Technical Memorandum

To: Jodi Knaus, East Range Water Board
From: Adam Janzen, PE; Pete Kero, PE
Subject: Embarrass Pit Groundwater Model Update
Date: June 19, 2023
Project: 23692735.00
c: Miles Jensen, SEH

This memorandum describes modeling of future withdrawals from the Embarrass Pit to supply drinking water to the East Range Water Board's Joint Water Project (Project). The model forecasted that the pumping associated with the Project may cause the Embarrass Pit stage to decline by up to 4 feet. The model forecasted negligible Project impacts to nearby surface water and groundwater resources.

1 Background

Barr developed a MODFLOW groundwater flow model of the Embarrass Pit and vicinity in 2015 (Barr, 2015). At the time, the four East Range communities of Biwabik, Aurora, Hoyt Lakes, and the Town of White were exploring the possibility of using the former Embarrass Pit (aka, Lake Mine) as their drinking water source. Barr used the model to simulate two steady-state scenarios of future withdrawal from the Embarrass Pit at rates of 0.816 million gallons per day (MGD) and 1.4 MGD. At these rates, the 2015 model forecasted that the Embarrass Pit stage would decrease by 5 feet and 9 feet, respectively. The stages of nearby Wynne Lake, Sabin Lake, and Embarrass Lake were forecasted to decrease by 1-3 feet.

In 2023, the East Range Water Board (ERWB) is advancing the Project, which involves the design and construction of a new intake on the Embarrass Pit and a water treatment plant that will supply Aurora and the Town of White. Hoyt Lakes is not currently participating in the Project. Biwabik began using Embarrass Pit water from its own intake in 2021. The Minnesota Department of Natural Resources (MnDNR) requested an update to the 2015 model to support the water appropriations permit for the ERWB project. Staff from Barr, Short Elliott Hendrickson (SEH), and Aurora met with Mike Liljegren and Martin van Oort from the MnDNR on April 12, 2023 to discuss the proposed scope of this study prior to Barr beginning the work.

2 Model Updates

A complete description of the model construction can be found in Barr (2015). This section will only document the changes made to the original model for this study. The model's length units are meters; however, most model inputs and outputs will be presented in feet in this memo.

The original model calibration consisted of a steady-state component that simulated average 2013 conditions and a transient component that simulated the post-mining refilling of the Embarrass Pit from 1964-1972. For this study, the following changes were made to these models:

- The representation of the Embarrass River flowing through Sabin, Wynne, and Embarrass Lakes was improved for both the steady-state and transient models,
- Lake input parameters and calibration targets for the steady-state model were updated to reflect 2022 conditions instead of 2013, and
- Minor updates for consistency were made to the lake inputs for the transient model.

These changes are described in more detail in the following sections.

2.1 Embarrass River System

In the original model, the Embarrass River was represented with MODFLOW's River boundary condition. River boundaries simulate the exchange of water between the stream and the aquifer but do not simulate surface water flow in the stream itself. For this study, the segment of the Embarrass River from the northern boundary of the model to Sabin Lake, the segment that connects Wynne Lake and Embarrass Lake, and the segment immediately downstream of Embarrass Lake were converted from the River boundary condition to the Streamflow Routing (SFR) boundary condition. Figure 1 shows the locations of the SFR cells. By making this change, the routing of the Embarrass River through Sabin, Wynne, and Embarrass Lakes can be explicitly simulated in the model. Table 1 summarizes the input data required for the SFR cells.

Table 1 SFR Input Data

Parameter	Segment 1	Segment 2	Segment 3
Upstream Bed Elevation (ft NAVD88)	1399.93	1364.18	1361.42
Downstream Bed Elevation (ft NAVD88)	1364.18	1361.42	1357.51
Length (ft)	4,421	9,901	348
Slope (m/m)	0.0081	0.0003	0.0112
Width (m)	15	30	15
Bed thickness (m)	0.1	0.1	0.1
Manning's n	0.030	0.030	0.030
2022 Upstream Inflow (cfs)	113.08	0	0
1964-1972 Upstream Inflow (cfs)	93.5	0	0

The upstream elevation for Segment 1 and the downstream elevation for Segment 3 were approximated based on the Arrowhead LiDAR (MnDNR, 2011). The outlet elevation of Wynne Lake is the downstream elevation of Segment 1 and the upstream elevation of Segment 2. MnDNR surveyed an outlet elevation of 1363.50 feet NGVD29 for Wynne Lake January 1991 (MnDNR, 1991). Similarly, the outlet elevation of Embarrass Lake is the downstream elevation of Segment 2 and the upstream elevation of Segment 3. MnDNR surveyed an outlet elevation of 1360.74 feet NGVD29 for Embarrass Lake in May 1992 (MnDNR, 1992). Barr converted the surveyed elevations from NGVD29 to NAVD88 by applying an offset of +0.68 feet calculated from VERTCON (NOAA, 2023a).

The segment lengths were measured in GIS, and the widths were approximated from aerial photos in GIS. The slopes were calculated from the upstream and downstream elevations and the lengths. The bed elevation applied to each individual cell was interpolated using the slope and distance of the cell center from the upstream end of the segment. The bed thickness of 0.1 meters and the roughness coefficient (i.e., Manning's n) were both assumed values.

Figure 2 is a hydrograph of 2018-2022 Embarrass River streamflow measured at MnDNR gage 03153002, which is located upstream of the model as shown on Figure 1. The average 2022 streamflow of 113.08 cubic feet per second (cfs) was specified as upstream inflow to SFR Segment 1 in the steady-state 2022 simulation. This assumes that there are no significant sources of inflow to the Embarrass River between the gage and the upstream end of SFR Segment 1.

Because the available streamflow data record at gage 03153002 is June 1, 2017 to the present, upstream inflows to SFR Segment 1 in the 1964-1972 transient simulation were estimated using a correlation between streamflow and precipitation. The inset on the upper right of Figure 2 is a plot of average annual discharge at gage 03153002 for the years 2018 through 2022 versus annual precipitation at the Embarrass, MN weather station (NOAA, 2023b), located approximately 7 miles to the north-northeast of the Embarrass Pit as shown on Figure 1. The linear regression equation shown on Figure 2 was used to estimate average annual Embarrass River flows for 1964-1972 as a function of annual precipitation. Data from the Embarrass, MN station only go back to 1994, so an average 1964-1972 annual precipitation of 29.59 inches was calculated using data from the Hoyt Lakes, MN station shown on Figure 1. With an input precipitation of 29.59 inches, an estimated Embarrass River streamflow of 93.5 cfs was obtained from the regression equation. This value was used as a constant input to the upstream end of SFR Segment 1 in the transient model.

