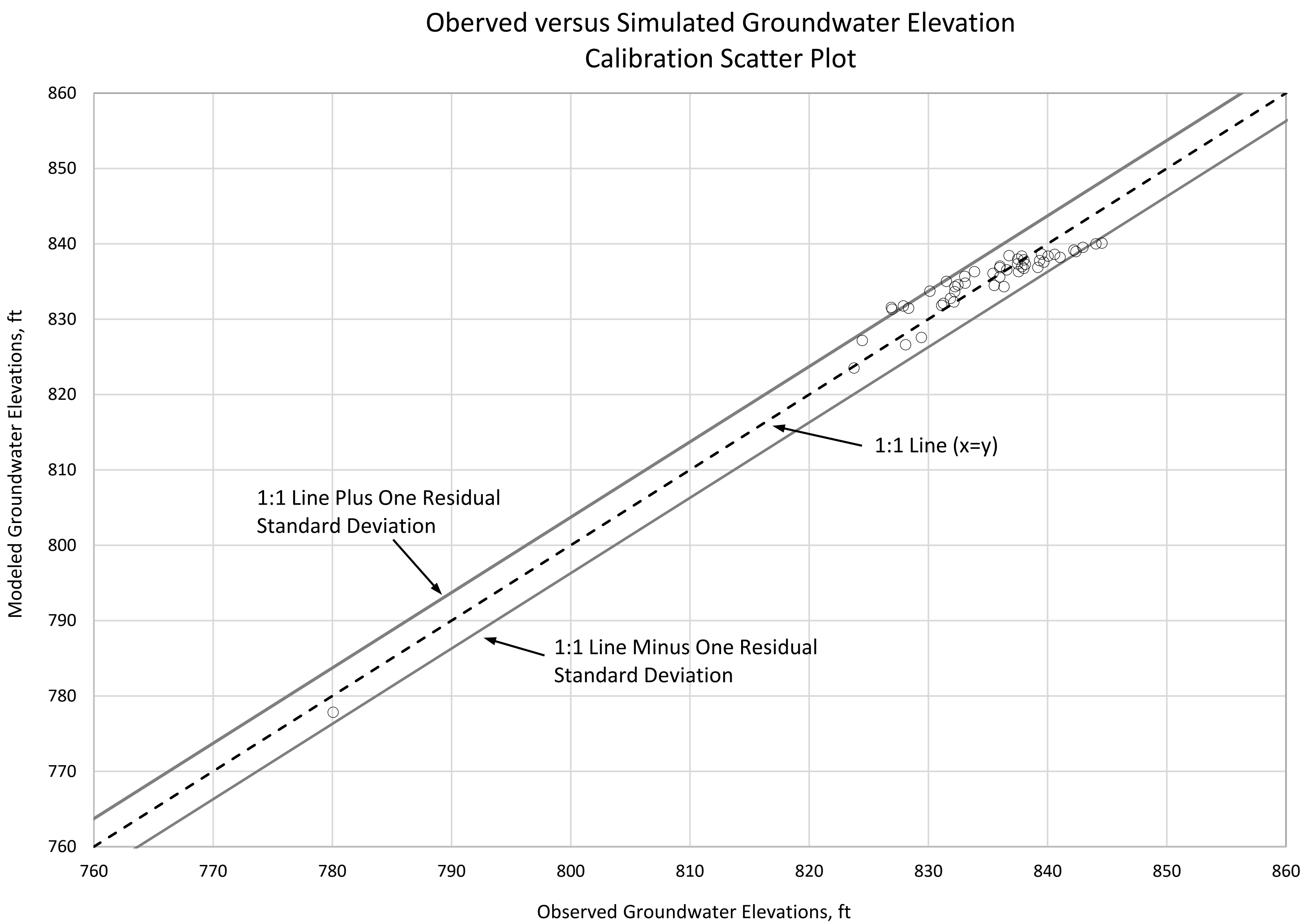
N

0 800 1,600 2,400
FEET

Date: October 14, 2024
Data Sources: BLM, ESRI, ODOT, USGS, Imagery (2022)

GSI Water Solutions, Inc.

Document Path: Y:\0464_Keller_Assoc\Source_Figures\030_MillCity_DEQ_Comments\002_Nirate_Modeling\FigureA-3_Model_Domain.aprx, FigureA3_Model_Domain, npalmer



Oberved versus Simulated Groundwater Elevation
Calibration Scatter Plot
Modeled Groundwater Elevations, ft
Observed Groundwater Elevations, ft
860
850
840
830
820
810
800
790
780
770
760
760
770
780
790
800
810
820
830
840
850
860
1:1 Line (x=y)
1:1 Line Plus One Residual Standard Deviation
1:1 Line Minus One Residual Standard Deviation

