Technical Memorandum

To: Mark Umholtz, Doug Day
From: Evan Christianson, PG; John Greer, PG
Subject: Groundwater Transport Simulations for Future Conditions at Freeway Landfill
Date: September 30, 2015
Project: 23/19-1283 Freeway Landfill Groundwater Modeling
Minnesota Pollution Control Agency (MPCA) contract number 93979

1.0 Introduction

Barr Engineering conducted groundwater model simulations to estimate the potential future impacts in groundwater beneath the Freeway Landfill in Burnsville, Minnesota. As shown on Figure 1, the Landfill is located between the Minnesota River (north) and the Kraemer Quarry (south). Currently, the groundwater near the Landfill is heavily influenced by the significant, long-term dewatering operations at the Kraemer Quarry located to the south of Freeway Landfill. Barr has been working with the City of Burnsville (City) and the MPCA to estimate future groundwater conditions near the Landfill that are anticipated when the Quarry ceases operation and discontinues dewatering pumping.

The modeling presented in this memo involves simulations of contaminant transport associated with contaminants leaching from waste to shallow groundwater and migrating towards the Minnesota River and a future pit-lake that will form when dewatering ceases at the Kraemer Quarry. The transport simulations discussed in this memo include 1) the average condition with the pit-lake stage at an elevation of 690 feet above mean sea level (ft MSL) and 2) a 100-year flood. The MPCA installed new monitoring wells at the Freeway Landfill (see Figure 2) and collected groundwater samples from these wells in June 2015. These simulations used the groundwater analytical results from the June 2015 MPCA groundwater investigation and built off previous groundwater modeling work completed by Barr Engineering for the City. The previous modeling was conducted to assess future water table conditions near Freeway Landfill after dewatering in the Quarry ceases. In general, the previous modeling effort indicated that groundwater elevations will rise after the Kraemer Quarry operations cease and that the shallow water table will intercept the waste in the Landfill in some areas. A Technical Memorandum dated May 22, 2015 (Barr Engineering, 2015), provides description of the previous modeling work that included model development, calibration, simulation of various potential quarry pit-lake stages, and assessment of the potential for the water table to rise above the bottom of the waste in the Landfill.

2.0 Simulation of Groundwater Contaminant Concentrations Under Future Conditions (Post-Pit Dewatering)

The potential transport of contaminants leaching from the Landfill to shallow groundwater was simulated for two future conditions; a long term average condition (steady-state) and a 100-year flood condition (transient).

2.1 Changes to the Groundwater Flow Model

The groundwater flow model as described in the May 22, 2015 Technical Memorandum (Barr, 2015) was used to generate the groundwater flow field for both the average and 100-year flood conditions. The following changes were made to the model:

- All simulations assumed a pit-lake stage of 690 feet; the lowest stage that the City of Burnsville believes they will be able to maintain. Based on results presented in the May 2015 memo, and current infrastructure in place at the Quarry, additional mechanical methods (i.e. pumping) would be necessary to maintain a pit-lake stage below 690 feet. For the 100-year flood scenario the pit-lake stage was initially at an elevation of 690 feet above mean sea level and allowed to rise during the flood event and then fall back to 690 feet after the flood.
- For the 100-year flood scenario the Minnesota River was simulated with the Reservoir Package of MODFLOW instead of the River Package. The Reservoir Package allows for the stage and areal extent of the river to be adjusted through time, whereas the River Package uses a fixed stage and area. The stage of the river was allowed to rise to an elevation of 716 feet, which is the 100-year flood stage for the reach of the Minnesota River near the Landfill (FEMA, 2011). The total flood time was based on review of previous floods of similar magnitude and set at 120 days (60-day rise and 60-day fall).
- Transient simulations of the 100-year flood scenario require the inclusion of aquifer storage parameters (specific yield and specific storage). Storage parameter values were obtained from the Twin Cities Metropolitan Area Regional Groundwater Flow Model, Version 3 (Metro Model 3, Metropolitan Council, 2014). As described in the May 2015 memo, Metro Model 3 was the base model used in the construction of the model used for this study.

2.2 Groundwater Transport Modeling

The groundwater transport model MT3DMS (Zheng and Wang, 1999; Zheng, 2010) was used to simulate the transport of contaminants in groundwater. MT3DMS interfaces directly with MODFLOW, which was used to simulate groundwater flow. Conservative groundwater transport was simulated (i.e. dispersion was included but contaminant attenuation, retardation, or degradation were not included). Contaminants of concern evaluated included selected metals and PFOA. No data were available to suggest significant attenuation or retardation of dissolved metals is occurring in the groundwater at the Landfill site. It is not known if attenuation and degradation would be important for groundwater transport modeling of some other constituents, such as VOCs. However, simulation of these constituents was not part of the scope of this work and VOCs present less concern based on monitoring data collected in June, 2015 (See Section 2.2.1).

2.2.1 Source Concentration

The MPCA installed ten monitoring wells at eight locations at the Landfill in June, 2015. At each location, a monitoring well was installed within the landfill waste with the bottom of the well set at or near the top of Prairie du Chien (the uppermost bedrock unit beneath the site). At two of the locations, a paired deeper well was installed in the Prairie du Chien and below the water table. The locations of the monitoring wells (Figure 2) were chosen to try and target areas where previous data (Gorman Surveying, 2005) indicated the waste was wet. Eight of the ten monitoring wells yielded sufficient volumes of water to allow collection of groundwater samples. Wells MW-02 and MW-03 were dry and samples were not collected from these locations. Two rounds of groundwater sampling were conducted by the MPCA; June 17-18, 2015 and June 23-24, 2015. Results from these sampling events are summarized in Attachment A.

The results from the June 2015 sampling events were used to define source concentrations for the transport simulations. The following method was used:

- The average concentration for each constituent was calculated from all shallow well locations where water was present in the waste (the data from the deeper wells was not used and there was no data for two of the shallow wells because they were dry). This average concentration was used as a constant source concentration in the MT3DMS transport model.
- If the dissolved concentration of a constituent in a sample from a shallow well was reported as "non-detect" then the constituent concentration in that sample was assumed to be one-half the reporting limit in the calculation of the average concentration for that constituent. For example, the dissolved concentrations of mercury were reported as non-detect for the shallow groundwater samples collected in June 2015 so the calculated average concentration for mercury included this approach for the samples. This is an industry-standard approach to using "non-detect" results.
- The constant source was applied at the water table for areas where the water table is predicted to rise above the bottom of waste. The modeled source area footprint is shown on Figure 3.
- For the flood simulation, areas where additional waste is predicted to become wet (i.e., be below the water table) during a flood event were set as source areas at the same average concentrations. However, these areas were only active as a contaminant source during the flood

event. The maximum extent of the source area footprint used in the flood simulation is shown on Figure 3.

- Transport simulations were conducted for those constituents that were present at elevated concentrations with respect to the corresponding water quality standards (see Table 1) and were present in most samples. Results from these transport simulations were used to estimate concentrations for other constituents (see Section 2.4)

2.3 Uncertainty Analysis

To address uncertainty in the model predictions, simulations were conducted using numerous parameter sets. A subset of parameter sets used for previous modeling uncertainty analysis described in the May 22, 2015 memo were used. Latin hypercube sampling (Swiler and Wyss, 2004; Watermark Numerical Computing, 2012) was used to generate 1000 unique parameter sets, allowing parameters to vary over expected ranges. Model simulations were then conducted using these parameter sets and the results were compared to the calibration dataset. Parameter combinations that resulted in no more than a 5% increase in the calibration objective function (error of best-fit model to measured data) were deemed acceptable and used to assess potential future conditions. Parameter sets that resulted in more than a 5% increase in the calibration objective function were deemed unacceptable (i.e. poor model fit to observations) and excluded from further analysis. A total of 298 unique parameter combinations, out of 1000 possible, were ultimately deemed acceptable. For previous assessments of future water table elevations, described in the May 22, 2105 memo, all 298 parameter sets were used for uncertainty analysis. However, for transport simulations a random subset of 20 parameter sets was used because of the much longer model runtimes associated with transport simulations. Using all 298 parameter sets was deemed not practical given project time constraints and computing resources.

The 20 parameter sets described above account for variations in only hydraulic parameters (e.g. hydraulic conductivity). They do not account for uncertainty in transport parameters. Because conservative transport was simulated, the main parameter controlling groundwater concentrations is dispersivity. Simulations were conducted using each of the 20 hydraulic parameter datasets while also varying the longitudinal dispersivity from 1, to 10, to 100. The ratios of longitudinal to transverse dispersivity and longitudinal to vertical dispersivity were 10 and 100 respectively for all simulations. In total, 60 parameter sets were developed for assessing the uncertainty in transport simulations.

2.4 Results

Results from the groundwater transport simulations for average, steady-state, conditions are presented in Table 1. Four constituents were simulated with MODFLOW-MT3DMS: chromium, cobalt, copper, and chloride. Based on sampling data from June 2015, these constituents were prevalent in all samples and of most concern since their concentrations in the June 2015 groundwater samples exceed surface water standards (Attachment A). The modeled areal distribution of cobalt is shown on Figure 4. Transport of the remaining constituents was estimated based on the simulations of chromium, cobalt, copper, and chloride (Table 1). Because the transport simulations assume conservative transport (i.e. no degradation or retardation) and use the same source area (area where water table is predicted to rise into the waste) results for other constituents and source concentrations can be estimated by assuming conservative transport and applying the same ratio between source concentration and maximum concentration at a receptor determined by the MODFLOW-MT3DMS simulations. Maximum concentrations discharging to the river and pit-lake (Table 1) represent the maximum simulated concentration at any model cell that discharges into each receptor. Concentrations are presented as a range and represent the range of maximum concentrations determined through 60 separate simulations with 60 different parameter sets as described in Section 2.3. Groundwater discharging to either the pit-lake or river exceeds water quality standards for the following constituents (purple and blue highlights in Table 1): chromium, cobalt, chloride, antimony, arsenic, cadmium, iron, lead, manganese, mercury, nickel, zinc, and perfluorooctanoic acid (PFOA). It is noted that water quality standards for chromium are based on hexavalent chromium; samples for chromium were not analyzed for hexavalent chromium.

Results from the 100-yr flood scenario are presented in Table 2. Maximum concentrations discharging to the River and pit-lake increase slightly over the non-flood scenario simply because of a larger source area during the flood event as the water table rises. The modeled maximum areal distribution of cobalt is for the flood scenario does not differ significantly from the steady-state scenario.

2.5 Limitations of Model Simulations

The model simulations conducted for this study were designed to simulate conditions at the Landfill that do not currently exist but are anticipated in the future after dewatering at the Kraemer Quarry stops. Groundwater sample data collected in June 2015 were used as a surrogate for what groundwater concentrations may be in the future when the water table is in contact with the waste. The June 2015 sampling locations were targeted at locations previously identified to have wet waste. As the water table rises beneath the Landfill, more waste is predicted to come into contact with groundwater. Concentrations of contaminants in groundwater for the areas where waste will intersect the water table in the future are unknown. The June 2015 data provides a current estimate of source concentrations for groundwater, but likely does not capture the full range of potential concentrations (both higher and lower) that will occur when future conditions emerge.

Conservative transport was used for all simulations. This assumption was deemed to be valid given the contaminants of most concern are dissolved metals and no data exists to suggest that significant attenuation or retardation of these metals will occur during transport from the Landfill to either the future pit-lake or the River. In addition, transport of PFOA would be expected to occur in a conservative manner as well. Other potential contaminants, such as VOCs, may degrade or be attenuated during transport to the pit-lake or River.

3.0 References

Barr Engineering (Barr), 2015. Simulations of Future Kraemer Quarry Pit-Lake Stage and Rise of the Water Table at the Freeway Landfill, Technical Memorandum from Evan Christianson and John Greer to Steve Albrecht, May 22, 2015.

Federal Emergency Management Agency (FEMA). 2011. Flood Insurance Study, Dakota County Minnesota and Incorporated Areas, Study Number 27037CV001A. Volume 1 of 3, Cross Section X.

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Metropolitan Council. 2014. Twin Cities Metropolitan Area Regional Groundwater Flow Model, Version 3.0. Prepared by Barr Engineering. Metropolitan Council: Saint Paul, MN.

Swiler, L.P. and Wyss, G.D. 2004. A User's Guide to Sandia's Latin Hypercube Sampling Software: LHS UNIX Library/Standalone Version. Sandia National Laboratories, Report SAND2004-2439.

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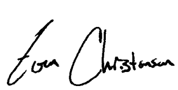
Zheng, C., 2010, MT3DMS v5.3 Supplemental User's Guide, Department of Geological Sciences, University of Alabama, Tuscaloosa, Alabama.

Certification

I hereby certify that this plan, document, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Geologist under the laws of the state of Minnesota.