2.2 Lake Inputs

The model uses MODFLOW's Lake boundary condition to represent the following water bodies (in both the steady-state and transient models unless noted):

- Embarrass Pit
- Embarrass Lake
- Wynne and Sabin Lakes (simulated as one combined lake)
- St. James Pit
- Canton Pit
- Mary Ellen Pit
- McKinley Pit (steady-state only)
- Former LTV Area 1, Area 6, Area 9, and Area 9S Pits (steady-state only)
- Stephens Pit (steady-state only).

The Lake boundary condition has input parameters for precipitation rate (L/T), evaporation rate (L/T), runoff (L^3/T), and withdrawal (L^3/T). MODFLOW calculates volumetric precipitation and evaporation rates in L^3/T by multiplying the input rates in L/T by the lake surface area at the calculated stage. This section describes the updates made to these input parameters for this study.

2.2.1 Precipitation

Total 2022 precipitation at the Embarrass, MN station was 32.55 inches, and this value was applied to all lakes in the 2022 steady-state model. The average annual precipitation for 1964-1972 at the Hoyt Lakes weather station was 29.59 inches, and this average rate was applied to all lakes for the duration of the transient model.

2.2.2 Evaporation

The lake evaporation terms were based on reference evapotranspiration data obtained from the Utah Climate Center (Utah State University, 2023a; 2023b). These values were calculated using the Hargreaves-Samani method. The 2022 reference evapotranspiration for the Embarrass, MN station was 30.12 inches, and this value was applied to all lakes in the 2022 steady-state model. The average annual Hoyt Lakes reference evapotranspiration for 1964-1972 was 30.97 inches, which is greater than the average annual precipitation of 29.59 inches for 1964-1972. Evaporation typically does not exceed precipitation in northeastern Minnesota (MnDNR, 2021), and therefore evaporation was assumed equal to precipitation (29.59 inches) for all lakes in the transient model.

2.2.3 Runoff

Previous GoldSim modeling of the Embarrass Pit (Barr, 2012) estimated a runoff coefficient of 0.10 for the Embarrass Pit watershed. This runoff coefficient was used along with the precipitation rates from Section 2.2.1 and lake watershed areas to estimate the runoff terms applied to the Embarrass Pit, Embarrass Lake, and the combined Wynne/Sabin Lake in both the steady-state and transient models. The runoff calculations are summarized in Table 3. The watershed areas were derived from the Level 09 – AutoCatchment data in the MnDNR Watershed Suite (MnDNR, 2018) and reflect the total watershed area minus the lake water surface areas from the same dataset.

Table 3 Runoff Calculations

Lake/Pit	Watershed Area (acres)	1964-1972 Runoff Rate (cfs)	2022 Runoff Rate (cfs)
Embarrass Pit	826	0.28	0.30
Embarrass Lake	3,313	1.11	1.22
Wynne/Sabin Lakes	8,867	2.96	3.26

The runoff term was neglected for the St. James, Canton, Mary Ellen, and McKinley Pits. The runoff terms used for the former LTV pits and the Stephens Pit in the original model were left unchanged.

2.2.4 Withdrawal

Table 3 contains a list of water appropriations permits from the MPARS database that are represented in the model. The pumping rates for these 10 installations were updated to the rates shown in Table 3, which are based on 2022 reported pumping data in million gallons per year (MGY) provided by MnDNR.

Permits 2015-1065 and 2017-3231 did not exist when the original model was developed. It appears that permit 1984-2184 was inadvertently omitted from the original model. The Mary Ellen and McKinley pumping rates were calibrated parameters in the original model because the simulated lake levels were too low if the MPARS reported rates for each pit (shown in parentheses in Table 3) were used. The Area 1 pumping rate in the original model was adjusted for recirculation, but this calculation was not necessary for the updated model because there was no 2022 reported pumping from the Area 1 Pit.

Table 3 Updated MPARS Pumping Rates

Pit/Lake	Permit Number	Permittee	Original Model Withdrawal (MGY) (2013)	Updated Model Withdrawal (MGY) (2022)
Embarrass Pit	2001-2029	Giants Ridge	29.80	23.01
Embarrass Pit	2015-1065	Biwabik Public Utilities	0	344.03
Wynne/Sabin Lakes	1984-2184	Giants Ridge	0	63.92
Wynne/Sabin Lakes	1995-2152	Giants Ridge	22.29	22.81
St. James Pit	1962-0182	City of Aurora	74.75	80.68
St. James Pit	2017-3231	City of Aurora	0	15.55
Canton Pit	1981-2070	Biwabik Public Utilities	60.74	0
McKinley Pit	2007-0559	Minorca Mine	192.83 (1068.07)	516.43
Mary Ellen Pit	2007-0559	Minorca Mine	192.83 (1062.05)	729.24
Area 1 Pit	2005-2058	Mesabi Nugget	991.06 (1510.75)	0

2.3 Calibration Targets

The historical 1964-1972 water levels for the Embarrass Pit, Embarrass Lake and Wynne Lake that were used as calibration targets in the transient calibration of the original model were reused for this study. Also unchanged from the previous study was the Embarrass Pit dewatering rate target of 5,000 gpm applied to the historical steady-state simulation that sets the initial condition for the transient model. The following two sections describe updates made to the remaining steady-state calibration targets.

2.3.1 Steady-State Lake Level Calibration Targets

As a condition of water appropriations permit 2015-1065, Biwabik Public Utilities is required to monitor water surface elevations in the Embarrass Pit, Wynne Lake, Sabin Lake, and Embarrass Lake. MnDNR provided a copy of the 2022 Annual Water Appropriation Report (Levelwind, 2023) that includes the lake level monitoring data from 8/31/2021 through 3/28/2023. Figure 3 shows the 2022 data for the Embarrass Pit, Wynne Lake, and Embarrass Lake. Barr converted elevations from NGVD29 to NAVD88 by applying an offset of +0.68 feet. Figure 3 also shows 2022 precipitation data from the Embarrass, MN station.

MnDNR (2023) shows a hydrograph of St. James Pit levels for 2009-2023. MnDNR provided the hourly transducer data displayed on the hydrograph, and a subset of these data (2022 weekly readings) are shown on Figure 3. No datum was specified for the St. James Pit data; Barr assumed the St. James Pit data were in NAVD88.

Barr calculated the average 2022 stages shown on Figure 3 and used them as calibration targets for these lakes in the model recalibration. Note that the Wynne Lake data were assumed to apply to the combined Wynne/Sabin Lake in the model.

The previous steady-state calibration to 2013 conditions included lake stage calibration targets for the Mary Ellen, McKinley, Area 1, Area 6, Area 9, Area 9S, and Stephens Pits. 2022 data for these pits were not available, so no lake stage calibration targets were used for these pits in the model recalibration.

2.3.2 Steady-State Groundwater Calibration Targets

Figure 4 shows the locations of 28 head targets obtained from the Minnesota Well Index (MWI) database, along with the 4 steady-state lake stage targets. Twenty-one of these wells are completed in the unconsolidated aquifer (model layer 1) and the remaining 7 are completed in bedrock aquifers (model layer 2). The heads at 10 of these wells were measured in 1960-1961, and these measurements were used as targets for the historical steady-state simulation that sets the initial condition (1964) for the transient model. The remaining 18 head measurements were taken in 2014-2019 and were used as calibration targets for the steady-state model of 2022 conditions.