Figure A.4

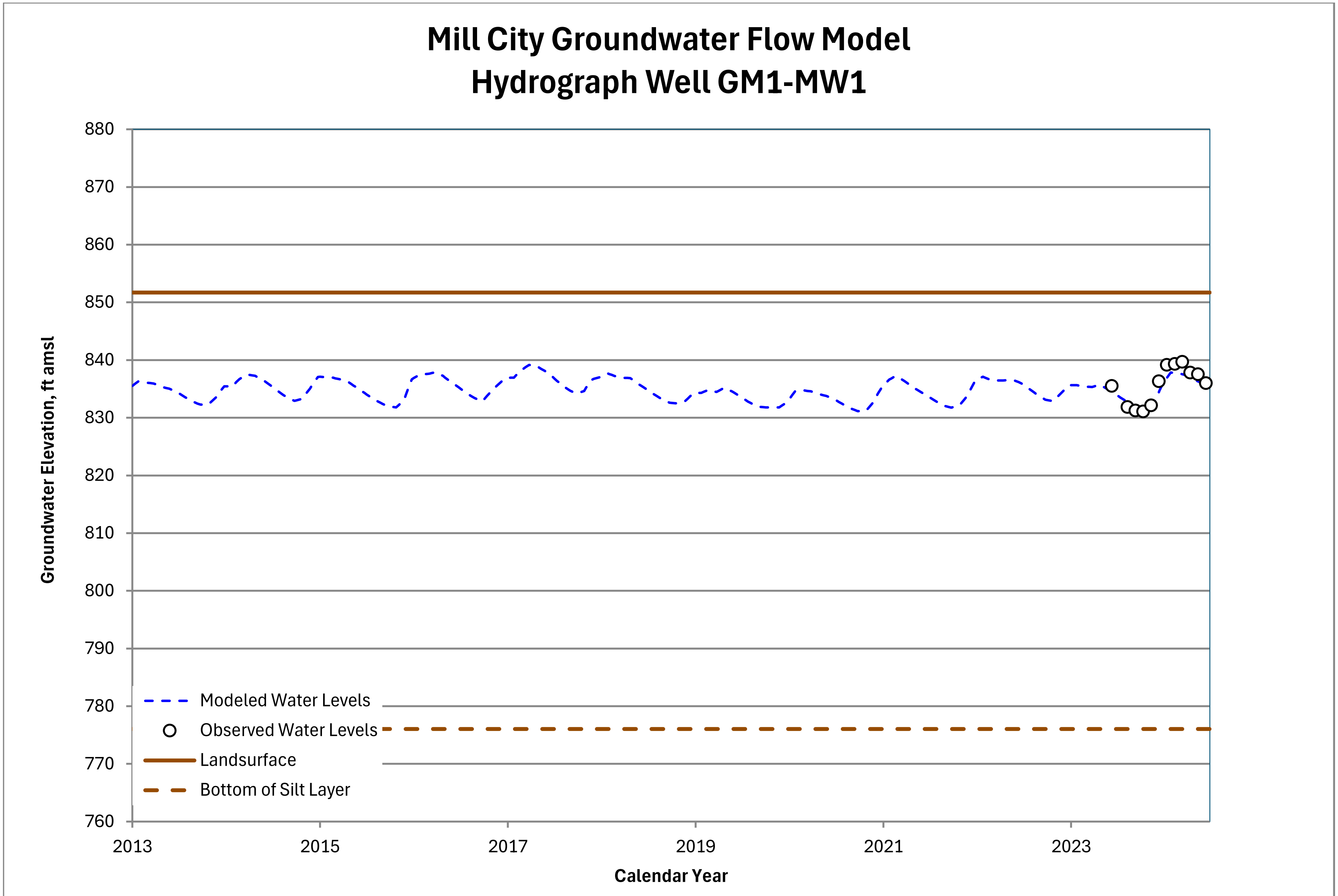
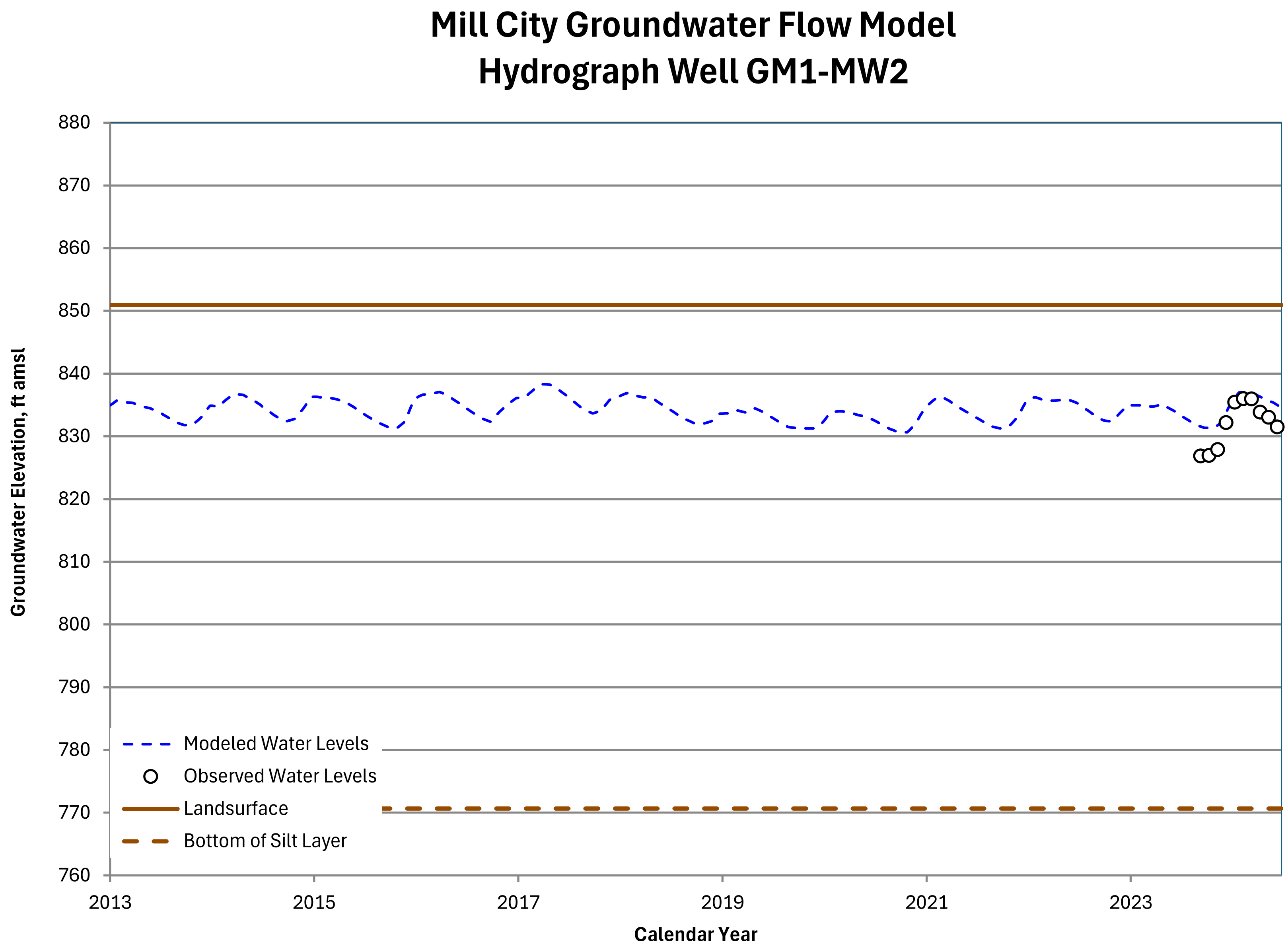
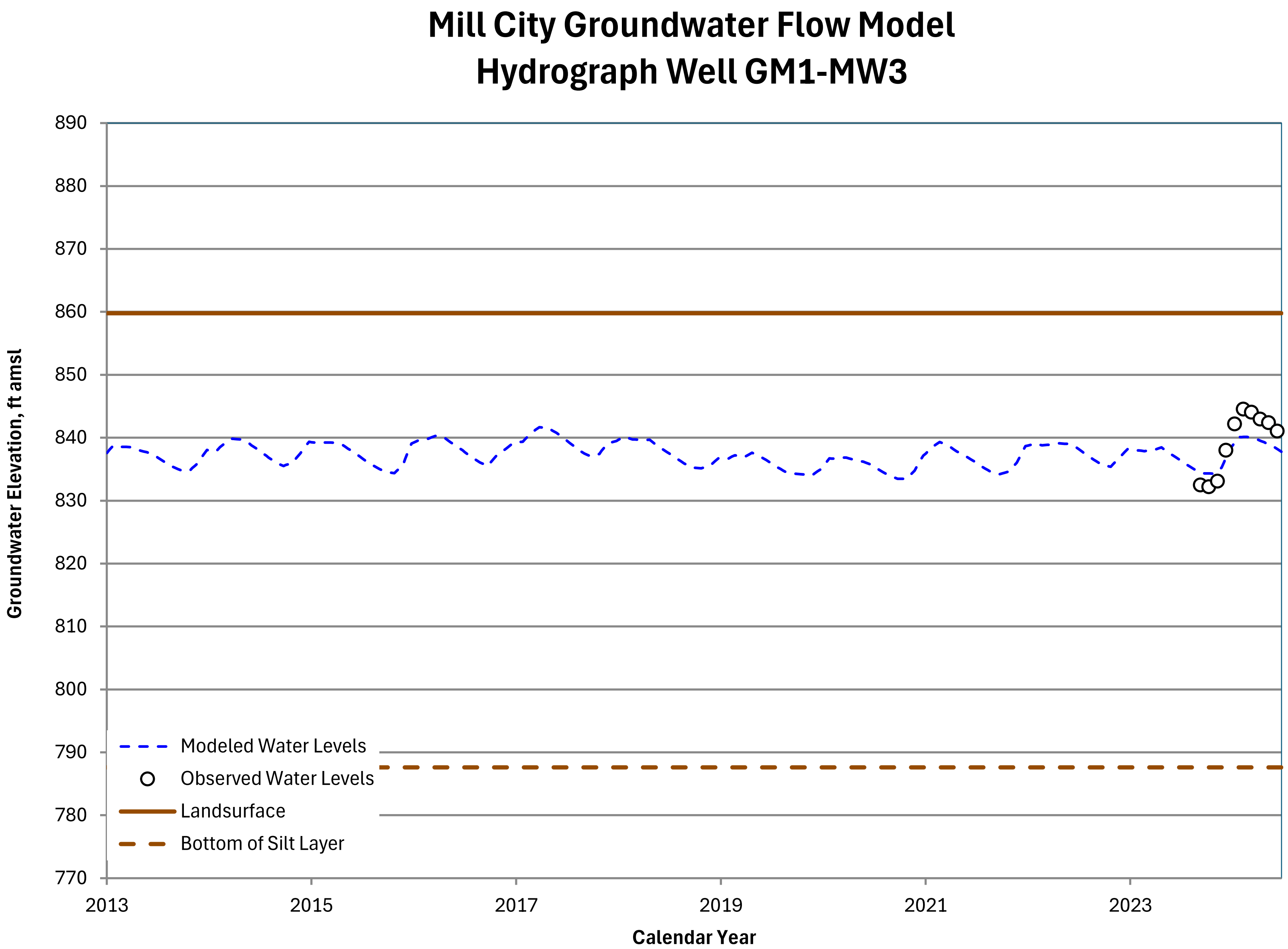

Mill City Groundwater Flow Model
Hydrograph Well GM1-MW1
880
870
860
850
840
830
820
810
800
790
780
770
760
Groundwater Elevation, ft amsl
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.6



Mill City Groundwater Flow Model
Hydrograph Well GM1-MW2
880
870
860
850
840
830
820
810
800
790
780
770
760
Groundwater Elevation, ft amsl
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.7



Mill City Groundwater Flow Model
Hydrograph Well GM1-MW3
Groundwater Elevation, ft amsl
890
880
870
860
850
840
830
820
810
800
790
780
770
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.8