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September 30, 2015

Evan G. Christianson
PG #: 51379

Date

Table 1

Results of Groundwater Transport Simulations for Average Steady-State Conditions

Model Simulations, Steady-State Flow Field, Conservative Constituents[e]												
				Water Quality Standards								
	Avg. Concentration from June 2015[a]	**Range of Simulated Maximum Concentration to River[d]**	**Range of Simulated Maximum Concentration to Pit Lake[d]**	**Class 2A Chronic (350 Hardness)**	**Class 2A Maximum (350 Hardness)**	**Class 2A Acute (350 Hardness)**	**Class 2B Chronic (350 Hardness)**	**Class 2B Maximum (350 Hardness)**	**Class 2B Acute (350 Hardness)**	**EPA Secondary Drinking Water Regulations**	**MDH Human Health Based Water Guidance**	**EPA Maximum Contaminant Levels**
Chromium (µg/L)[b]	35.7	8.7 - 21.0	7.4 - 33.8	11 (CR6)	16 (CR6)	31 (CR6)	11 (CR6)	16 (CR6)	31 (CR6)	--	100 (CR6)	100
Cobalt (µg/L)	89.5	21.9 - 52.5	18.5 - 84.6	2.8	436	872	5	436	872	--	--	--
Copper (µg/L)	17.8	4.5-10.5	3.7 - 16.8	21	55	111	21	55	111	1000	--	1300
Chloride (mg/L)	759.2	189 - 446	161 - 718	230	860	1720	230	860	1720	250	--	--
Estimated Concentrations Based on Model Simulations of Conservative Constituents												
Sulfate, as SO4 (µg/L)	274.5	68.6 - 161.4	54.9 - 260.8	--	--	--	--	--	--	250	--	--
Antimony (µg/L)	7.0	1.8 - 4.1	1.4 - 6.7	5.5	90	180	31	90	180	--	6	6
Arsenic (µg/L)	5.2	1.3 - 3.1	1.0 - 4.9	2	360	720	53	360	720	--	--	10
Barium (µg/L)	644.4	161 - 379	129 - 612	--	--	--	--	--	--	--	2000	2000
Cadmium (µg/L)	1.5	0.4 - 0.9	0.3 - 1.4	2.8	15	30	2.8	130	260	--	0.5	5
Calcium (µg/L)	708000.0	177000 - 416304	141600 - 672600	--	--	--	--	--	--	--	--	--
Iron (µg/L)	479504.8	119876 - 281949	95901 - 455530	--	--	--	--	--	--	300	--	--
Lead (µg/L)	15.0	3.7 - 8.8	3.0 - 14.2	12	318	638	12	318	638			15
Magnesium (µg/L)	221225.0	55306 - 130080	44245 - 210164	--	--	--	--	--	--	--	--	--
Manganese (µg/L)	7420.1	1855 - 4363	1484 - 7049	--	--	--	--	--	--	50	100	
Mercury (µg/L)[c]	0.2[c]	0.04 - 0.1[c]	0.03 - 0.1[c]	0.0069[c]	2.0	4.2	0.0069[c]	2.0	4.2	--	--	2
Nickel (µg/L)	397.3	99.3 - 233.6	79.5 - 377.4	296	4085	8169	454	4085	8169	--	100	
Potassium (µg/L)	229183.3	57296 - 134760	45837 - 217724	--	--	--	--	--	--	--	--	--
Selenium (µg/L)	1.5	0.4 - 0.9	0.3 - 1.4	5	20	40	5	20	40	--	30	50
Sodium (µg/L)	528108.3	132027 - 310528	105622 - 501703	--	--	--	--	--	--	--	--	--
Zinc (µg/L)	15253.1	3813 - 8969	3051 - 14490	302	331	662	306	338	677	5000	2000	--
Perfluorinated Compounds												
Perfluorobutane sulfonate (PFBS) (µg/L)	0.1	0.02 - 0.04	0.01 - 0.1	--	--	--	--	--	--	--	7	--
Perfluorobutyric acid (µg/L)	2.7	0.7 - 1.6	0.5 - 2.6	--	--	--	--	--	--	--	7	
Perfluorohexane sulfonate (µg/L)	0.1	0.0 - 0.1	0.02 - 0.1	--	--	--	--	--	--	--	--	--
Perfluorohexanoic acid (µg/L)	0.4	0.1 - 0.3	0.1 - 0.4	--	--	--	--	--	--	--	--	--
Perfluorooctane sulfonate (PFOS) (µg/L)	0.1	0.0 - 0.1	0.02 - 0.1	--	--	--	--	--	--	--	0.3	--
Perfluorooctanoic acid (PFOA) (µg/L)	1.0	0.2 - 0.6	0.2 - 0.9	--	--	--	--	--	--	--	0.3	--
Perfluoropentanoic acid (µg/L)	0.4	0.1 - 0.2	0.1 - 0.3	--	--	--	--	--	--	--		

Key:

Prediction to pit-lake exceeds standard

Prediction to both pit-lake and river exceed standard

Notes:

[a]The average concentration for June 2015 was calculated using two sampling rounds conducted by the MPCA and included only shallow wells where nested. Non-detects were assumed to be one-half the reporting limit.
Individual compounds not detected in all wells.

[b]Water quality standards for chromium are based on hexavalent chromium (CR6). Samples for chromium were not analyzed for hexavalent chromium.
Based on pH data from June, 2015 samples it is likely that much of the chromium is not hexavalent chromium.

[c]Reporting limits for mercury above the chronic surface water standard. Actual concentrations unknown. One-half reporting limit used for analysis.

[d]All simulations assume conservative transport (i.e. no degradation or retardation); data are not available to support simulation of these transport mechanism. Only dispersivity was included in transport simulations.
The range for maximum concentration to the river and pit-lake based on model simulations with varying input parameters that bracket uncertainty in the data.
These include hydraulic parameters (hydraulic conductivity, recharge) and dispersivity.
All simulations assume the same source area based on area where water table would rise into the waste
Pit-lake assumed to be held at elevation of 690 feet

[e]Estimated concentrations based on same underlying assumptions of conservative transport mechanisms and same source area.
Minnesota River hardness data from *MPCA, 2006. Working Draft, Surface Water Pathway Evaluation user's Guide, Appendix E*

Table 2

Results of Groundwater Transport Simulations for 100-Year Flood Conditions

Model Simulations, 100 Year Flood Condition, Concervative Constituents													
				Water Quality Standards									
	Avg. Concentration from June 2015 [a]	Range of Maximum Concentration to River [c]	Range of Maximum Concentration to Pit Lake [c]	Class 2A Chronic (350 Hardness)	Class 2A Maximum (350 Hardness)	Class 2A Acute (350 Hardness)	Class 2B Chronic (350 Hardness)	Class 2B Maximum (350 Hardness)	Class 2B Acute (350 Hardness)	EPA Secondary Drinking Water Regulations	MDH Human Health Based Water Guidance	EPA Maximum Contaminant Levels
Chromium (µg/L)[b]	35.7	15.6 - 24.8	8.7 - 33.8	11 (CR6)	16 (CR6)	31 (CR6)	11 (CR6)	16 (CR6)	31 (CR6)	--	100 (CR6)	100
Cobalt (µg/L)	89.5	39.1 - 62.1	21.9 - 84.6	2.8	436	872	5	436	872	--	--	--
Chloride (mg/L)	759.2	332 - 527	186 - 718	230	860	1720	230	860	1720	250	--	--

Key:

Prediction to pit-lake exceeds standard

Prediction to both pit-lake and river exceed standard

Notes:

[a]The average concentration for June 2015 was calculated using two sampling rounds conducted by the MPCA and included only shallow wells where nested. Non-detects were assumed to be one-half the reporting limit.
Individual compounds not detected in all wells.

[b]Water quality standards for chromium are based on hexavalent chromium (CR6). Samples for chromium were not analyzed for hexavalent chromium.
Based on pH data from June 2015 samples it is likely that much of the chromium is not hexavalent chromium.

[c]All simulations assume conservative transport (i.e. no degradation or retardation); data are not available to support simulation of these transport mechanism. Only dispersivity was included in transport simulations.
The range for maximum concentration to the river and pit-lake based on model simulations with varying input parameters that bracket uncertainty in the data.
These include hydraulic parameters (hydraulic conductivity, recharge) and dispersivity.
All simulations assume the same source area based on area where water table would rise into the waste
Pit-lake assumed to be at elevation of 690 feet prior to flood

Minnesota River hardness data from *MPCA, 2006. Working Draft, Surface Water Pathway Evaluation user's Guide, Appendix E*

Approximate extent of waste material

Feet

1,000 0 1,000 2,000 3,000

BARR

Figure 1

SITE LOCATION
Freeway Landfill
Dakota County, Minnesota

MPCA Monitoring Well Location

Approximate extent of waste material

N

Feet

1,000 0

BARR

Figure 2

MONITORING WELL LOCATIONS
Freeway Landfill
Dakota County, Minnesota

Steady-state Scenario Source Zone

Flood Scenario Source Zone Maximum Extent

MPCA Monitoring Well Location

N

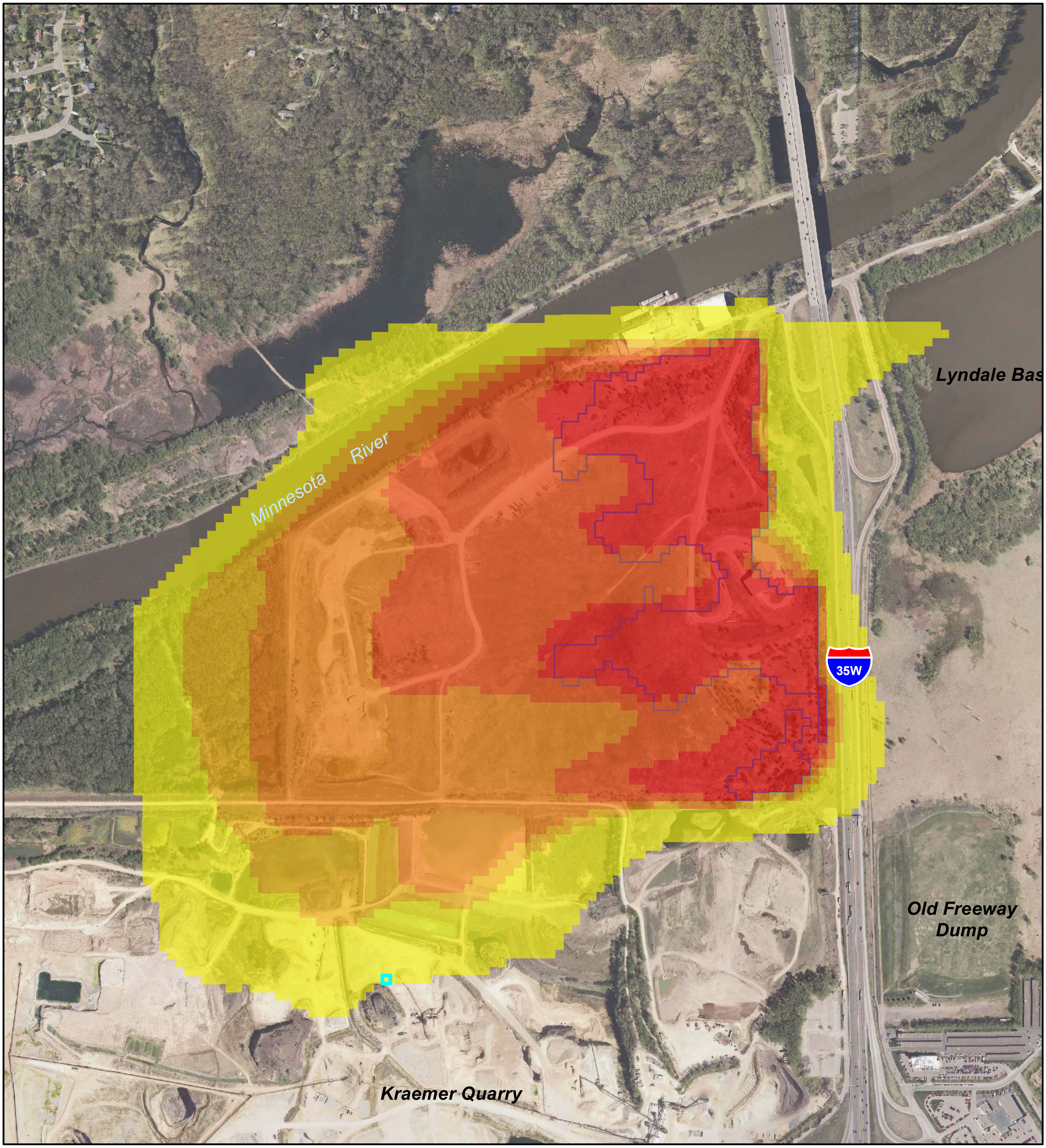
Feet

1,000 0

BARR

Figure 3

MODELED SOURCE AREAS
Freeway Landfill
Dakota County, Minnesota



Steady-state Cobalt Plume (ug/L)

Concentration

- 0.0 - 5.0
- 5.1 - 10.0
- 10.1 - 25.0
- 25.1 - 50.0
- 50.1 - 89.5
- Steady-state Scenario Source Zone

Feet
1,000 0

BARR

Figure 4

MODELED COBALT PLUME
STEADY-STATE SCENARIO
Freeway Landfill
Dakota County, Minnesota

Attachment 1
May 22, 2015 Modeling Tech Memo

resourceful. naturally.
engineering and environmental consultants
BARR

Technical Memorandum

To: Steve Albrecht
From: Evan Christianson, PG; John Greer, PG
Subject: Simulations of Future Kraemer Quarry Pit-Lake Stage and Rise of the Water Table at the Freeway Landfill
Date: May 22, 2015
Project: Freeway Landfill Assistance

1.0 Introduction

Groundwater model simulations were conducted by Barr Engineering to estimate future water table conditions near Freeway Landfill after dewatering ceases at the Kraemer Quarry located directly south of the landfill. The modeled future rise in the water table is compared against the bottom elevation of the waste that was identified in previous MPCA investigations to assess the potential for the waste in the Landfill to come into contact with the predicted higher water table.

2.0 Model Development

The Twin Cities Metropolitan Area Regional Groundwater Flow Model, Version 3.0 (Metro Model 3, Metropolitan Council, 2014) was used as the base model to help define initial layer geometries and boundary conditions for a local-scale model better suited for site-specific assessment of future conditions at the Freeway Landfill. Metro Model 3 was developed by Barr Engineering for the Metropolitan Council in consultation with groundwater experts from State and local agencies, academia, and private entities. The regional-scale model is designed to assist in evaluating groundwater use and water sustainability issues across the Twin Cities metropolitan area. Metro Model 3 was selected as an initial starting point for assessment of future groundwater conditions at the Freeway Landfill because it reasonably represents groundwater flow near the area of interest, allowing for the appropriate selection of boundary conditions, and uses the most up to data modeling code (MODLFOW-NWT) and geology information available.