3 Model Recalibration

Barr used PEST_HP software (Watermark Numerical Computing, 2020) to automate the calibration process of adjusting model input parameter values until the sum of squared weighted differences between the calibration targets and their associated model outputs was minimized. Adjustable parameters in the model recalibration included:

- Horizontal hydraulic conductivity values for the unconsolidated (Quaternary) and bedrock aquifers,
- Vertical anisotropy ratios (horizontal divided by vertical hydraulic conductivity) for the unconsolidated and bedrock aquifers,
- Storage coefficients (specific storage and specific yield) for the unconsolidated and bedrock aquifers,
- Aquifer recharge rates from infiltrating precipitation, and
- Riverbed hydraulic conductivity values.

Hydraulic conductivity and recharge were parameterized using a zone-based approach. The hydraulic conductivity and recharge zone boundaries were the same as described in Barr (2015). Some of the layer 1 hydraulic conductivity and recharge zones were grouped together ("tied" in PEST nomenclature) in the recalibration to avoid separately parameterized zones that contained no calibration targets. Some of the

River boundary reaches were also grouped together. The zone/reach groupings and final recalibrated parameter values are shown on Figure 5.

Figure 4 shows a map of the residuals (defined as the measured head/stage minus the best-fit modeled head/stage) for the steady-state calibration targets, and Figure 6 shows the same data in a 1-to-1 plot. An excellent fit was obtained to the four lake/pit stage targets. An acceptable fit was obtained to the MWI head targets given the lower quality of this dataset. Figure 4 indicates no obvious spatial bias to the residuals for the 2022 head targets; however, the 1964 head targets were biased low and are all located in the same general area. It was more important for this project to match the 2022 head targets, and as shown on Figure 4 a good fit was obtained to the 2022 head targets that were located near the 1964 head targets. A better fit could likely have been achieved for the 1964 head targets had a higher recharge value been used for the 1964 simulation. For simplicity, the same recharge values were used for all simulated time periods.

Figure 7 shows time-series plots of modeled and observed pit/lake stages for the transient recalibration. The recalibrated model produced an excellent fit to the 1964-1972 stages of the Embarrass Pit, Embarrass Lake, and Wynne Lake. Note that the model could not reproduce the seasonal peaks in the Embarrass Lake and Wynne Lake data because constant values were used for the upstream inflow, precipitation, and runoff terms in the simulation. Not shown on Figure 7 is the flow target for the 1964 Embarrass Pit dewatering rate. The modeled dewatering rate of 4,993 gpm closely matched the target value of 5,000 gpm.

Figure 8 shows the composite parameter sensitivities calculated by PEST_HP. Note that the horizontal axis is on a logarithmic scale. The model was most sensitive to the recharge parameters, which is to be expected given the mostly no-flow outer model boundaries and the domain's location near a major watershed divide. The most sensitive recharge parameters were zones 5, 14, and 15, which collectively cover the northeastern portion of the model domain. The most sensitive hydraulic conductivity parameters were zones 201 and 103, which surround the Embarrass Pit in layers 2 and 1, respectively.

4 Forward Simulations

4.1 Scenario Definitions

Barr used the recalibrated steady-state model to simulate 3 scenarios of future pumping from the Embarrass Pit. These scenarios were intended to evaluate the incremental surface water and groundwater level changes resulting from a new Project appropriation from the Embarrass Pit and inform the design of the proposed Project intake. The scenarios were defined as follows:

0. A baseline scenario with Giants Ridge and Biwabik pumping from the Embarrass Pit at their full appropriations,
1. The baseline scenario plus an additional Project pumping rate of 0.4 MGD (146 MGY) to supply Aurora and the Town of White. This scenario represents the current Project.

2. The baseline scenario plus an additional Project pumping rate of 0.8 MGD (292 MGY) to supply Aurora, the Town of White, and Hoyt Lakes. This scenario represents a case in which Hoyt Lakes decides to join the Project in the future.

4.2 Input Parameters

The calibrated 2022 steady-state model was used as the starting point for the forward simulations. All of the calibrated steady-state parameter values were used in the forward simulations. The non-calibrated 2022 input parameter values were also used, with the following exceptions:

- Lake Precipitation Rate. 2022 was a wet year on the East Range. Average precipitation for the last 10 years (2013-2022) at the Embarrass weather station was 27.13 inches compared to 32.55 inches in 2022 alone. For a more conservative forecast of future pit level decrease, Barr used the 2013-2022 average precipitation for all lakes in the forward simulations instead of the 2022 value.
- Lake Evaporation Rate. Evaporation was assumed equal to precipitation (27.13 inches per year) for the forward simulations.
- Lake Runoff Rates. Runoff to the Embarrass Pit, Embarrass Lake, and Wynne/Sabin Lakes were recalculated for the forward simulations using the same method described in Section 2.2.3 for an annual precipitation of 27.13 inches. The resulting values were 0.25 cfs for the Embarrass Pit, 1.02 cfs for Embarrass Lake, and 2.72 cfs for Wynne/Sabin Lakes.
- Embarrass River Upstream Inflow. The average 2013-2022 precipitation of 27.13 inches was used with the regression equation shown on Figure 2 to estimate an upstream Embarrass River inflow of 79.5 cfs for the forward simulations.
- Existing Embarrass Pit Water Appropriations.
    - Giants Ridge: Water appropriations permit 2001-2029 authorizes Giants Ridge to withdraw a total of 50 MGY from the Embarrass Pit for golf course irrigation. Average annual usage for 2013 through 2022 was 25.19 MGY; however, Giants Ridge exceeded the permit limit in both 2010 and 2012. The full appropriation of 50 MGY was assumed for all forward simulations.
    - Biwabik: Water appropriations permit 2015-1065 authorizes Biwabik Public Utilities to withdraw a total of 82 MGY from the Embarrass Pit. Biwabik's 2022 water use was 33.17 MGY. The full appropriation of 82 MGY was assumed for all forward simulations.
- Existing Wynne/Sabin Lakes Water Appropriations. Giants Ridge is authorized to withdraw a total of 89 MGY from Wynne and Sabin Lakes: 60 MGY for snow making under permit 1984-2184 and 29 MGY for golf course irrigation under permit 1995-2152. The average withdrawal for both permits combined for 2013-2022 was 80.86 MGY, and this value was assumed for all forward simulations.
- St. James Pit Water Appropriations.
    - Drinking Water: Water appropriations permit 1962-0182 authorizes Aurora to withdraw a total of 160 MGY from the St. James Pit for drinking water. Average 2013-2022 pumping was 87.36 MGY. The 2013-2022 average was used for the baseline scenario. Zero pumping for this permit was used for Scenarios 1 and 2 because the St. James Pit will no longer be used for Aurora's water supply once the Project is operational.