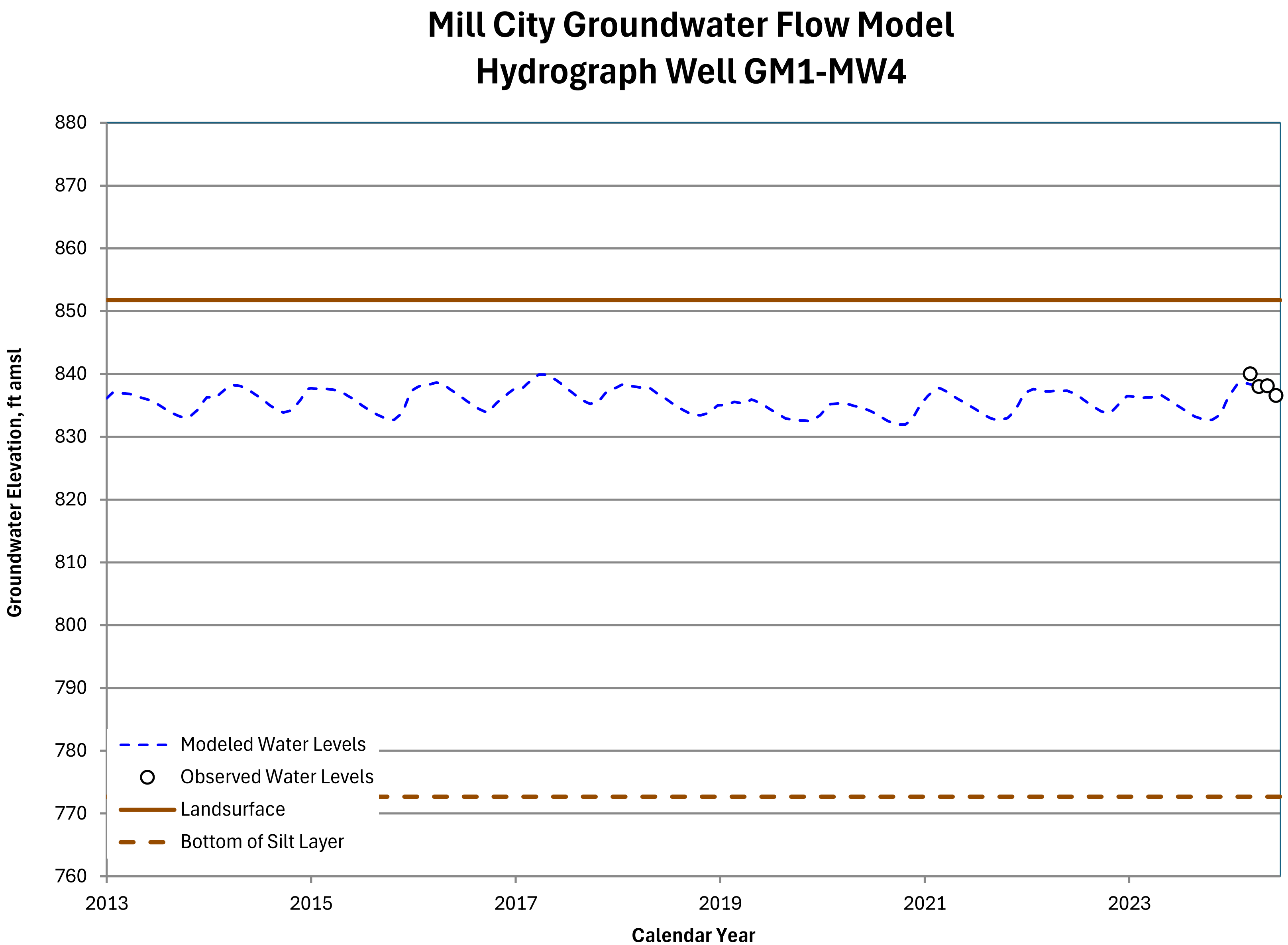
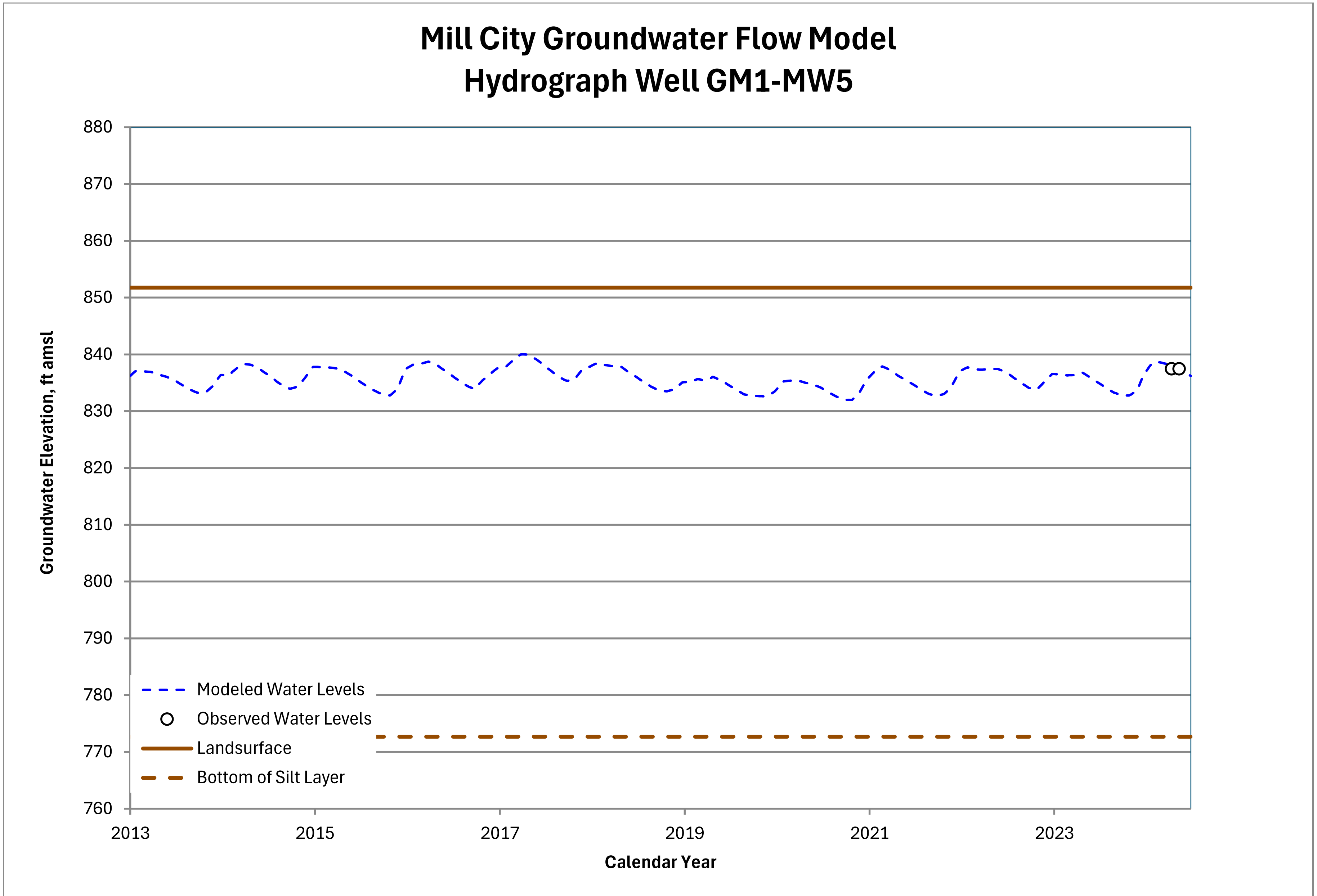

Mill City Groundwater Flow Model
Hydrograph Well GM1-MW4
Groundwater Elevation, ft amsl
880
870
860
850
840
830
820
810
800
790
780
770
760
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.9



Mill City Groundwater Flow Model
Hydrograph Well GM1-MW5
Groundwater Elevation, ft amsl
880
870
860
850
840
830
820
810
800
790
780
770
760
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.10