When defining the extent of a local-scale model, the anticipated stresses to be simulated must be carefully considered to avoid boundary conditions affecting the simulation results. Current dewatering from the Kraemer Quarry is one of the largest groundwater stresses in the Twin Cities area. Because the local-scale model was intended to simulate groundwater conditions with both full dewatering of Kraemer Quarry and no dewatering, the extent of the local model had to be carefully considered. Metro Model 3 was used to simulate regional groundwater conditions with both full quarry dewatering and no dewatering to guide selection of the local model extent so it is large enough to handle the large changes in simulated stresses but not so large that it would hinder analysis due to extreme computational demands. The local model domain was chosen to encompass the "zero-drawdown contour", defined by the locations where no change in hydraulic head is simulated between the dewatering and no-dewatering scenario in the regional model (Figure 1). This ensures that stresses can be varied in the local-scale model without boundary conditions influencing the results.

The telescopic mesh refinement method as implemented in Groundwater Vistas (ESI, 2011) was used to define the extent of the local-scale model and set boundary conditions based on the regional model. The outer edges of the local-scale model were all set as constant head boundaries based on head values extracted from the regional flow model (Figure 2). The model grid was refined from the regional-scale cell size of 500 m by 500 m to 15.6 m by 15.6 m in the area of interest around Freeway Landfill and Kraemer Quarry. Five additional layers were also added to better simulate flow conditions within the Prairie du Chien Group, the upper most bedrock at the Landfill and the unit currently being quarried (Figure 3). Following grid refinement and addition of layers, the geometry and extent of bedrock units were adjusted to reflect the finer grid scale and site-specific data regarding bedrock topography gathered from boring and well logs from Freeway Landfill and Burnsville Landfill along with data obtained from Kraemer Quarry.

Lakes and rivers are simulated in the model using the River Package of MODFLOW. Lakes and rivers simulated in Metro Model 3 were remapped to allow for better spatial representation with the refined model grid in the area of interest (Figure 2). The river stage of the Minnesota River was set at 690.6 feet (210.5m), which is near the average river stage and the value used in the regional model. High capacity wells that have an appropriation permit with the Minnesota DNR and for which pumping volumes have been reported were included in the simulation (Figure 2). Pumping rates and locations for the high capacity wells were transferred from Metro Model 3. In Metro Model 3, quarry dewatering and withdrawal from the pit for City of Burnsville water supply is simulated with wells. For the local-scale model these withdrawals are simulated with the Drain Package, hence this pumping was removed from the well dataset for the local-scale model.

The Quarry pit was simulated with a series of Drain Package boundary cells and a zone of high hydraulic conductivity (high-K). Drain elevations were set at the elevation of the bottom of the Quarry pit in the model layer associated with that elevation. High-K cells within the footprint of the pit allow the hydraulic head to equilibrate across the Quarry or, alternatively, allow the model cells in upper layers to become "dry". For simulations with little to zero dewatering from the Quarry the high-K zone is used to represent a pit-lake (Anderson et al., 2002).

The local-scale model was calibrated using site specific data collected in January, 2015 (Figure 4) in addition to datasets used for calibration of Metro Model 3. Model parameter values from Metro Model 3 (hydraulic conductivity, River Cell conductance, recharge, etc.) were used as initial starting values. These starting values were adjusted using multiplier arrays defined using the pilot point method (Doherty, 2003).

The automated parameter estimation software PEST (Doherty, 2010) was used for the calibration. A total of 10,832 calibration targets were used; 36 site-specific targets from January, 2015 and 10,796 targets developed for Metro Model 3 that are within the local model domain.

The optimized model had the following characteristics with respect to all hydraulic head calibration targets:

- n = 10,814
- Mean residual = -6.0 m
- Absolute residual mean = 9.2 m
- Residual standard deviation = 10.6 m

Not all hydraulic head targets are equally accurate or reliable. In particular, hydraulic head targets derived from the County Well Index may have error exceeding 20 feet. Hydraulic head targets from monitoring wells (data collected in January 2015, DNR observation wells, and other miscellaneous observation wells) had the following characteristics:

- n = 211
- Mean residual = -1.0 m
- Absolute residual mean = 5.0 m
- Residual standard deviation = 9.2 m

Head calibration targets established from the January, 2015 data collection had the following characteristics:

- n = 36
- Mean residual = -0.2 m
- Absolute residual mean = 2.4 m
- Residual standard deviation = 3.2 m

Plots showing measured versus simulated hydraulic head values are shown on Figure 5.

3.0 Simulation of Future Conditions

After calibration, the local-scale model was used to simulate potential future conditions with varying pit-lake stages to estimate the water table elevation within the footprint of the waste at the Freeway Landfill. To address uncertainties in the model simulations, Latin hypercube sampling (Swiler and Wyss, 2004; Watermark Numerical Computing, 2012) was used to generate 1000 unique parameter sets, allowing parameters to vary over expected ranges. Model simulations were then conducted using these parameter sets and the results were compared to the calibration dataset. Parameter combinations that resulted in no more than a 5% increase in the calibration objective function (error of best-fit model to measured data) were deemed acceptable and carried forward for use in simulating potential future conditions. Parameter sets that resulted in more than a 5% increase in the calibration objective function were deemed unacceptable (i.e., poor model fit to observations) and excluded from further analysis. A total of 298 unique parameter combinations, out of 1000 possible, were ultimately used for the uncertainty analysis.

For each unique parameter set a series of steady-state simulations were conducted. First, pumping from Kraemer Quarry was reduced to include only pumping for the City of Burnsville supply. The average reported pumping from the quarry for Burnsville from 2010 to 2013 of 3.4 million gallons per day was used; no pumping was included for quarry dewatering operations (an average of 8.4 million gallons per day (MGD) for pit dewatering was reported for 2010-2013) since this scenario was intended to simulate conditions after the Quarry ceases operations. Second, a series of simulations were conducted where pumping rates from the Quarry were adjusted to achieve pit-lake stages between 205 meters and 213 meters (672.6 feet to 698.8 feet) in one meter increments. For each simulation, the simulated water table elevation was compared to the bottom of waste at the Freeway Landfill as measured by Gorman Surveying (2005). The bottom of waste ranges in elevation between 687.8 feet and 713.4 feet (Gorman, 2005).

For all simulations of future conditions the footprint of the Quarry was simulated with high-K cells and the water level within the Quarry was allowed to equilibrate to a static condition. The analysis assumed the current outlet system being utilized by the Kraemer Quarry would not be operating. It is our understanding that the City of Burnsville is currently evaluating options to utilize portions of the existing quarry outlet system. It appears the utilization or enhancement of the gravity portions of the current quarry outlet system would allow the City to manage the quarry lake elevation as low as elevation 690 ft. This elevation is preliminary and the final elevation may change based on additional studies and quarry end use plans. No control structures were simulated to manage the level of the pit lake since the City of Burnsville has not completed their evaluation of options related to the quarry outlet system. Pumping for the City of Burnsville supply or outflow via drain cells for the managed stage scenarios were the only means of controlling the pit lake stage in the model. Currently there is a flood control berm around the Quarry built to an elevation of approximately720 feet (219.5m). Without any additional control structures there is no surface water outflow for the pit lake stages below this elevation. Detailed investigation of the surficial topography, including identification and mapping of culverts and swales around the existing quarry and landfill, were outside of the scope of our services. As noted previously, if any features currently exist that might control the water table as it rises after Quarry dewatering ceases they were not included in the modeling scenarios.

The results of these simulations are summarized on Figures 6 to 16 and in Tables 1 and 2. The range of results (minimum, average, and maximum) using all 298 unique parameter sets as defined above are shown. The waste saturation for the various scenarios is estimated as a percentage of the landfill footprint coming into contact with the groundwater (i.e., percentage of area, not percentage of volume).

The simulated pit lake stage for the scenario with just Burnsville pumping from the Quarry pit at a rate of 3.4 MGD ranged between 706.3 feet and 707.9 feet (Table 1). Compared to historical and surrogate data this result seems reasonable. Wetland areas to the east of Interstate 35 have surface elevations ranging between 700 feet and 720 feet. This is also an area known to have, or previously had, very strong upward gradients and groundwater discharge to the surface, typical of the many fens in the area. Data from investigations done in the 1970's at Freeway Landfill (Barr Engineering, 1970) indicate a water table elevation of 702 feet near the southern boundary of the landfill, which is down gradient of the Quarry pit. Using the 1970's data and assuming a constant hydraulic gradient of 0.006 ft/ft, the water table in the pit area would have been between 709 feet and 719 feet. It is noted that dewatering for the Quarry was occurring in the 1970's, albeit at a lower rate than current conditions, which may have led to an artificially depressed water table at that time.

Table 1. Results of simulations with pumping from Kraemer Quarry for Burnsville supply only, no dewatering for quarry operations.

Pumping for Burnsville Supply (MGD)	Pit-Lake Stage						Percent Waste Saturated by Area		
	Min.		Avg.		Max.				
	m	ft	m	ft	m	ft	Min.	Avg.	Max.
3.4	215.3	706.3	215.8	707.9	216.6	710.5	89	96	98

Table 2 summarizes the percentage of area where groundwater is simulated to rise above the bottom of waste in the Landfill for a range of fixed pit-lake stages between 672.6 feet and 698.8 feet (205 m to 212 m), which are a subset of the pit lake stages evaluated. For all these simulations, the water table rises above the bottom of the waste somewhere within the footprint of waste at the Landfill. At the lowest simulated pit lake stage (672.6 feet) the water table rises into the waste for between 9 and 12 percent of the waste area even though the pit lake stage is lower than the minimum recorded river stage. At the highest simulated pit lake stage (698.8 feet) the water table rises into the waste for between 75 and 85 percent of the waste area.

The lowest measured bottom of waste (687.8 feet) at the Freeway Landfill is below the average river stage and only slightly above the lowest recorded stage (see Figure 6). In addition, the location of the lowest measured bottom of waste elevation occurs in the northern part of the Landfill. Therefore, a scenario in which the water table is always entirely below the waste requires nearly full dewatering of the Quarry since the river can act as a large source of water, losing to groundwater in the reach north of the Landfill and Quarry.

Table 2. Results of simulations maintaining pit lake at specified stage.

Pit-Lake Stage		Simulated Pumping Rate to Maintain Stage (MGD)			Percent Waste Saturated by Area		
meters	feet	Min.	Avg.	Max.	Min.	Avg.	Max.
205	672.6	8.1	9.1	10.2	9	11	12
206	675.9	7.7	8.6	9.7	11	13	15
207	679.1	7.2	8.2	9.2	13	16	19
208	682.4	6.8	7.7	8.6	17	21	24
209	685.7	6.3	7.2	8.1	22	28	33
210	689.0	5.9	6.7	7.5	31	37	42
211	692.3	5.4	6.2	7.0	41	48	54
212	695.5	5	5.7	6.4	54	64	71
213	698.8	4.5	5.1	5.8	75	81	85

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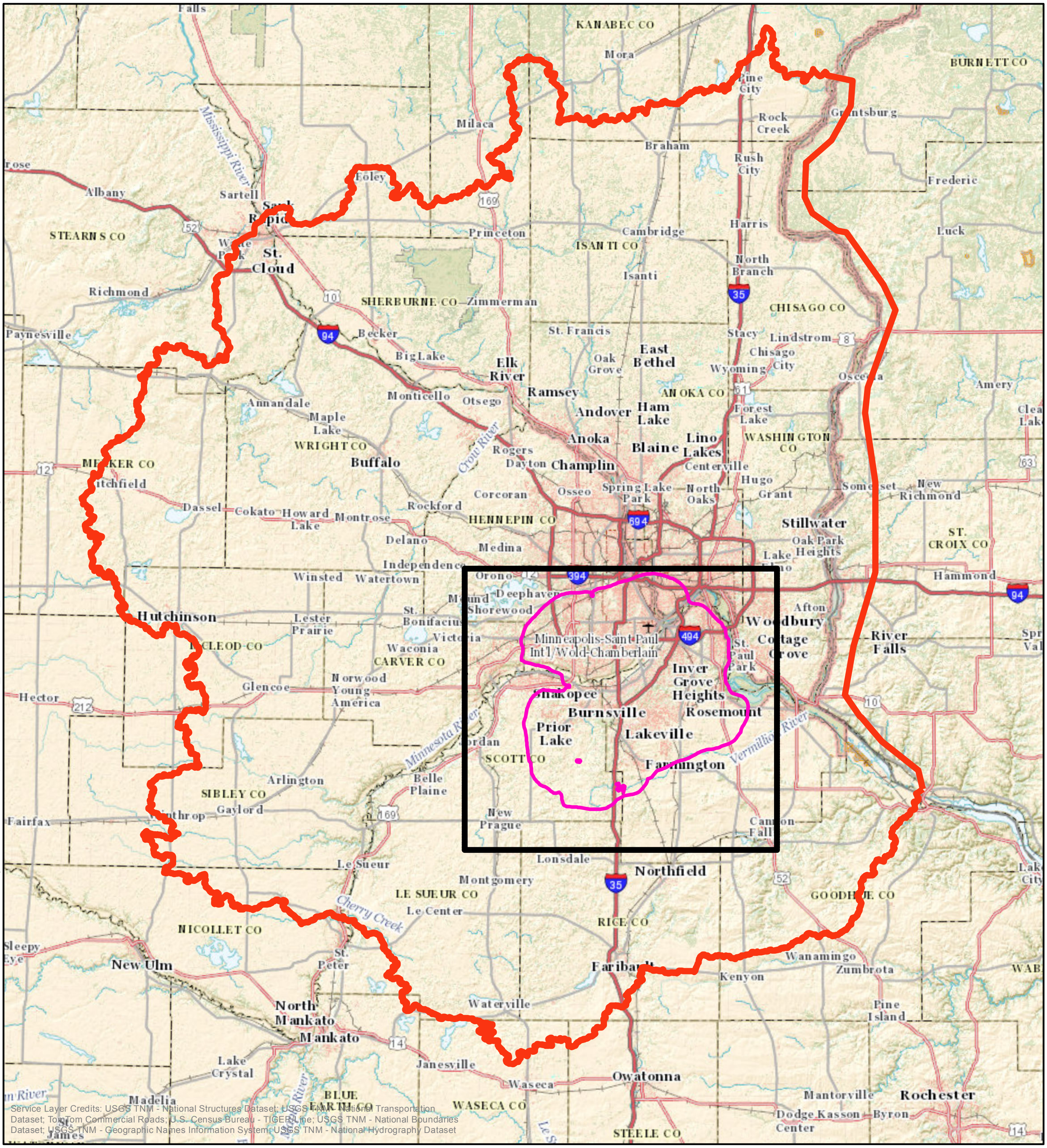
Watermark Numerical Computing. 2012. PEST Utilities to complement Latin Hypercube Sampling Software developed by Sandia National Laboratories.