- Water Level Maintenance: Water appropriations permit 2017-3231 authorizes Aurora to withdraw a total of 250 MGY for St. James Pit water level maintenance. The average pumping for 2017-2022 of 104.64 MGY was assumed for all forward simulations.

The forward simulation input parameters for the Embarrass Pit are summarized in Table 4.

Table 4 Embarrass Pit Inputs for Forward Simulations

Input	Baseline	Scenario 1 Value	Scenario 2 Value
Precipitation (in/yr)	27.13	27.13	27.13
Evaporation (in/yr)	27.13	27.13	27.13
Runoff (cfs)	0.25	0.25	0.25
Giants Ridge Pumping (MGY)	50	50	50
Biwabik Pumping (MGY)	82	82	82
ERWB Pumping (MGY)	0	146	292

4.3 Results

4.3.1 Surface Water Levels

The forecasted stages for the Embarrass Pit, Embarrass Lake, Wynne/Sabin Lakes, and the St. James Pit for the forward simulations are summarized in Table 5. The model forecasted that the Embarrass Pit stage would decrease between 1 and 2 feet for Scenario 1 and between 3 and 4 feet for Scenario 2. The model forecasted that the proposed Project pumping would not affect the stages of Embarrass Lake and Wynne/Sabin Lakes. Removal of Aurora's pumping under permit 1962-0182 (while keeping the permit 2017-3231 pumping fixed) was forecasted to cause the St. James Pit stage to rise between 3 and 4 feet.

Table 5 Forecasted Pit/Lake Stages

Lake/Pit	Baseline	Scenario 1		Scenario 2	
	Modeled Stage (ft NAVD88)	Modeled Stage (ft NAVD88)	Change from Baseline (ft)	Modeled Stage (ft NAVD88)	Change from Baseline (ft)
Embarrass Pit	1371.9	1370.3	-1.6	1368.4	-3.5
Embarrass Lake	1361.9	1361.9	0.0	1361.9	0.0
Wynne/Sabin Lakes	1361.9	1365.2	0.0	1365.2	0.0
St. James Pit	1436.5	1440.0	+3.6	1439.5	+3.1

4.3.2 Groundwater Levels

Figures 9 and 10 show forecasted drawdown contours for Scenario 1 and Scenario 2, respectively. The top panel of each figure shows the unconsolidated aquifer (model layer 1) and the bottom panel shows the bedrock aquifer (model layer 2). Both panels show MWI water supply wells completed in these aquifers. In this area, the MWI database contains many exploration borings and monitoring wells. Barr filtered the MWI database to only display wells with an active (or unknown) status code and domestic, industrial, or public supply (both community and non-community) use code. Note that the MWI database is incomplete and does not contain records for all extant wells.

Figure 9 indicates that 4 unconsolidated aquifer wells may experience drawdown between 1 and 2 feet as a result of increased Embarrass Pit withdrawal for Aurora and the Town of White. Well 109519 is a domestic drinking water well. Wells 1000022305, 1000022306, and 1000022307 are listed as domestic wells but the logs have almost no other information. When pumping for Hoyt Lakes was included, the forecasted drawdown increased to 2-3 feet for well 109519; was approximately the same for wells 1000022305, 1000022306, and 1000022307; and was approximately 1 foot for wells 274536 and 735566. Well 274536 is listed as an industrial well for Lake Mining Co.; the MWI status is "unknown," but this well is likely inactive or abandoned. Well 735566 is a domestic well. As shown on Figures 9 and 10, no bedrock wells were forecasted to experience drawdown greater than 1 foot for either scenario.

Figures 9 and 10 show areas of water table and hydraulic head increase of 1-3 feet in Aurora due to the higher St. James Pit stage (which is displayed as a negative drawdown on the figures).

4.3.3 Embarrass River Flow

Table 6 summarizes the simulated Embarrass River discharges into Embarrass Lake. The model forecasted very small (< 1 cfs) decreases in streamflow resulting from the additional Embarrass Pit withdrawals.

Table 6 Forecasted Embarrass Lake Inflow

Scenario	Modeled Embarrass Lake Inflow (cfs)	% Change from Baseline
Baseline	83.9	N/A
Scenario 1	83.6	-0.4
Scenario 2	83.1	-0.9

5 Summary and Recommendations

Barr updated its existing MODFLOW model of the Embarrass Pit and its vicinity to better reflect present-day conditions and then used the updated model to simulate 2 scenarios of future pumping from the Embarrass Pit. The results are summarized as follows:

- The Embarrass Pit stage was forecasted to decline by 1-2 feet if Hoyt Lakes does not participate in the Project. If Hoyt Lakes does participate, the stage was forecasted to decline by 3-4 feet.
- With Hoyt Lakes included, the model forecasted an ultimate steady-state Embarrass Pit stage of approximately 1368 feet (NAVD88).
- The proposed Project pumping from the Embarrass Pit was forecasted to have no impact on the stages of Embarrass Lake, Wynne Lake, and Sabin Lake.
- As a consequence of the Project, Aurora would no longer pump from the St. James Pit for drinking water supply. All other things being equal, removal of this pumping was forecasted to cause the St. James Pit stage to rise by 3-4 feet.

- Forecasted drawdowns at water supply wells in the MWI database were generally 1 foot or less, with the exception of well 109519 in Pineville, which may experience drawdown between 2 and 3 feet. Drawdowns less than 5 feet are typically not of concern in water supply wells.
- The water table in Aurora was forecasted to rise 1-3 feet due to the higher forecasted St. James Pit stage. No depth to water data were available in Aurora to evaluate whether this magnitude of water table rise might result in wet basements.
- The proposed pumping from the Embarrass Pit was forecasted to have a negligible effect on Embarrass River flows.

Even though the forward simulations were based on conservative assumptions regarding future precipitation and withdrawal rates, it is still recommended to locate the proposed Project intake at least 5 feet below the ultimate forecasted Embarrass Pit stage of 1368 feet to account for seasonal variations and model uncertainty.

While not evaluated under this scope, it may be necessary for Aurora to increase future pumping under permit 2017-3231 to maintain the desired St. James Pit level in the absence of drinking water withdrawals under permit 1962-0182.