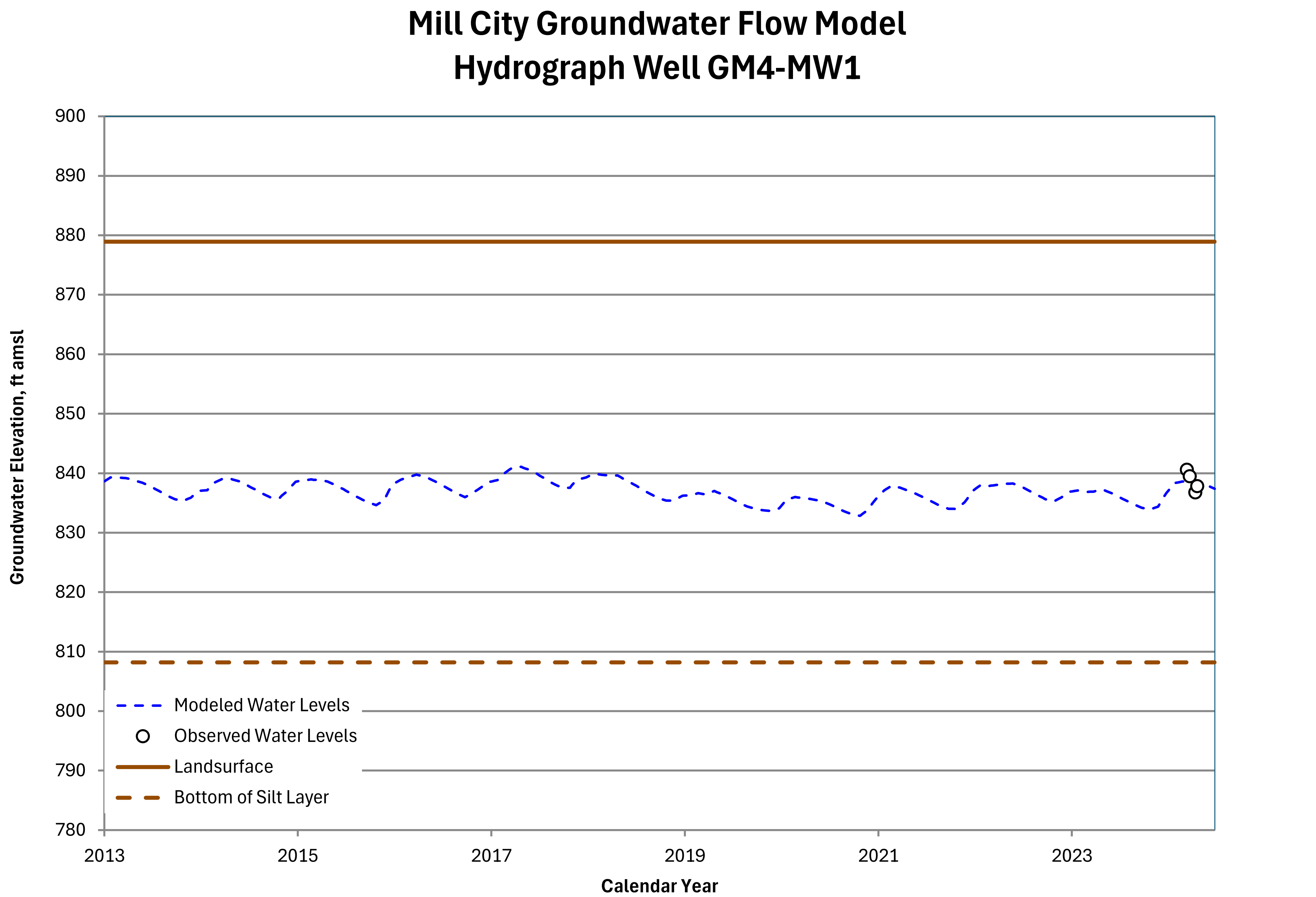
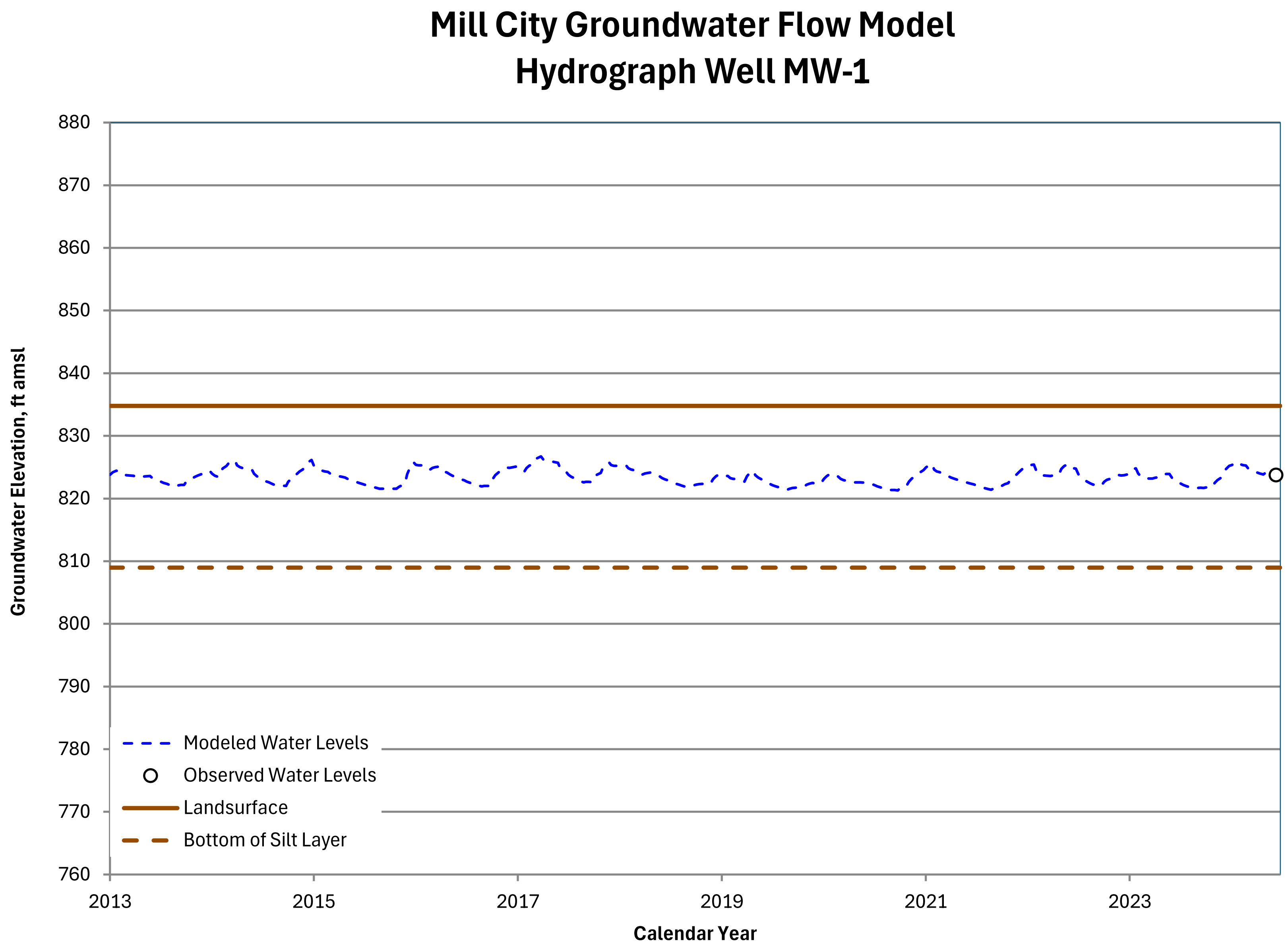
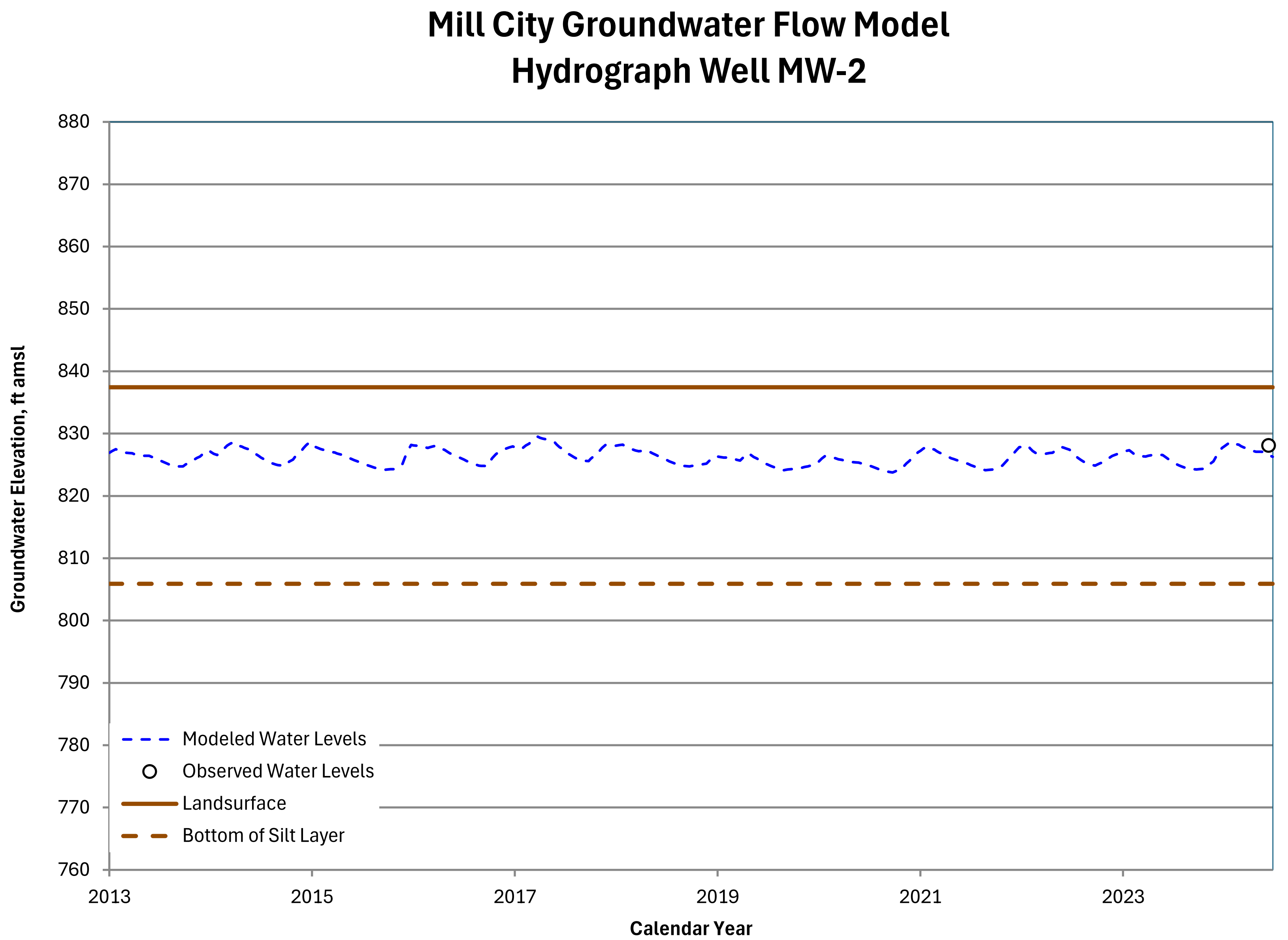

Mill City Groundwater Flow Model
Hydrograph Well GM4-MW1
Groundwater Elevation, ft amsl
900
890
880
870
860
850
840
830
820
810
800
790
780
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.12



Mill City Groundwater Flow Model
Hydrograph Well MW-1
Groundwater Elevation, ft amsl
880
870
860
850
840
830
820
810
800
790
780
770
760
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.13



Mill City Groundwater Flow Model
Hydrograph Well MW-2
Groundwater Elevation, ft amsl
880
870
860
850
840
830
820
810
800
790
780
770
760
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.14