Certification

I hereby certify that this plan, document, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Geologist under the laws of the state of Minnesota.

	May 22, 2015
Evan G. Christianson PG #: 51379	Date



Barr Footer: ArcGIS 10.3, 2015-05-12 10:47 File: I:\Projects\23\19\1241\Maps\Reports\Model_Results\Model_Extent.mxd User: egc

Metro Model 3 Extent

Local Model Extent

Zero Drawdown Contour, Quarry Dewatering

N

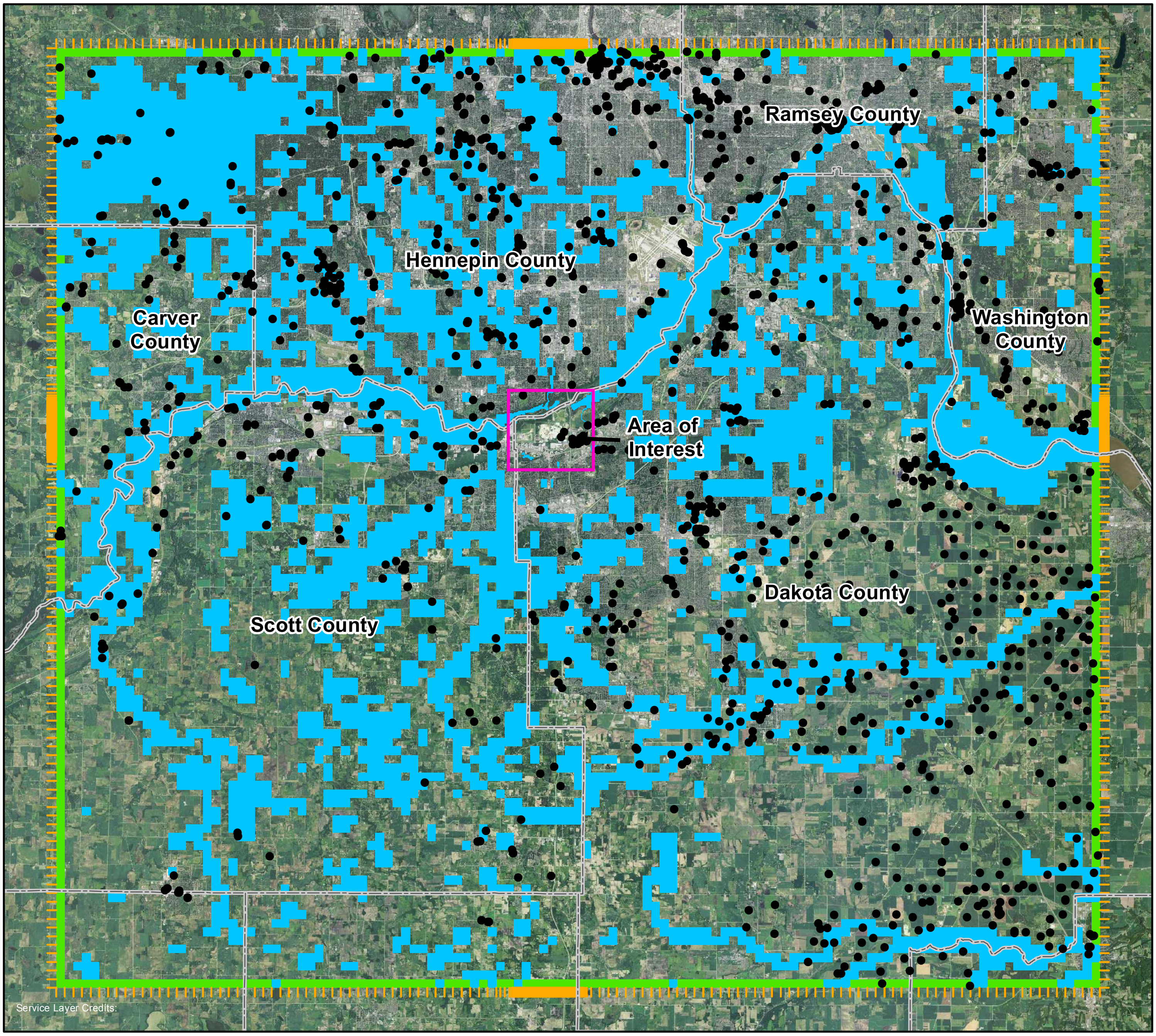
Kilometers
0 20 40

Miles
0 10 20

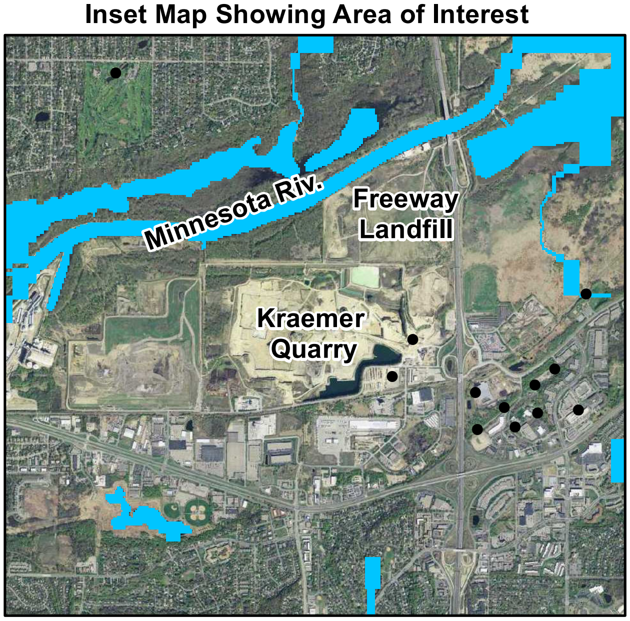
BARR

Figure 1

REGIONAL AND LOCAL MODEL EXTENT



Inset Map Showing Area of Interest



N

Kilometers
0 5 10

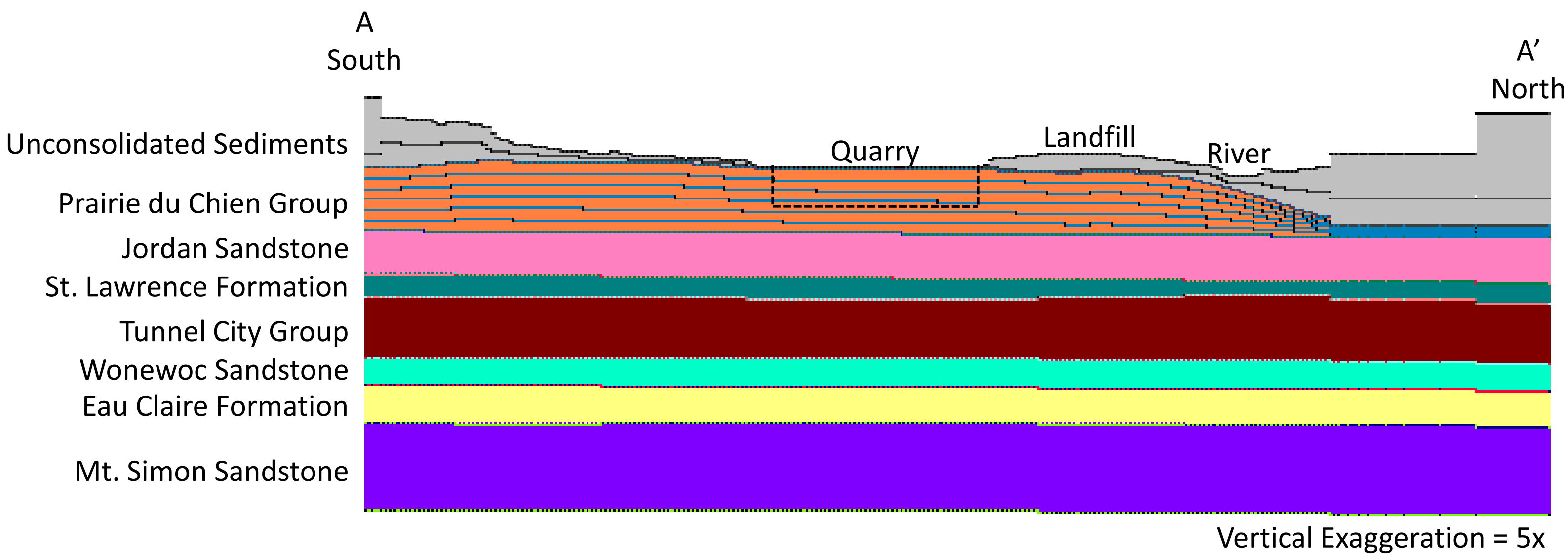
Miles
0 5 10

- Wells
- River Boundary Cells
- Constant Head Boundary Cells
- Model Grid

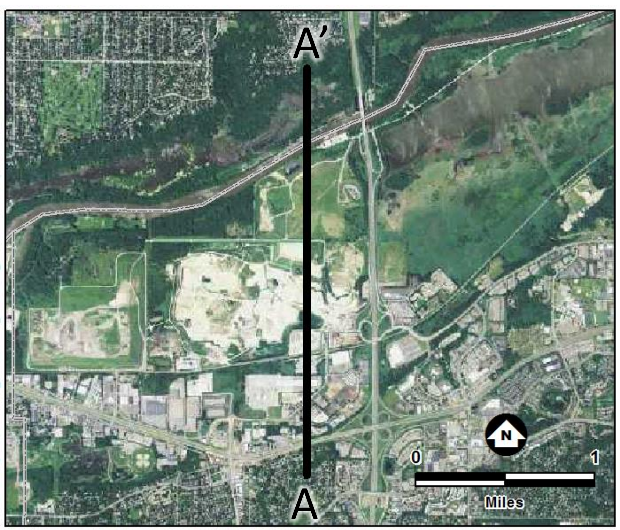
BARR

Figure 2

LOCAL MODEL EXTENT AND BOUNDARY CONDITIONS



Reference Map



BARR

Figure 3

MODEL CROSS SECTION
IN AREA OF INTEREST

Well Location (January 2015 Survey)

Wells Screened in Jordan (January, 2015 Survey)

Kraemer Well

Kraemer Sump

Minnesota River Well

SD001

Well or Piezometer Locations (Groundwater elevation not measured)

(Note: Locations are shown as obtained from Dakota County and Burnsville Landfill databases and Barr files)

Kraemer wells, sump, SD001, and Minnesota River data were provided by Kraemer Mining and Materials. All data collected on 1-21-2015.