6 References

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Certification

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

Adam K. Janzen

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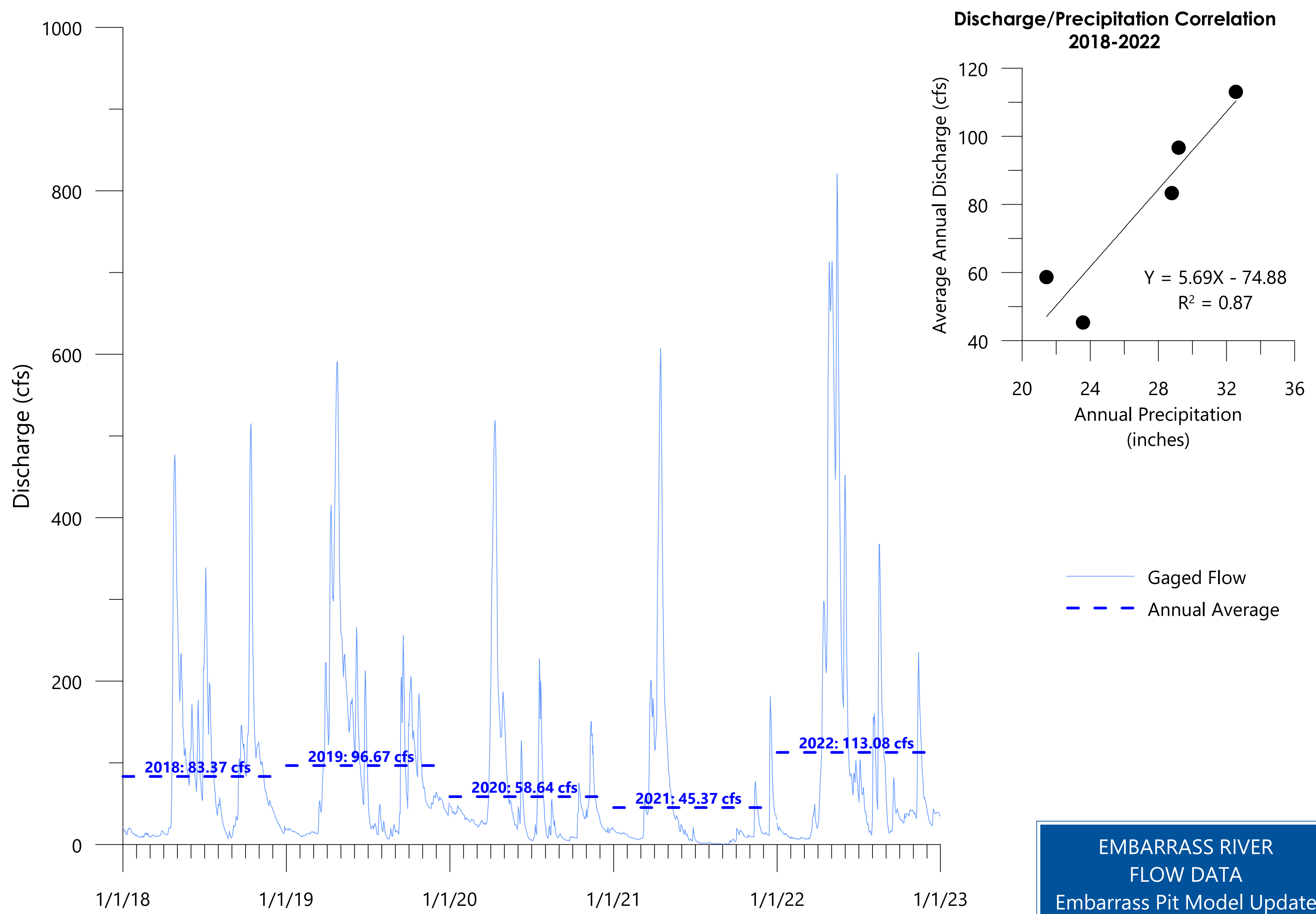
PE #: 53665

June 19, 2023
Date

SFR BOUNDARIES AND GAGING STATIONS
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

FIGURE 1



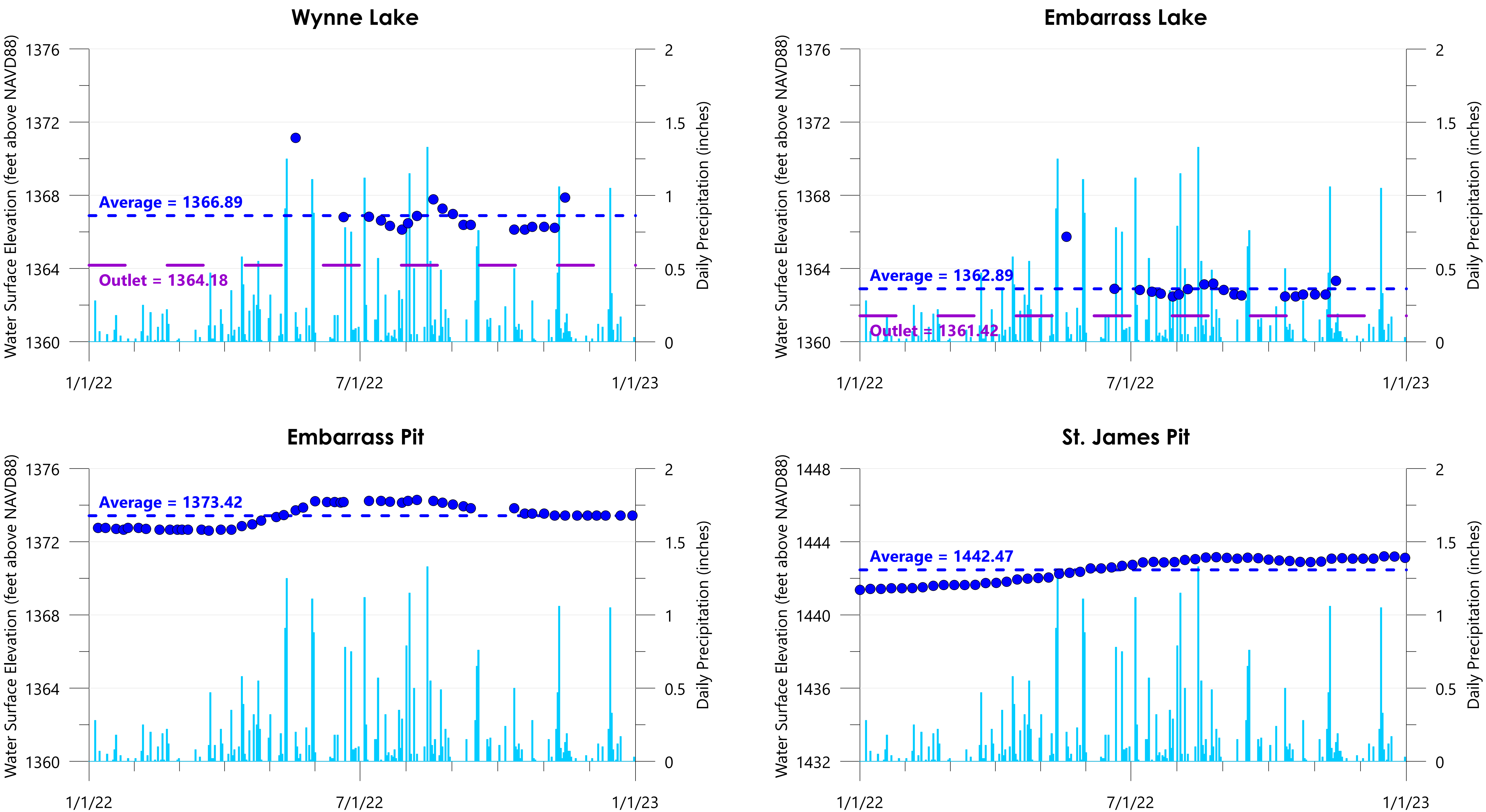
Streamflow data source: MnDNR gage 03153002
Precipitation data source: Embarrass, MN station (USC00212576)