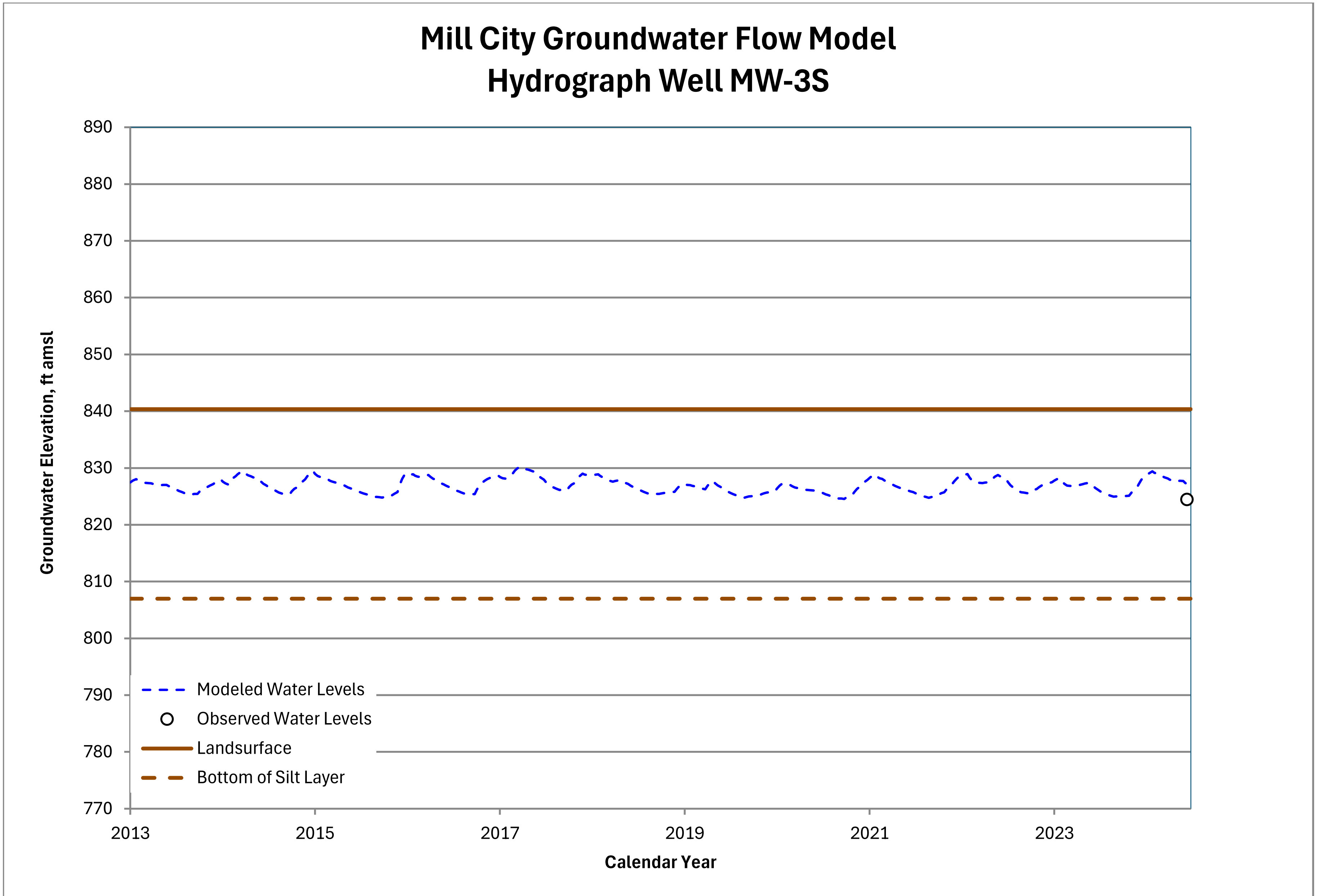

Mill City Groundwater Flow Model
Hydrograph Well MW-3S
Groundwater Elevation, ft amsl
890
880
870
860
850
840
830
820
810
800
790
780
770
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.15

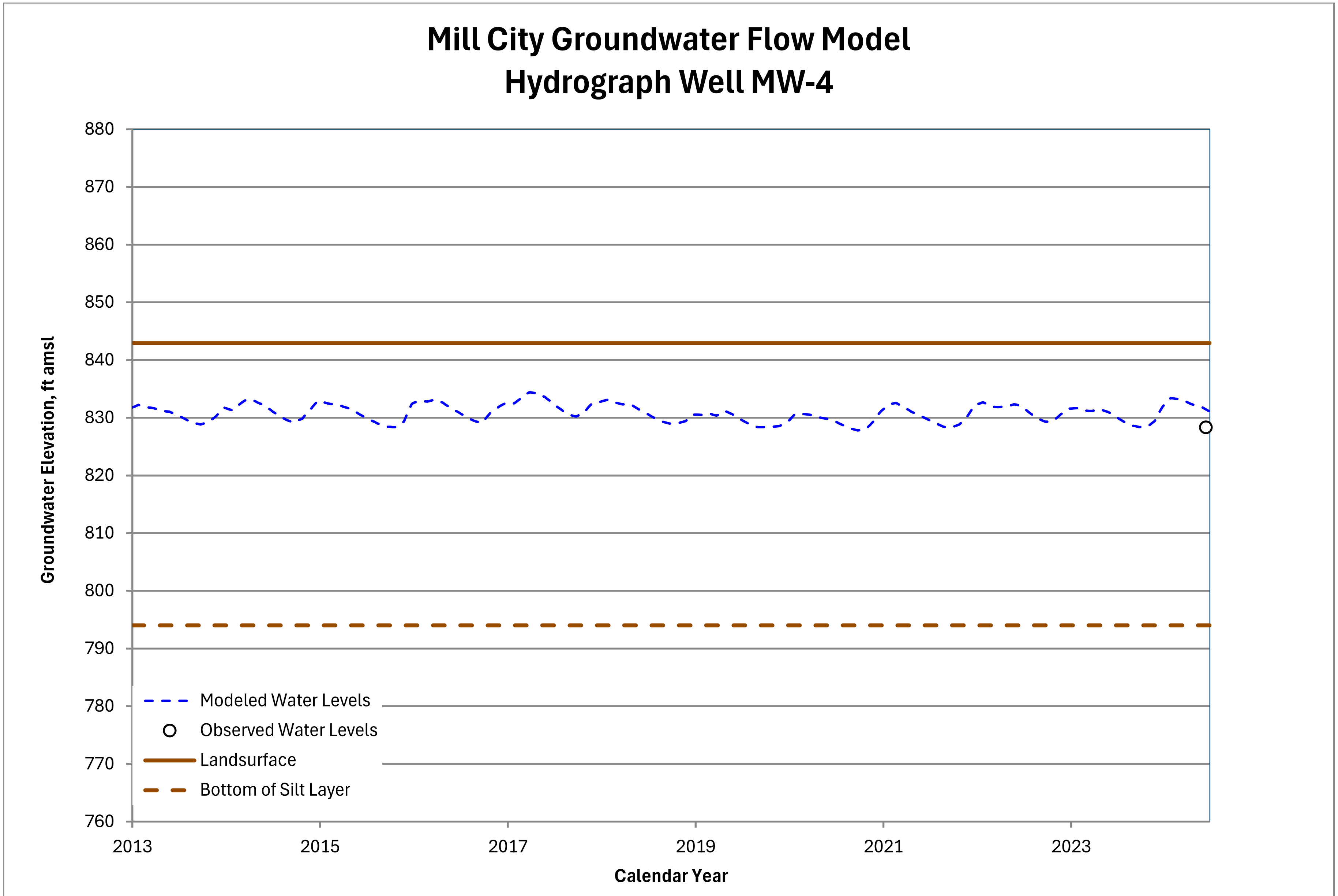
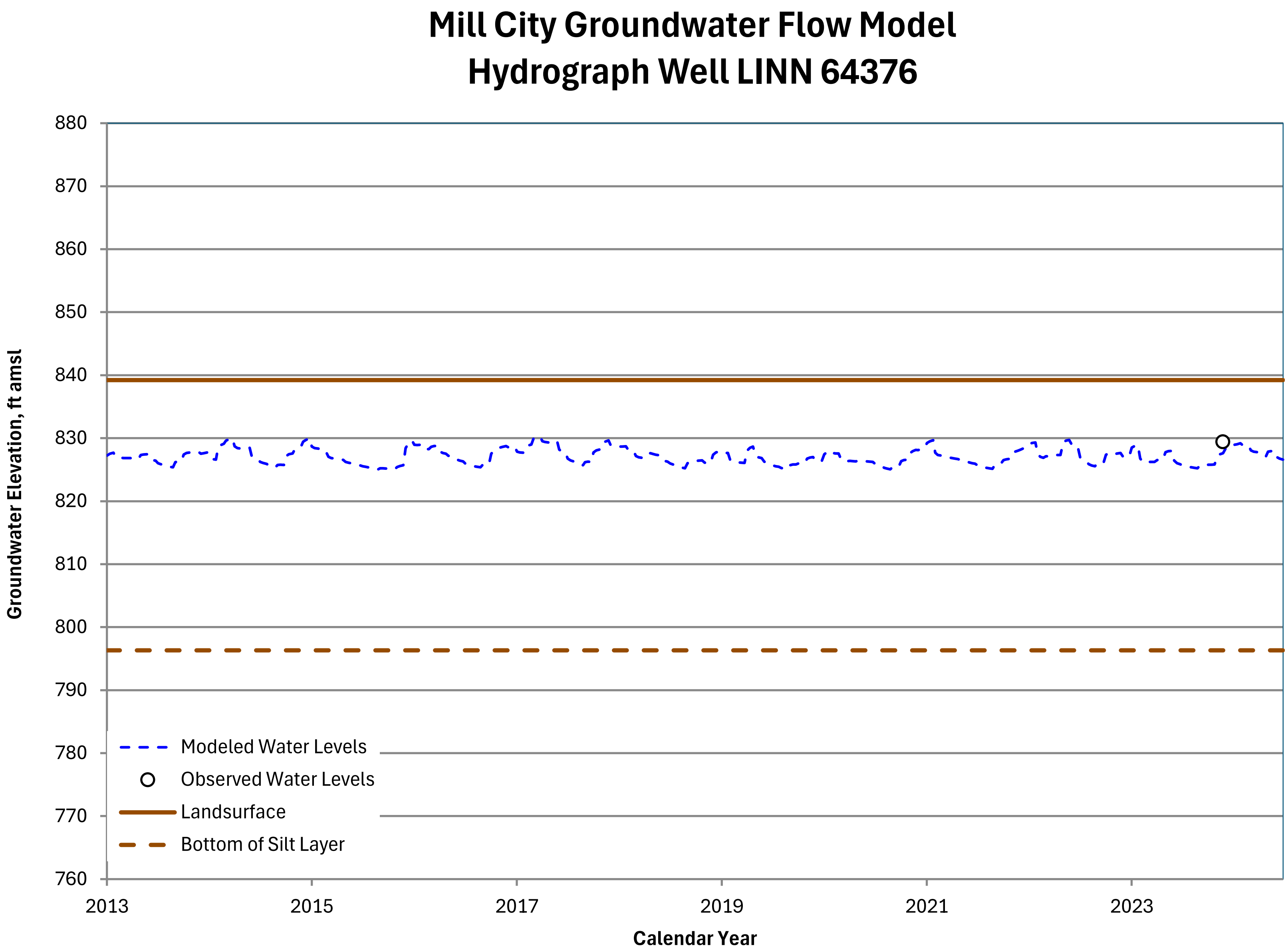