N

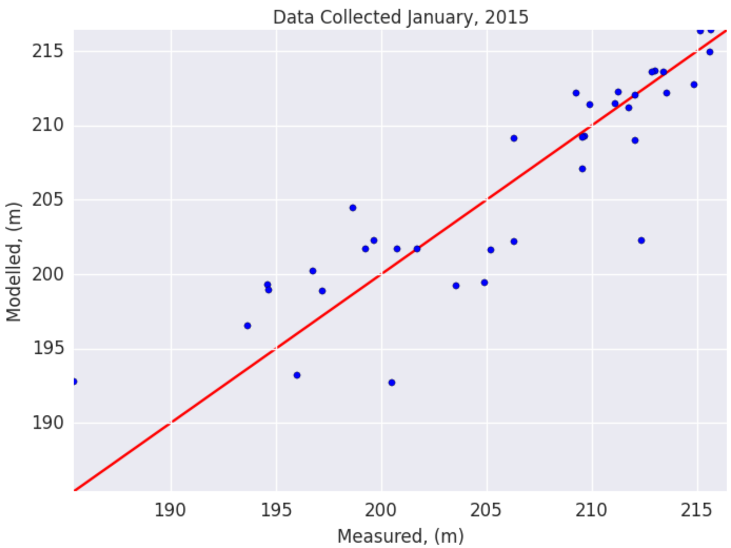
Feet

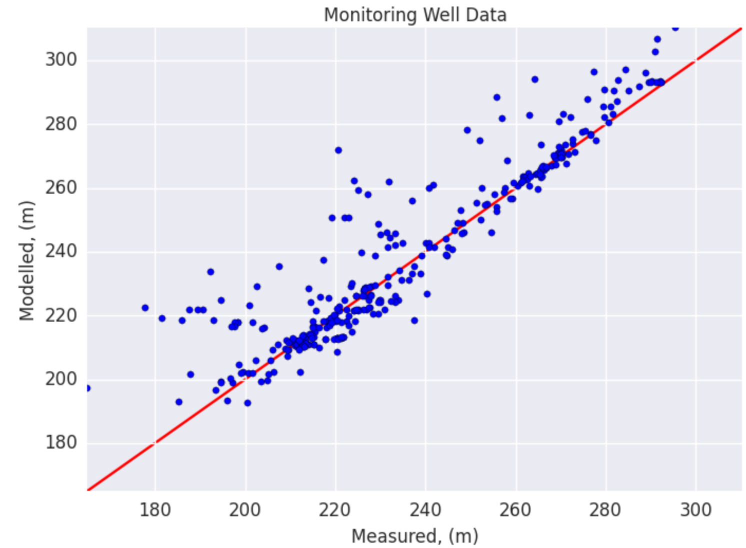
500 0 500 1,000 1,500 2,000

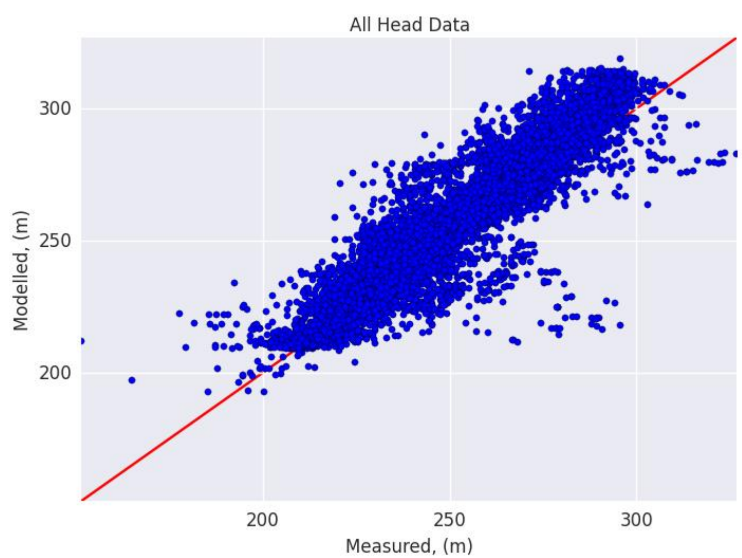
BARR

Figure 4

WELL LOCATIONS
DATA COLLECTED JANUARY, 2015



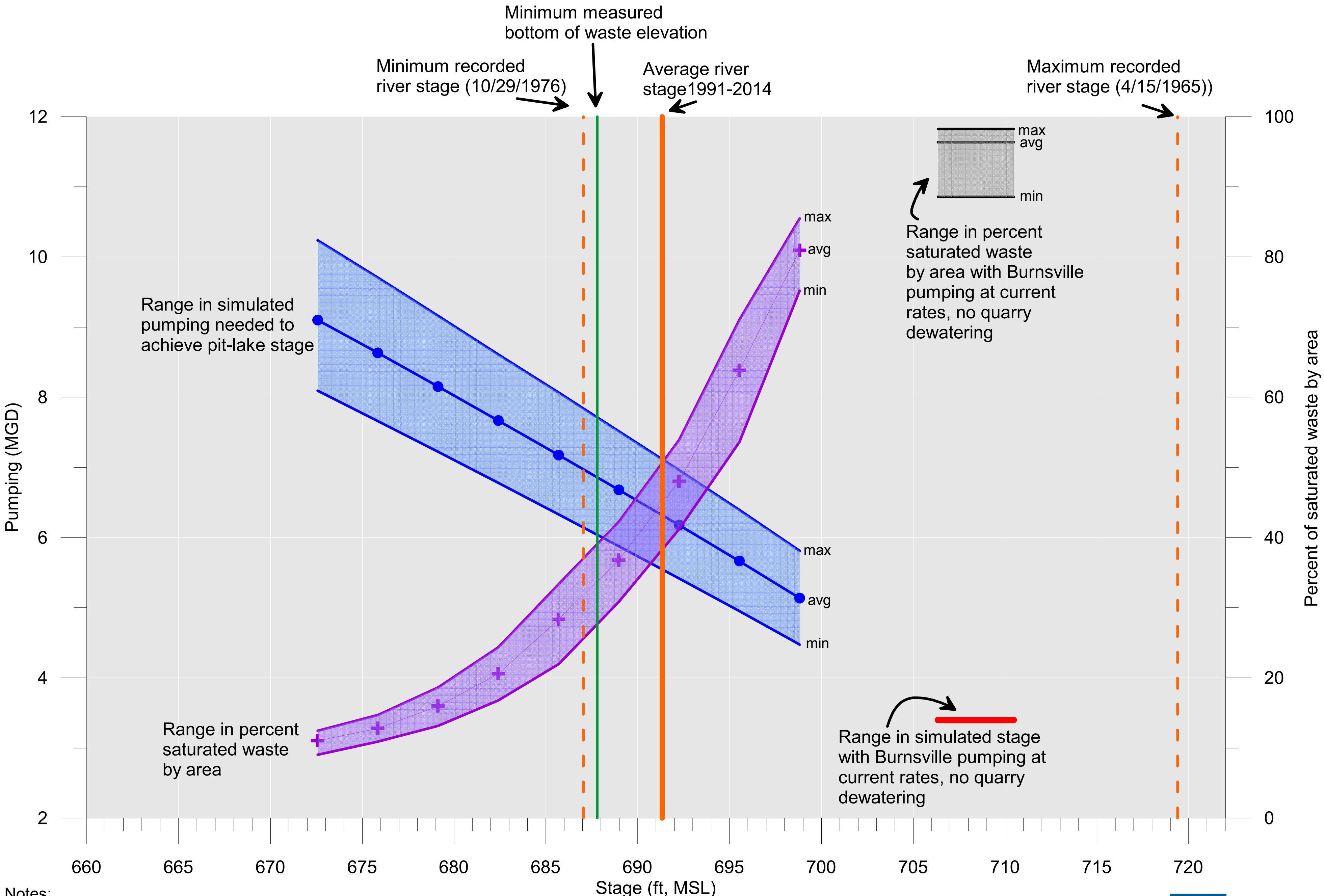




BARR

Figure 5

Measured vs Simulated Hydraulic Head

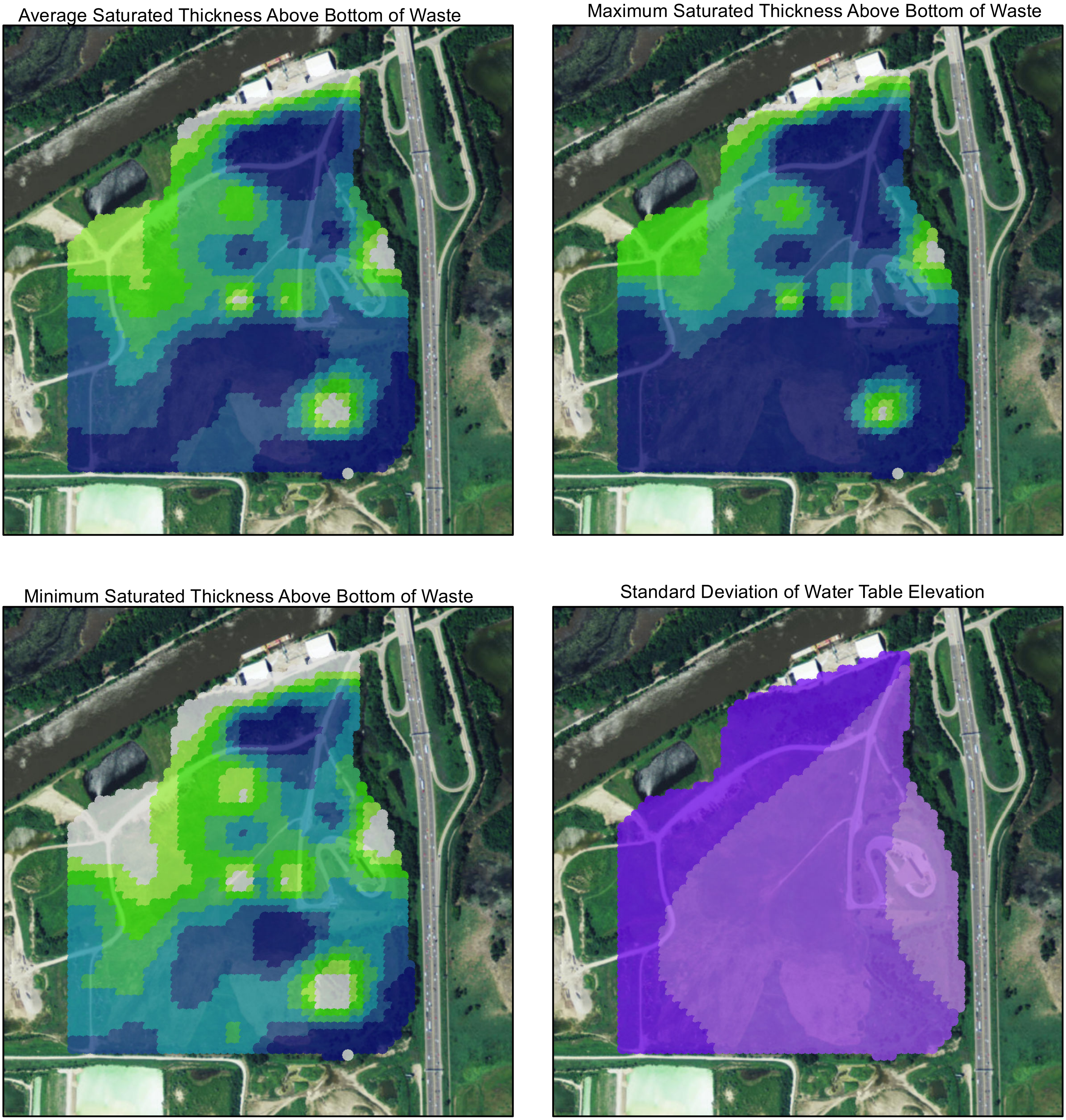


Notes:
Blue shaded area indicates the range of simulated pumping rates needed to achieve specified pit-lakes stage
Purple shaded area indicates the range of area of waste where the water table rises above the bottom of waste at specified pit-lake stages
Gray shaded area indicates the range of area of waste where the water table rises above the bottom of waste with pumping only for Burnsville supply
Red horizontal line indicates the range in simulated pit-lake stage with pumping only for Burnsville supply
Vertical orange lines indicate historical minimum, maximum, and average stage for the Minnesota River
Vertical green line indicates the lowest measured elevation for the bottom of waste in the Freeway Landfill

BARR

Figure 6

SUMMARY OF SIMULATIONS
OF FUTURE CONDITIONS



Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- 0.03 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20
- 0.21 - 0.25

N

Meters
0 200 400

Feet
0 375 750 1,500

BARR

Figure 7

WASTE SATURATION
BURNSVILLE PUMPING ONLY

Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

N

Meters
0 200 400

Feet
0 375 750 1,500

BARR

Figure 8

WASTE SATURATION
PIT LAKE AT
205 METERS (672.6 FT)

Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

N

Meters
0 200 400

Feet
0 375 750 1,500

BARR

Figure 9

WASTE SATURATION
PIT LAKE AT
206 METERS (675.9 FT)

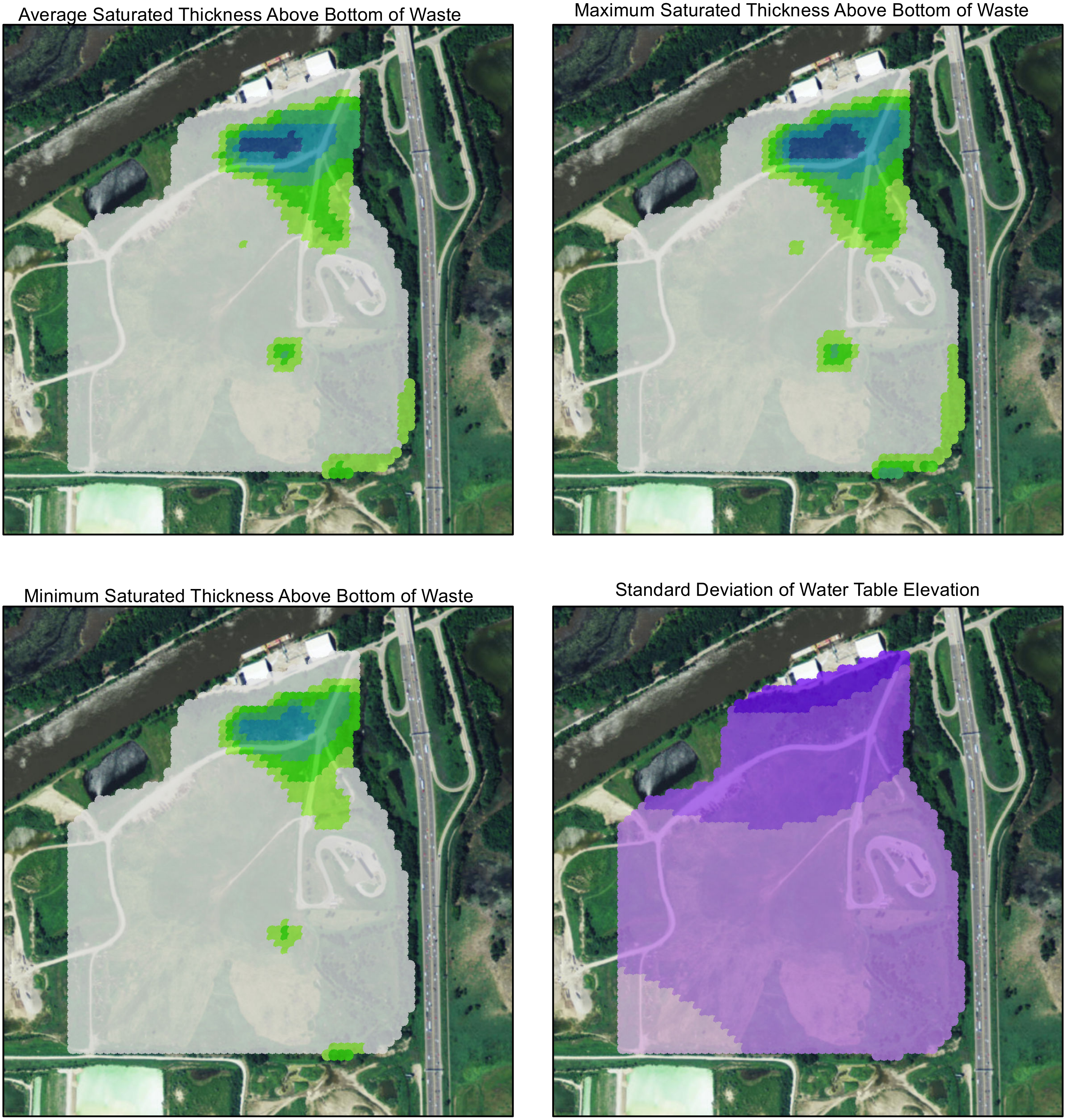
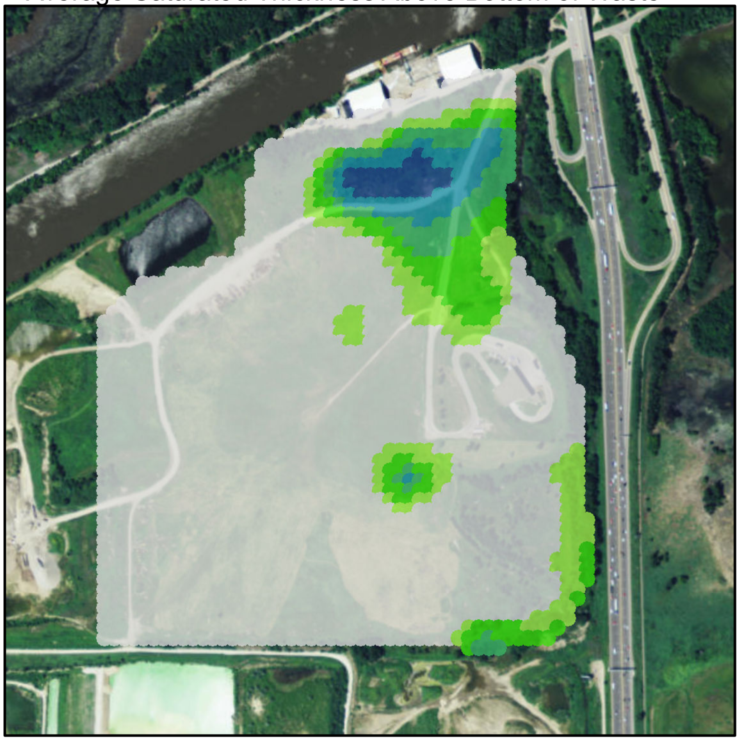