BARR

EMBARRASS RIVER
FLOW DATA
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

FIGURE 2

P:\Hibbing\23 MN\69\23692735 Embarrass Pit GW Model Update\WorkFiles\Tech Memo\figures\grapher\Figure 2 - Streamflow Data.grf



Lake Level Measurement
2022 Average Stage
Outlet Elevation
Precipitation (Embarrass, MN)

Precipitation data source: Embarrass, MN station (USC00212576)
Lake level data sources: Water Appropriations Permit 2015-1065 (Embarrass Pit, Wynne Lake, Embarrass Lake), MnDNR (St. James Pit)
Wynne Lake outlet data source: 1/16/1991 MnDNR survey
Embarrass Lake outlet data source: 5/13/1992 MnDNR survey
Embarrass Pit, Embarrass Lake, and Wynne Lake elevation data collected in NGVD29
NAVD88 = NGVD29 + 0.68 feet
St. James Pit data assumed to be in NAVD88

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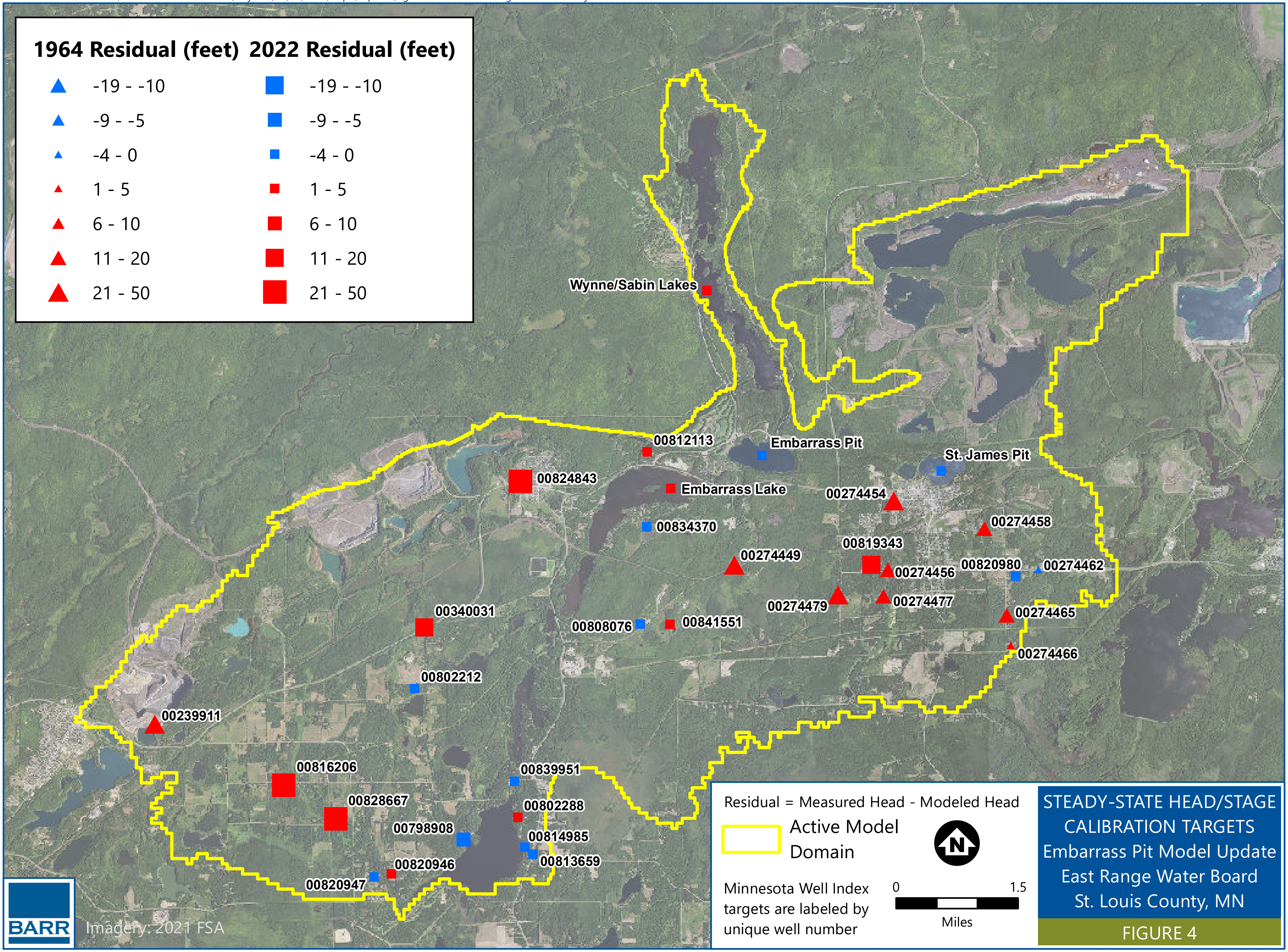
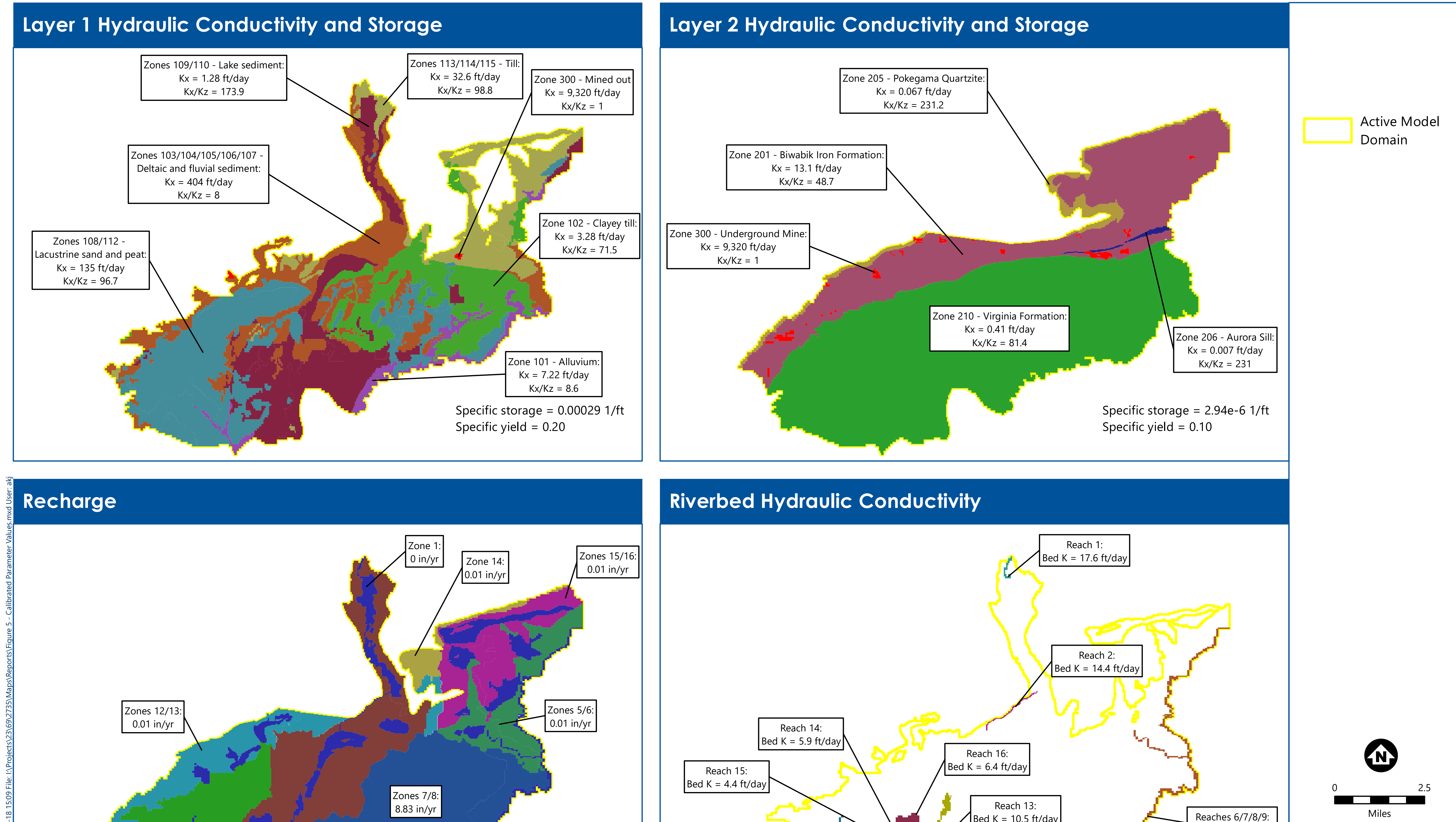
2022 LAKE LEVEL DATA
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN
FIGURE 3