Mill City Groundwater Flow Model
Hydrograph Well MW-4
880
870
860
850
840
830
820
810
800
790
780
770
760
Groundwater Elevation, ft amsl
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.16



Mill City Groundwater Flow Model
Hydrograph Well LINN 64376
Groundwater Elevation, ft amsl
880
870
860
850
840
830
820
810
800
790
780
770
760
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.5

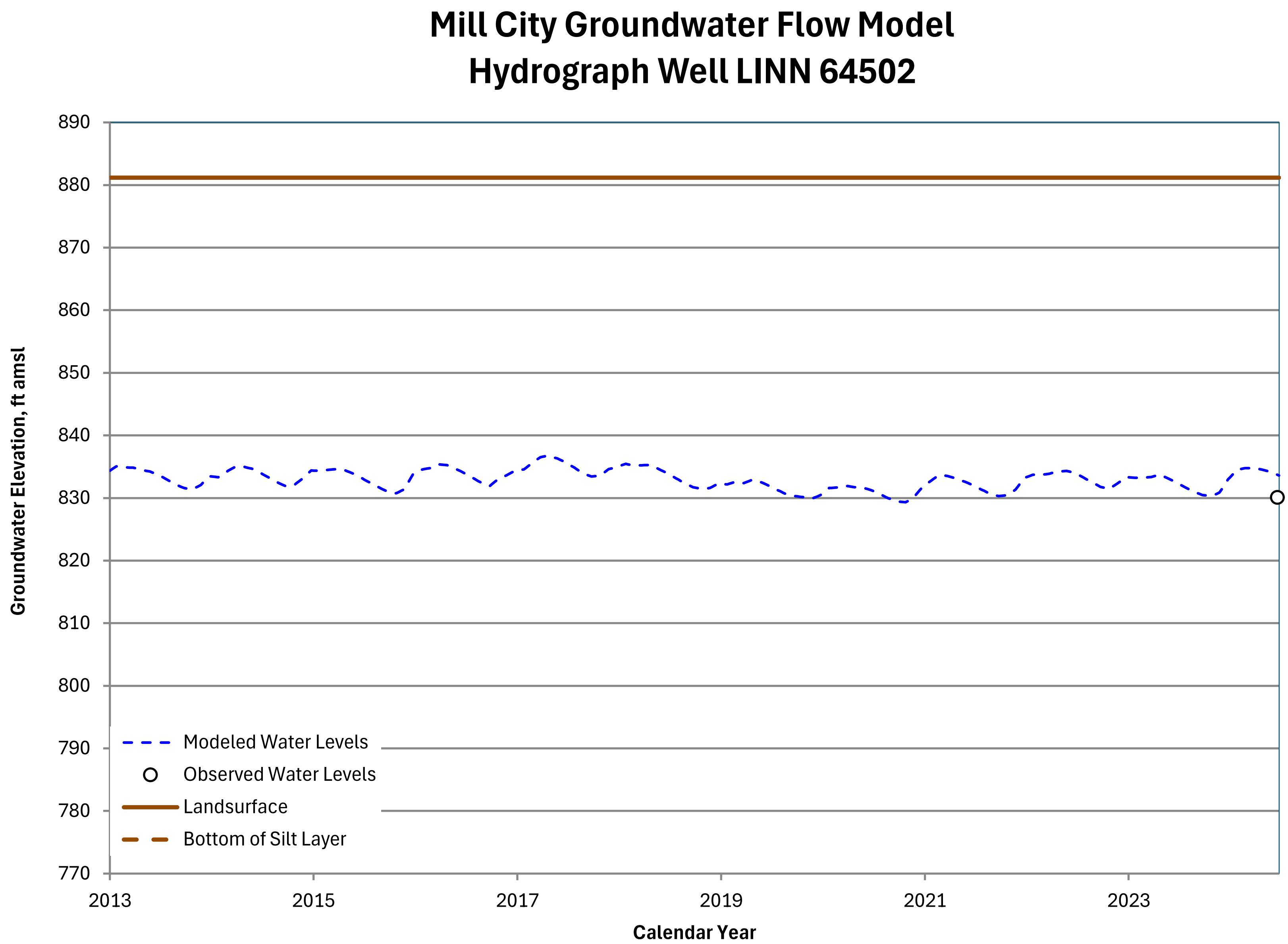

Mill City Groundwater Flow Model
Hydrograph Well LINN 64502
Groundwater Elevation, ft amsl
890
880
870
860
850
840
830
820
810
800
790
780
770
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.11

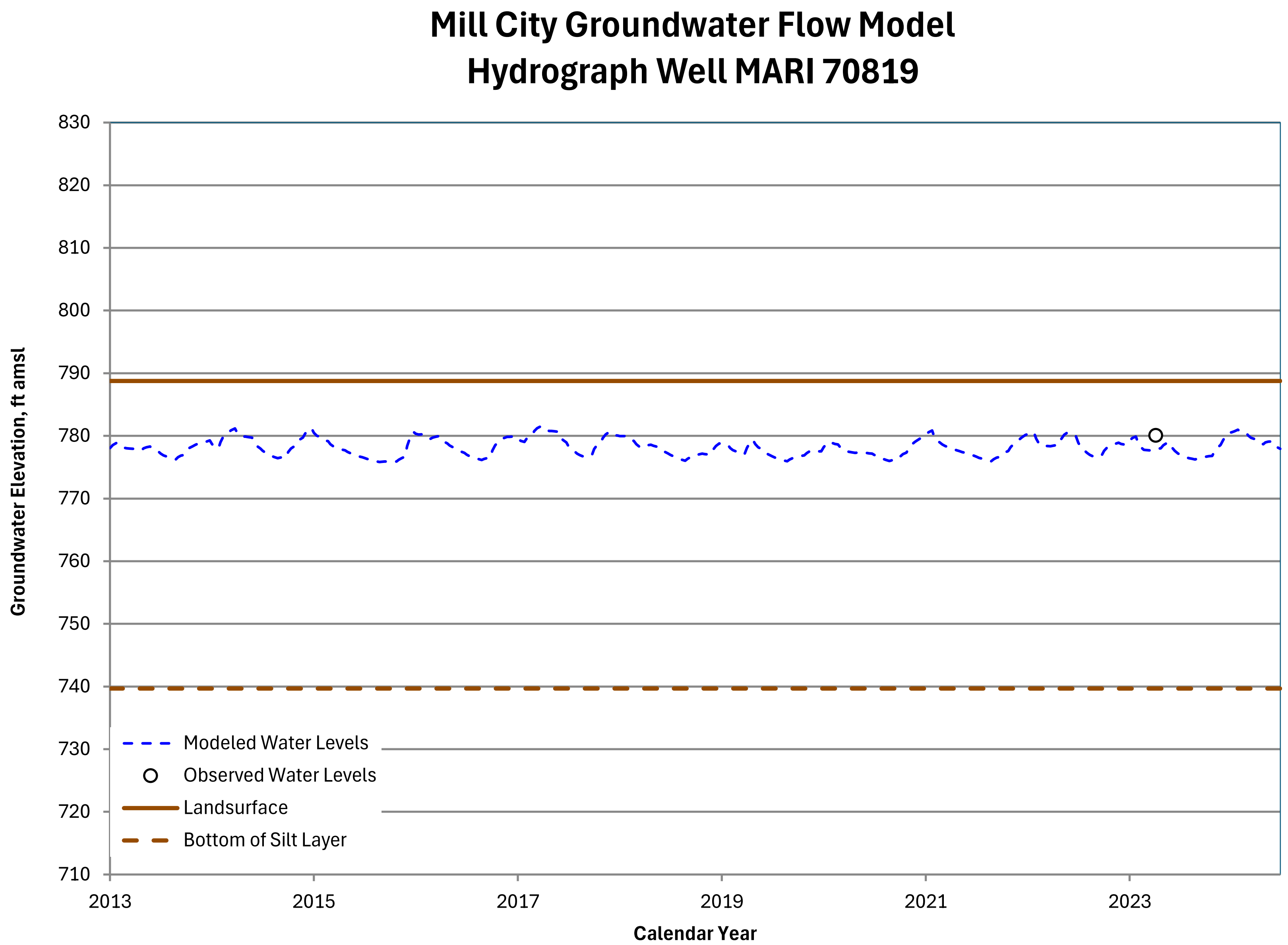

Mill City Groundwater Flow Model
Hydrograph Well MARI 70819
Groundwater Elevation, ft amsl
830
820
810
800
790
780
770
760
750
740
730
720
710
2013
2015
2017
2019
2021
2023
Calendar Year
Modeled Water Levels
Observed Water Levels
Landsurface
Bottom of Silt Layer