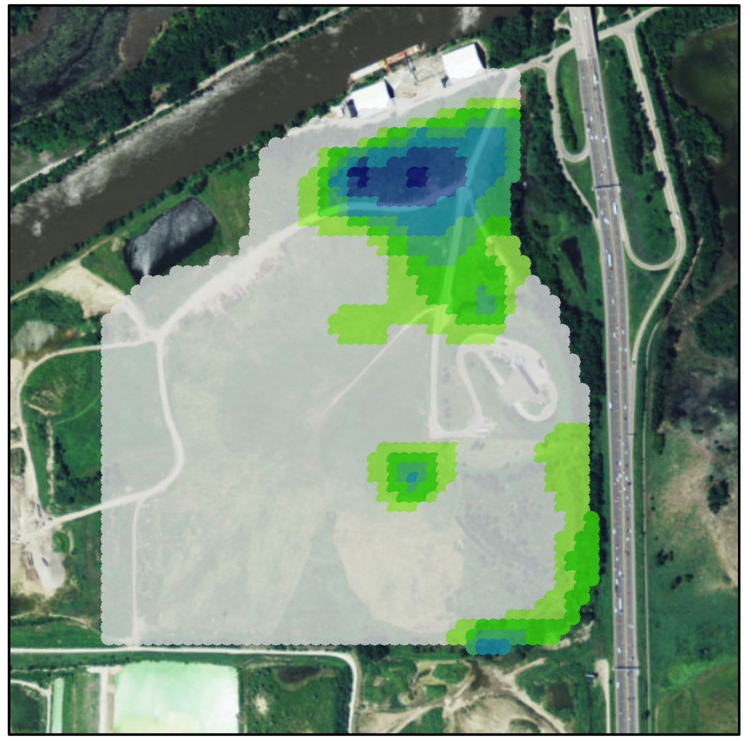
Figure 10

WASTE SATURATION
PIT LAKE AT
207 METERS (679.1 FT)

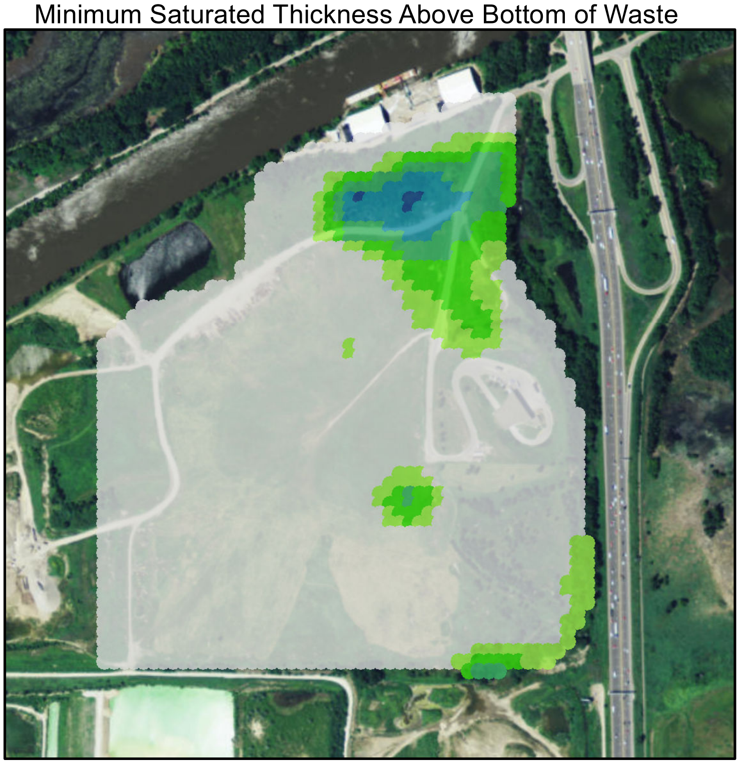
Average Saturated Thickness Above Bottom of Waste



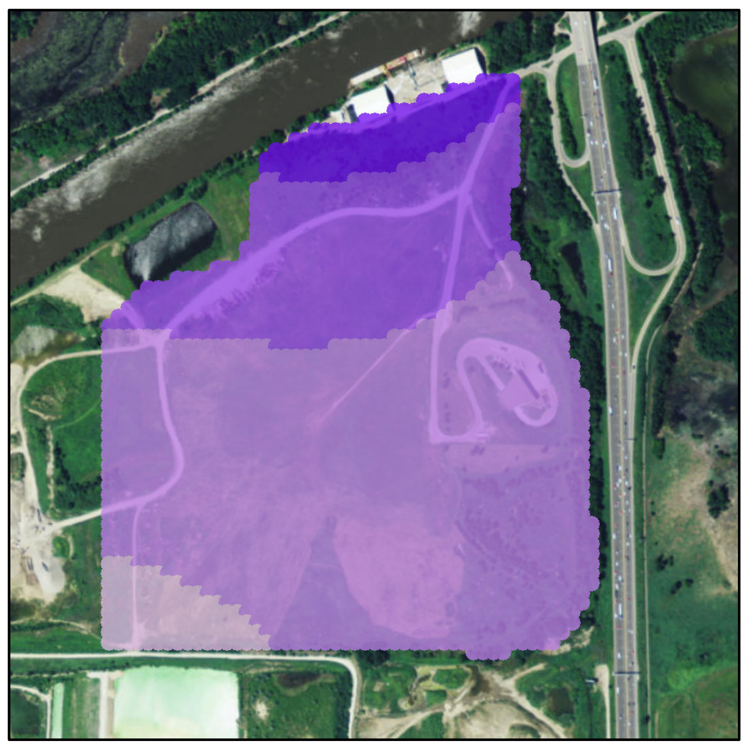
Maximum Saturated Thickness Above Bottom of Waste



Minimum Saturated Thickness Above Bottom of Waste



Standard Deviation of Water Table Elevation



Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

N

Meters
0 200 400

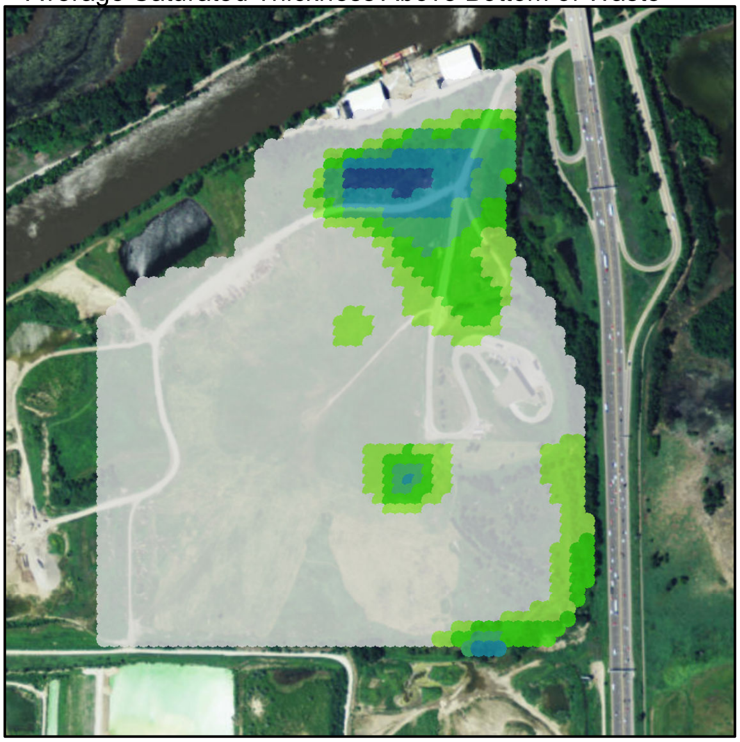
Feet
0 375 750 1,500

BARR

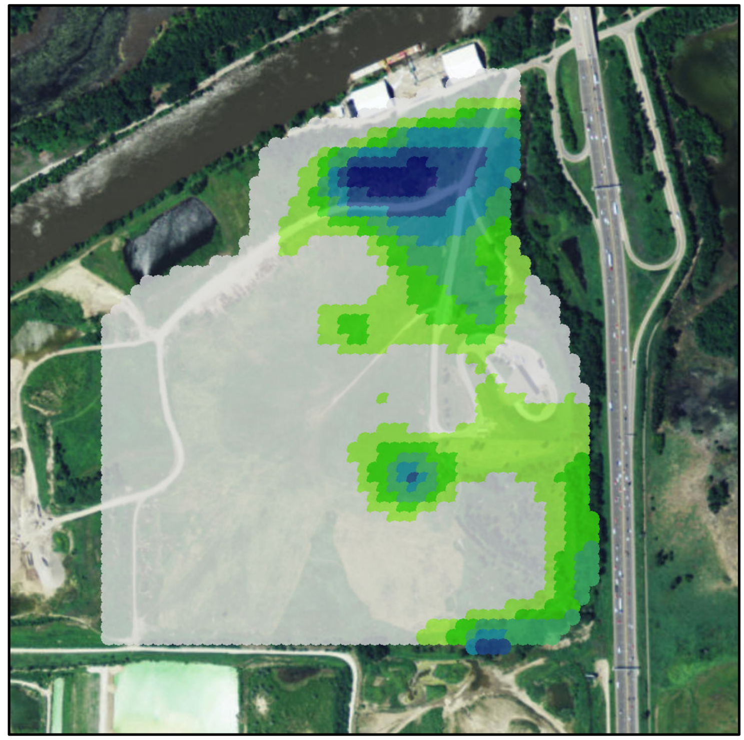
Figure 11

WASTE SATURATION
PIT LAKE AT
208 METERS (682.4 FT)

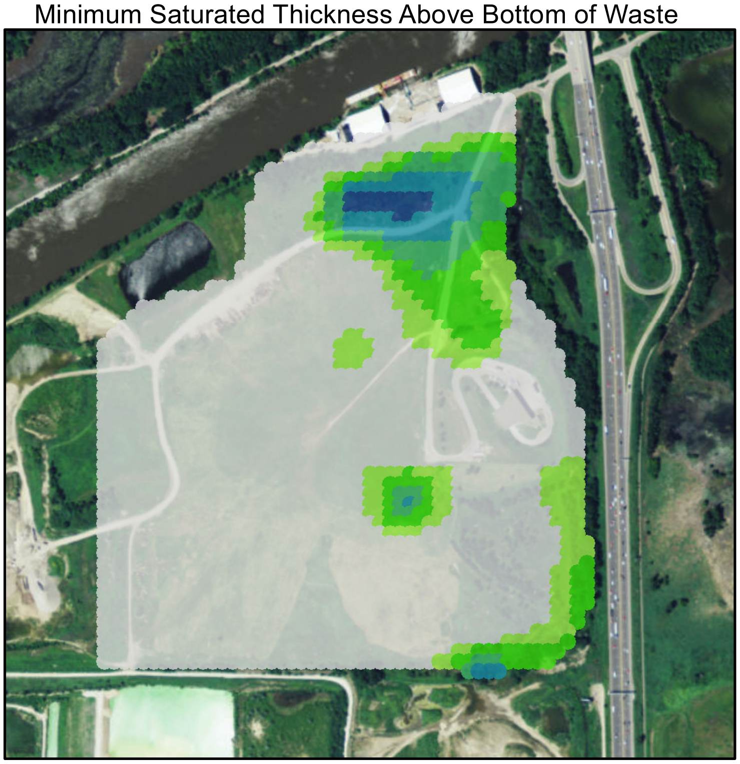
Average Saturated Thickness Above Bottom of Waste