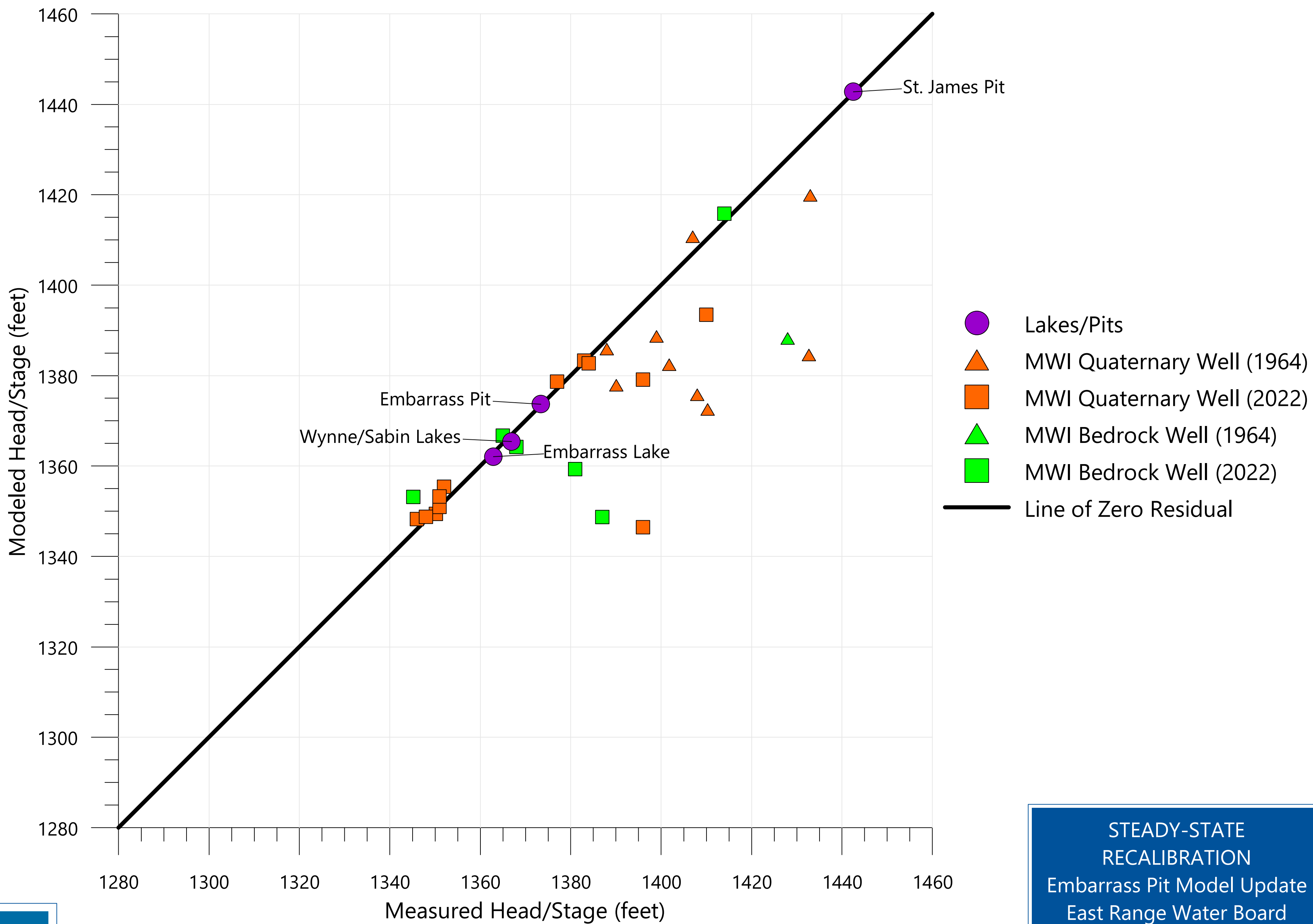


STEADY-STATE HEAD/STAGE CALIBRATION TARGETS
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN
FIGURE 4



CALIBRATED PARAMETERS