Figure A.17

Mill City Groundwater Fate and Transport Model
Nitrate Concentrations Adjacent to Santiam River

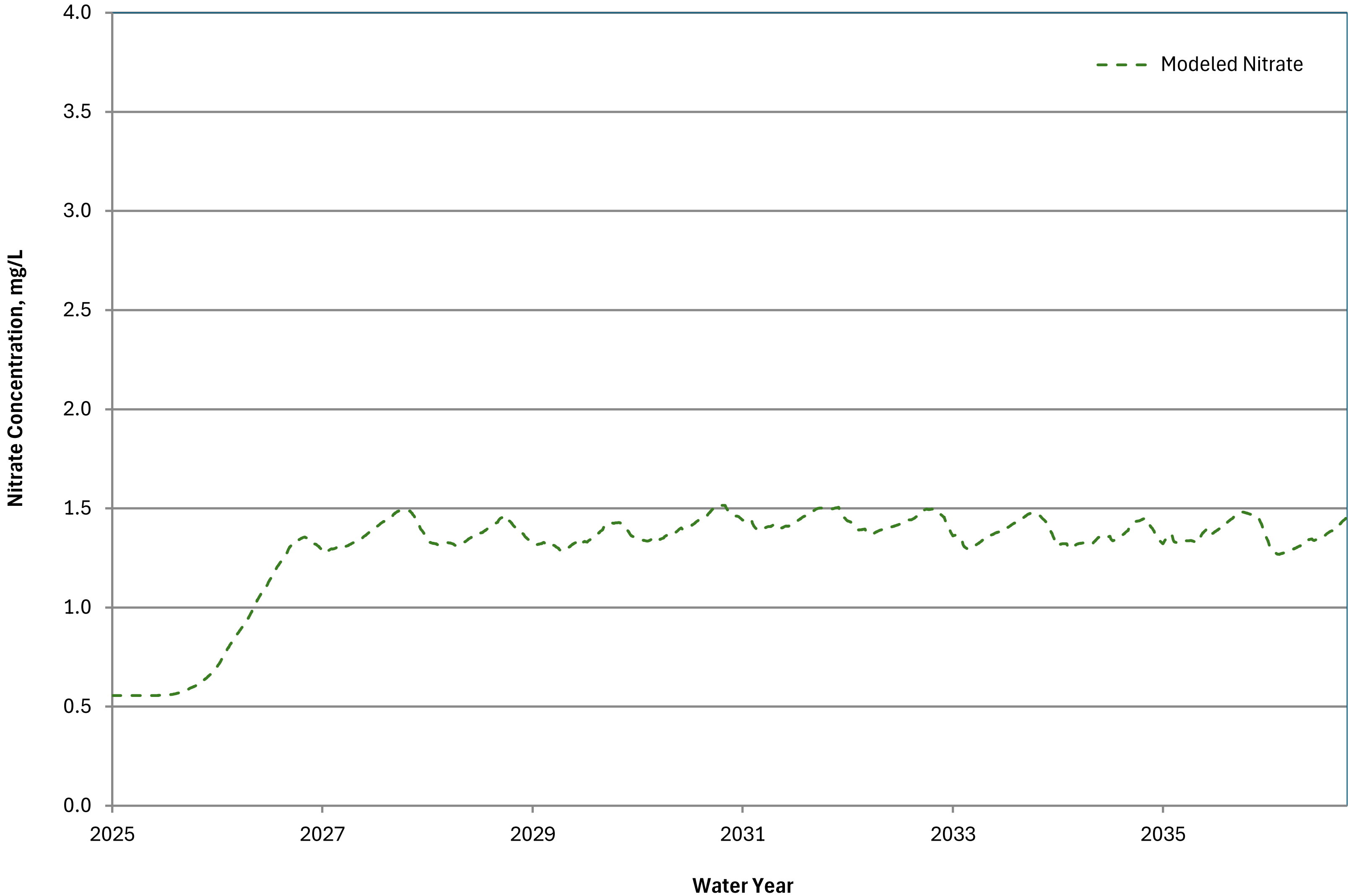


Figure A.18

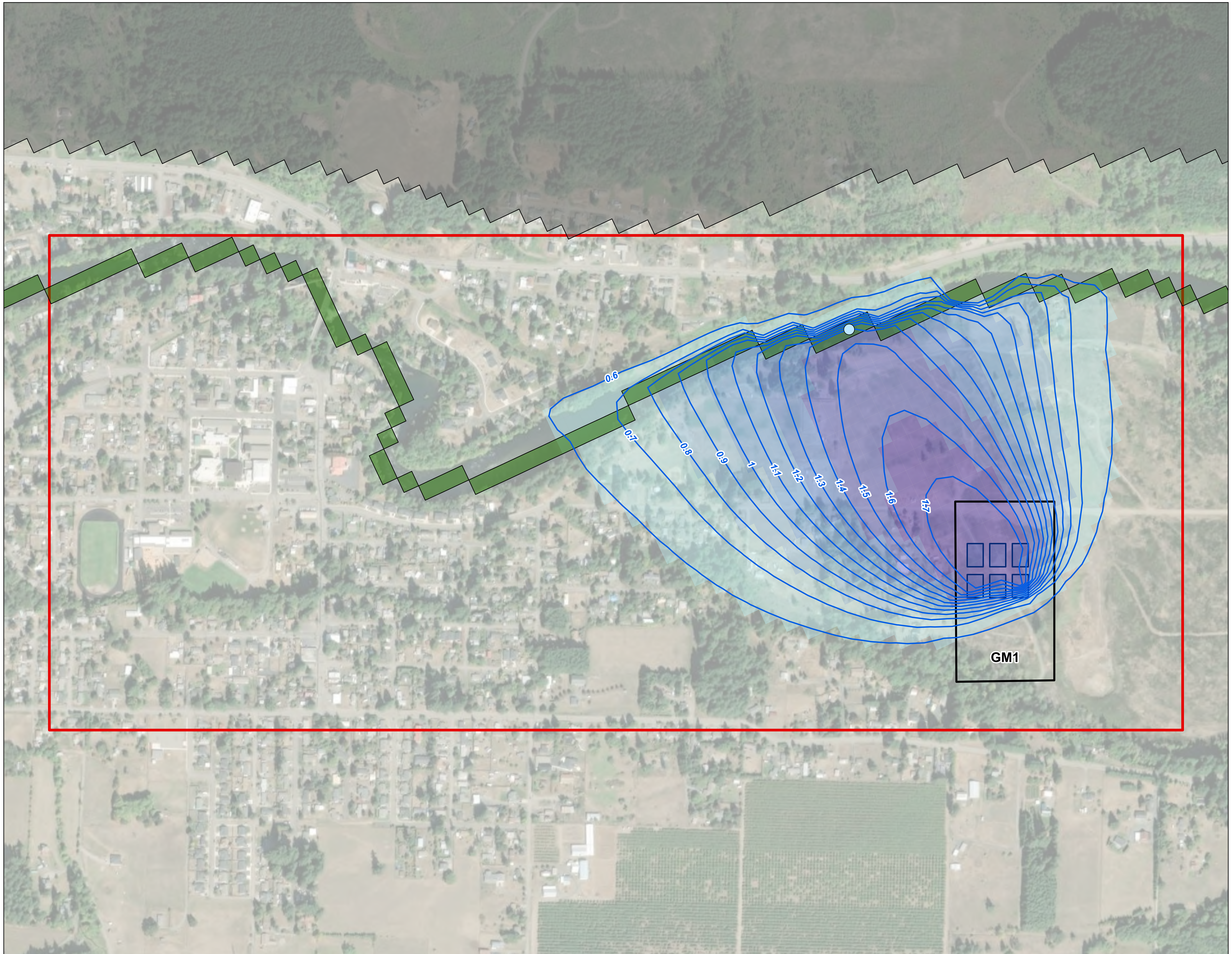


FIGURE A.19

Nitrate Concentrations in September 2045, Predictive MCF & TM Model

Fate and Transport Evaluation for Nitrate in Groundwater

LEGEND

- Nitrate Concentration Target
- Nitrate Concentration Contour (0.1 mg/L interval)
- Rapid Infiltration Basin
- Stream Cell
- No Flow Cell
- GM1 Site
- Area of Interest