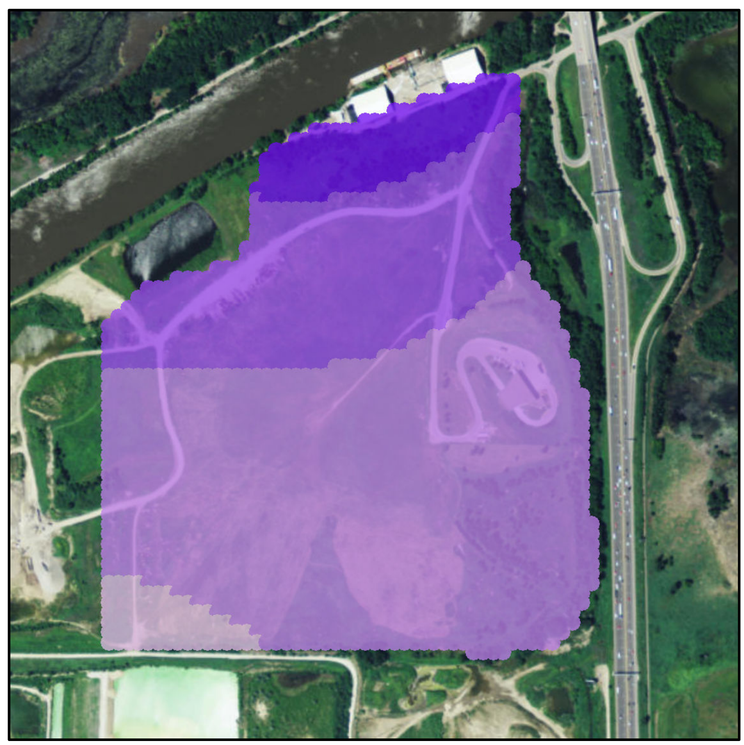
Maximum Saturated Thickness Above Bottom of Waste



Minimum Saturated Thickness Above Bottom of Waste



Standard Deviation of Water Table Elevation



Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

N

Meters
0 200 400

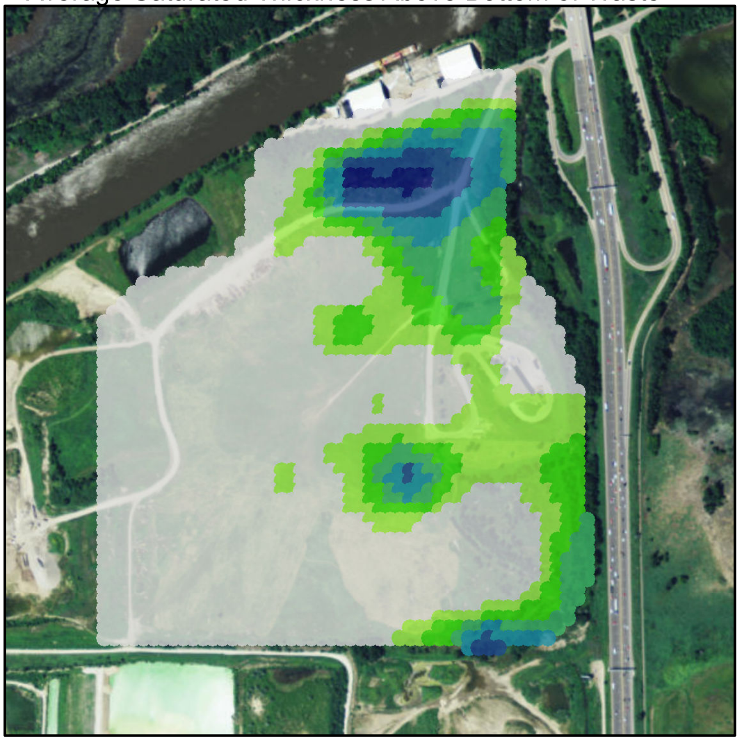
Feet
0 375 750 1,500

BARR

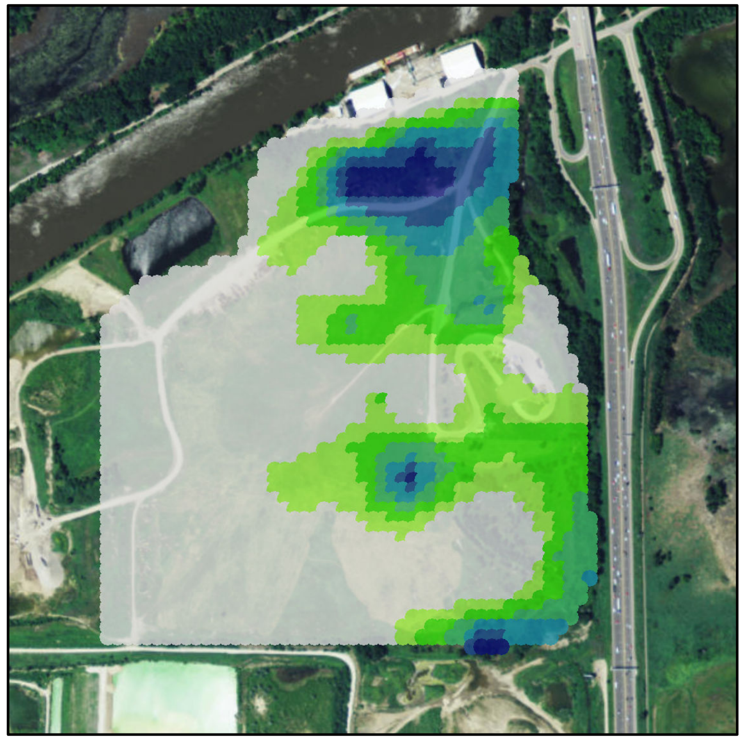
Figure 12

WASTE SATURATION
PIT LAKE AT
209 METERS (685.7 FT)

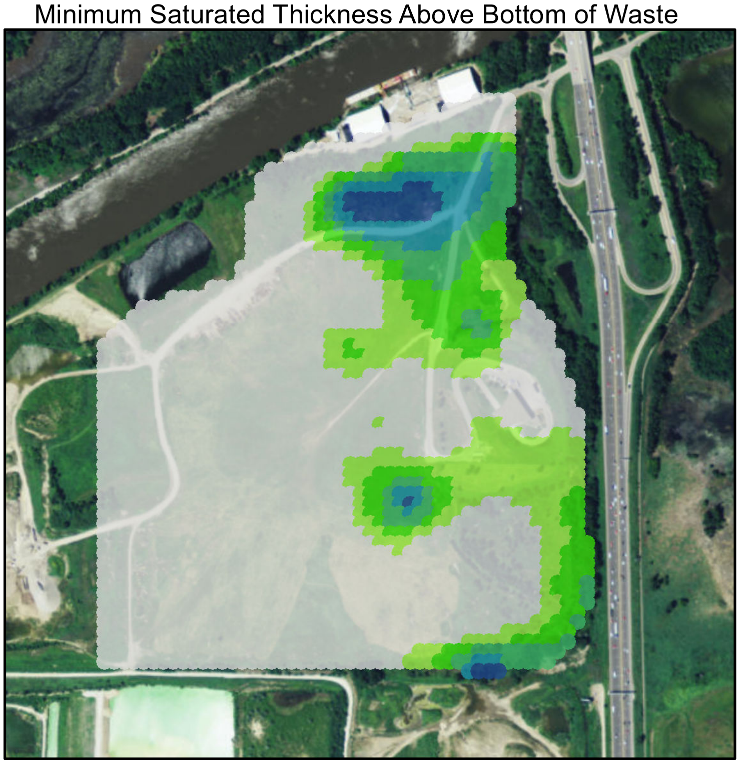
Average Saturated Thickness Above Bottom of Waste



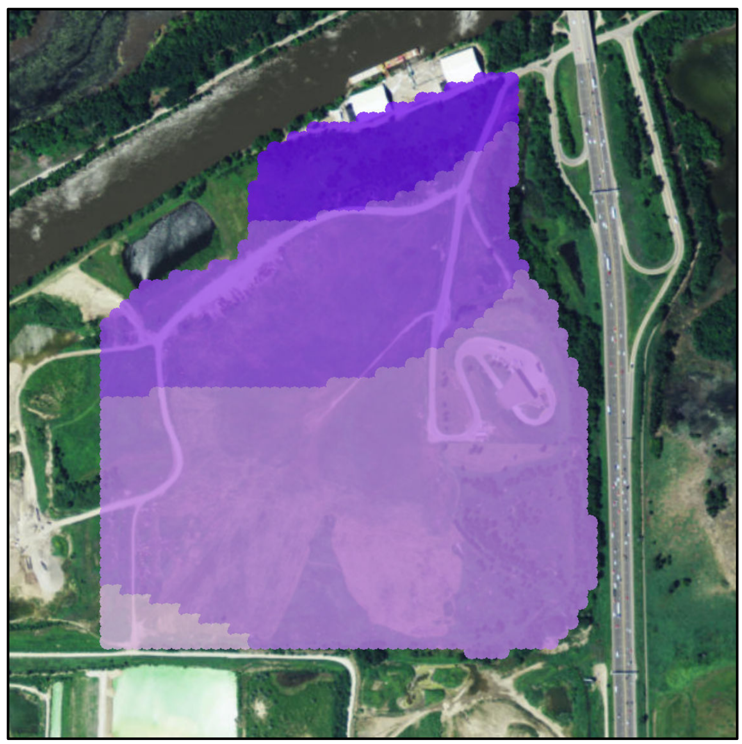
Maximum Saturated Thickness Above Bottom of Waste



Minimum Saturated Thickness Above Bottom of Waste



Standard Deviation of Water Table Elevation



Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

Meters
0 200 400

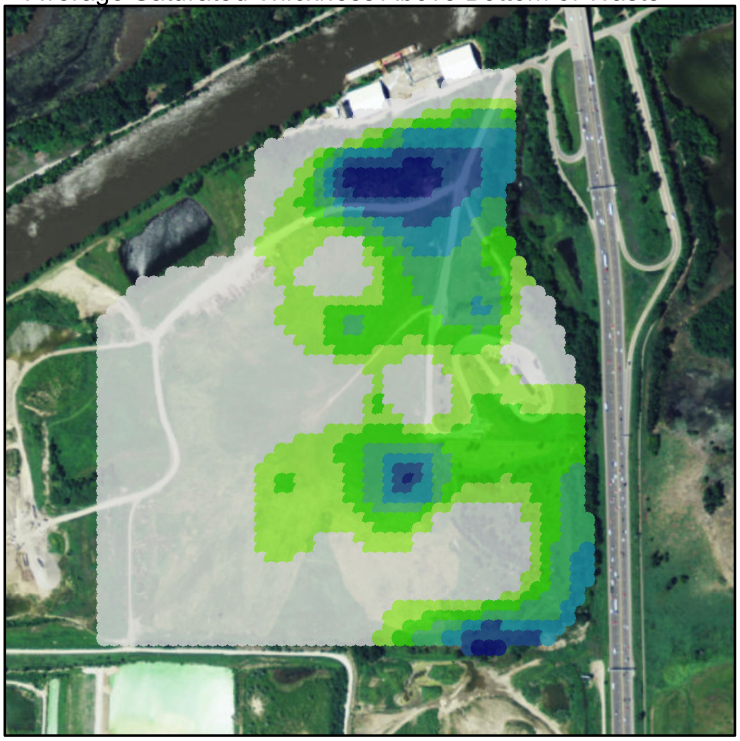
Feet
0 375 750 1,500

BARR

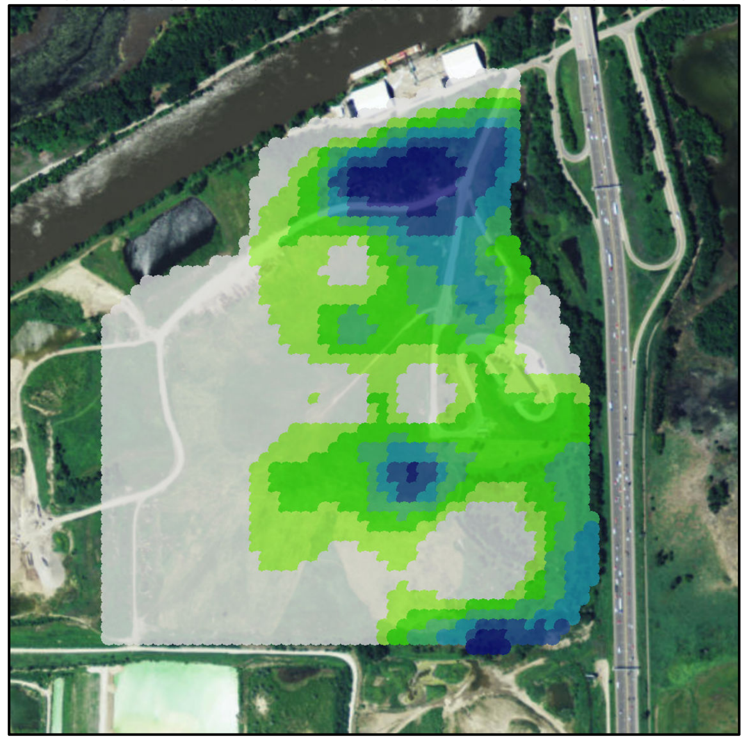
Figure 13

WASTE SATURATION
PIT LAKE AT
210 METERS (689.0 FT)