Nitrate Concentration

- 0.6 - 0.8 mg/L
- 0.8 - 1.0 mg/L
- 1.0 - 1.2 mg/L
- 1.2 - 1.4 mg/L
- 1.4 - 1.6 mg/L
- 1.6 - 1.8 mg/L

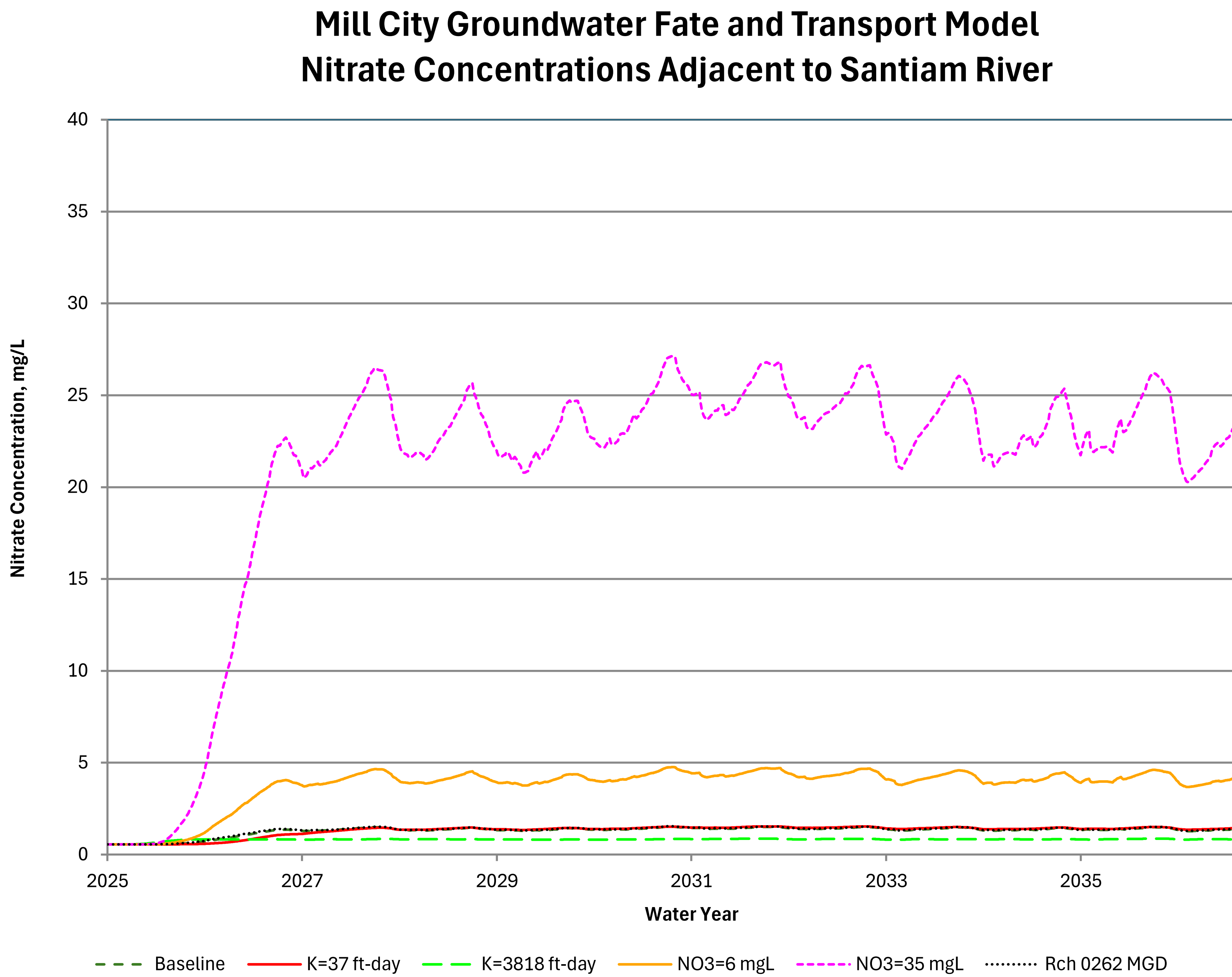
N

0 300 600 900
FEET

Date: October 14, 2024
Data Sources: BLM, ESRI, ODOT, USGS, Imagery (2022)

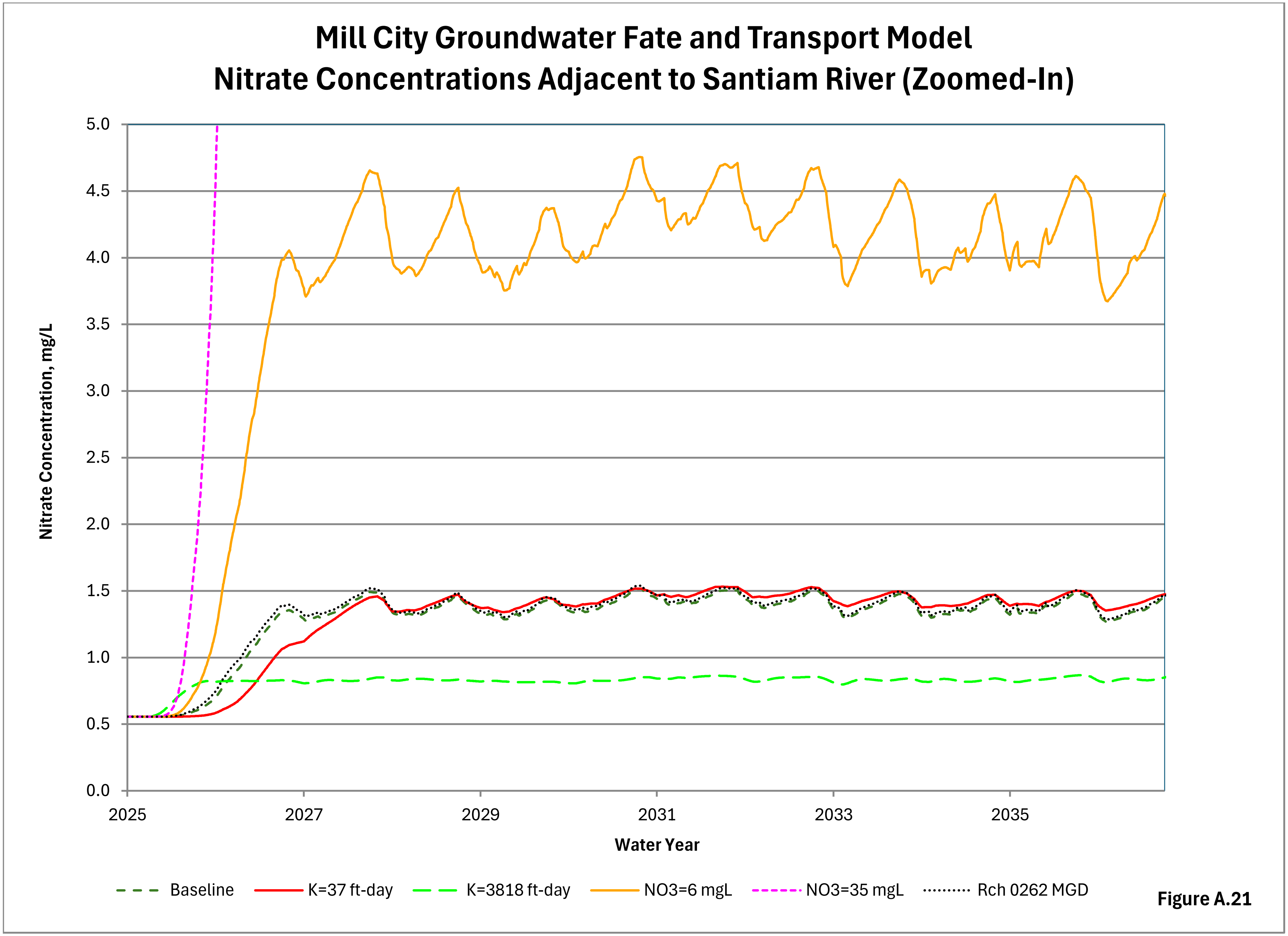
GSI Water Solutions, Inc.

Document Path: \\vms\GIS_Files\0464_Keller_Assoc\Source_Figures\030_MillCity_DEQ_Comments\002_Nirate_Modeling\FigureA-19_Nitrate2045.aprx, FigureA21_Future_Model_Nitrate_Concentration, npalmer



Mill City Groundwater Fate and Transport Model
Nitrate Concentrations Adjacent to Santiam River
Nitrate Concentration, mg/L
40
35
30
25
20
15
10
5
0
2025
2027
2029
2031
2033
2035
Water Year
Baseline
K=37 ft-day
K=3818 ft-day
NO3=6 mgL
NO3=35 mgL
Rch 0262 MGD

Figure A.20



Mill City Groundwater Fate and Transport Model
Nitrate Concentrations Adjacent to Santiam River (Zoomed-In)
Nitrate Concentration, mg/L
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2025
2027
2029
2031
2033
2035
Water Year
Baseline
K=37 ft-day
K=3818 ft-day
NO3=6 mgL
NO3=35 mgL
Rch 0262 MGD

Figure A.21