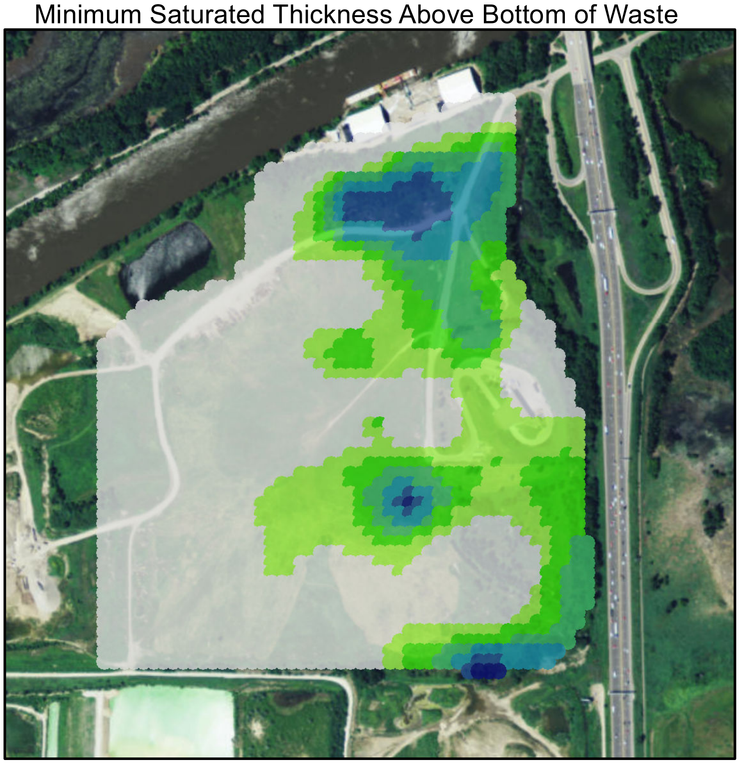
Average Saturated Thickness Above Bottom of Waste



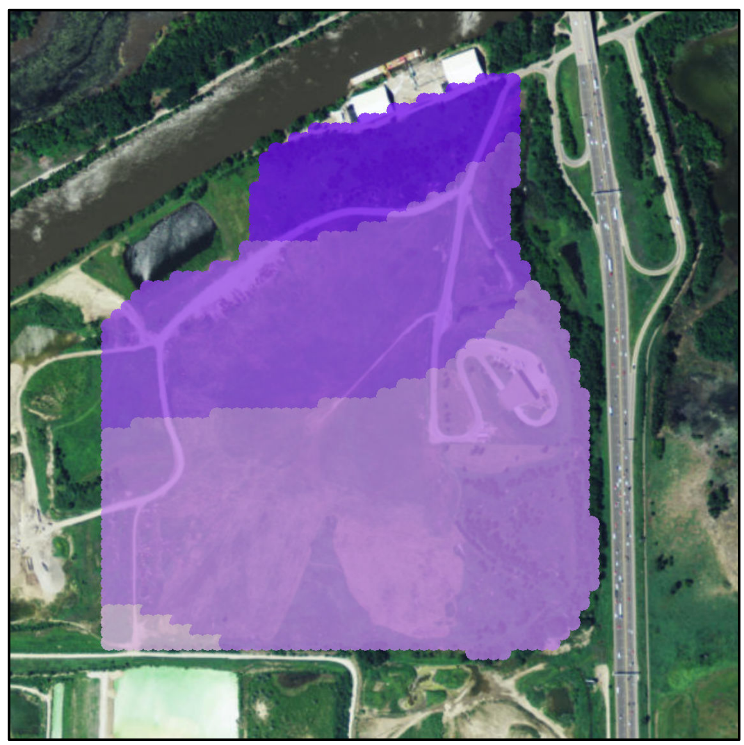
Maximum Saturated Thickness Above Bottom of Waste



Minimum Saturated Thickness Above Bottom of Waste



Standard Deviation of Water Table Elevation



Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

Meters
0 200 400

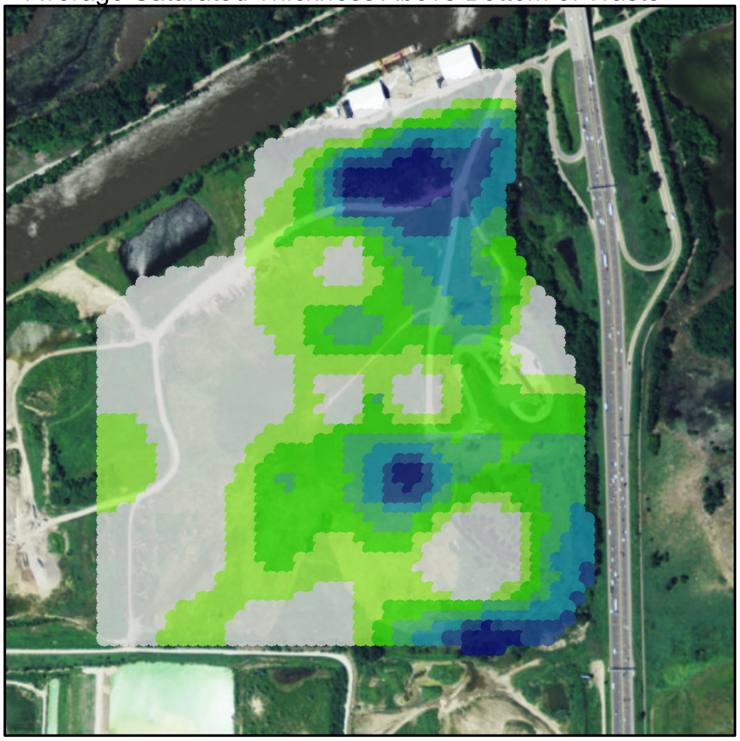
Feet
0 375 750 1,500

BARR

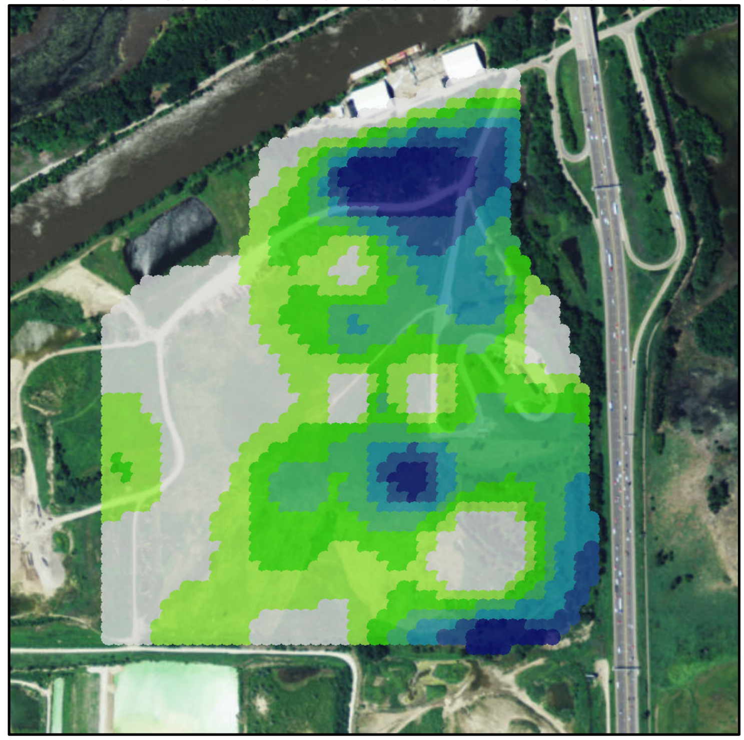
Figure 14

WASTE SATURATION
PIT LAKE AT
211 METERS (692.3)

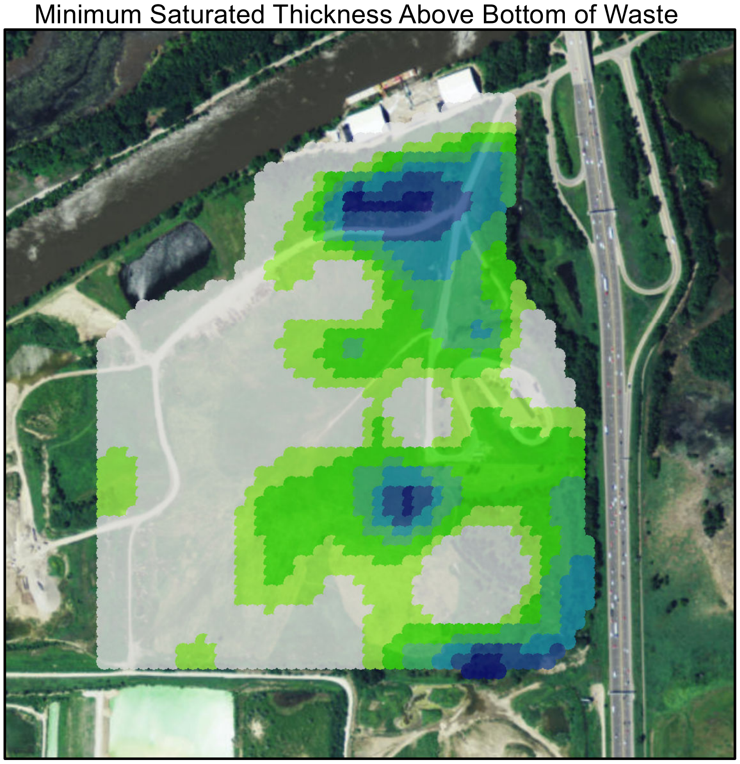
Average Saturated Thickness Above Bottom of Waste



Maximum Saturated Thickness Above Bottom of Waste



Minimum Saturated Thickness Above Bottom of Waste



Standard Deviation of Water Table Elevation

Saturated Thickness Above Bottom of Waste (m)
- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)
- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

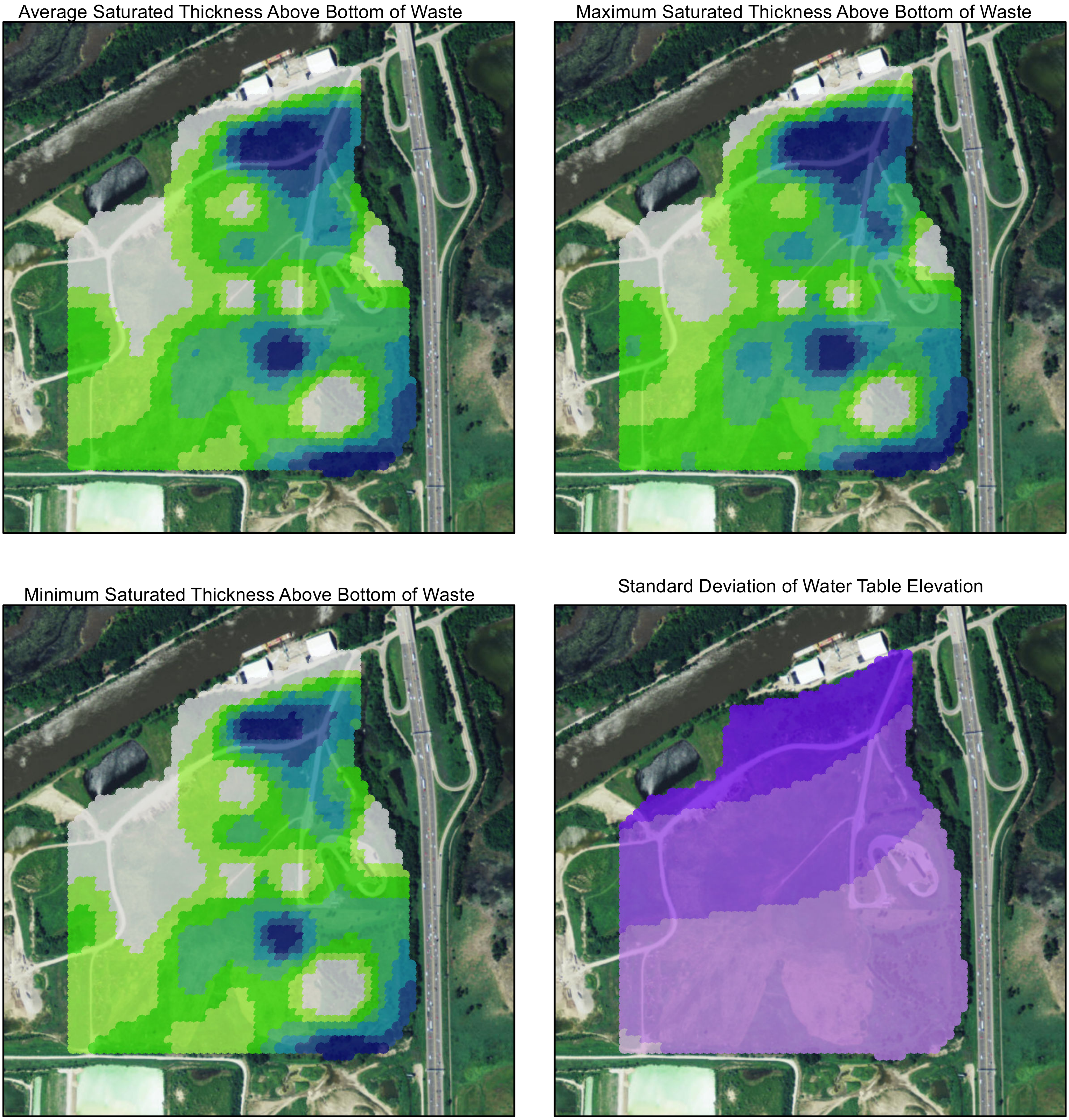
Meters
0 200 400

Feet
0 375 750 1,500

BARR

Figure 15

WASTE SATURATION
PIT LAKE AT
212 METERS (695.5)



Saturated Thickness Above Bottom of Waste (m)

- Dry
- 0.1 - 0.5
- 0.6 - 1.0
- 1.1 - 1.5
- 1.6 - 2.0
- 2.1 - 2.5
- > 2.5 m

Standard Deviation of Water Table Elevation (m)

- < 0.05
- 0.06 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20

N

Meters
0 200 400

Feet
0 375 750 1,500

BARR

Figure 16

WASTE SATURATION
PIT LAKE AT
213 METERS (698.8)