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

FIGURE 5



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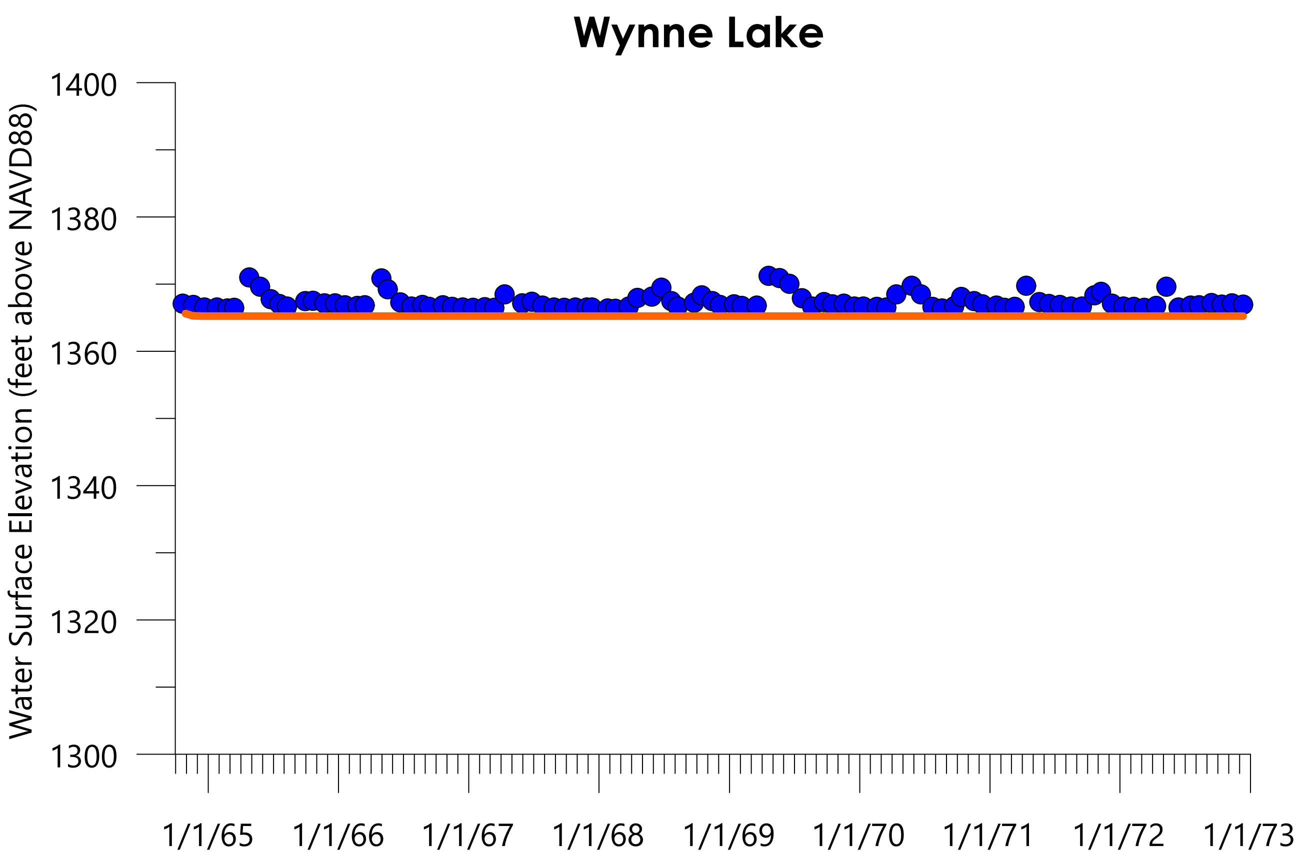
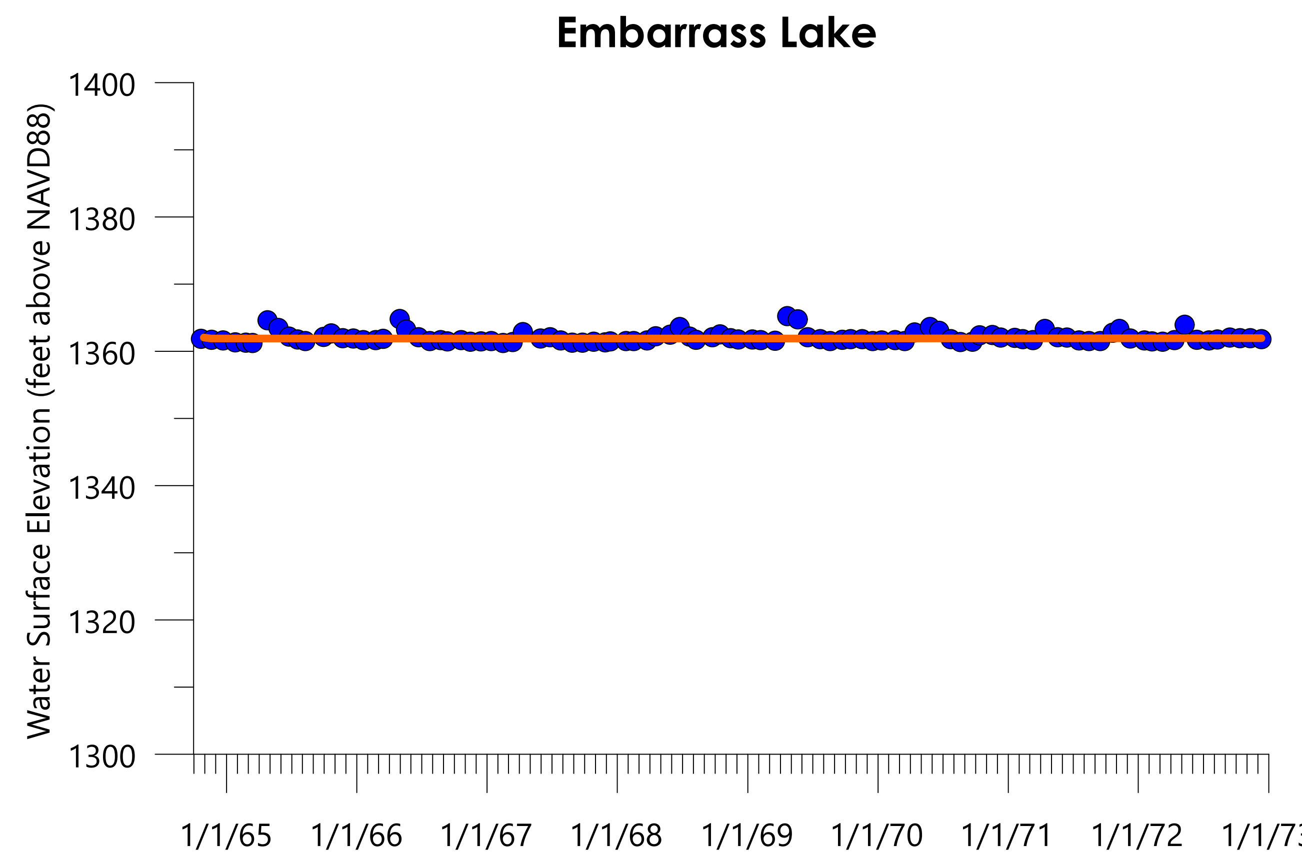
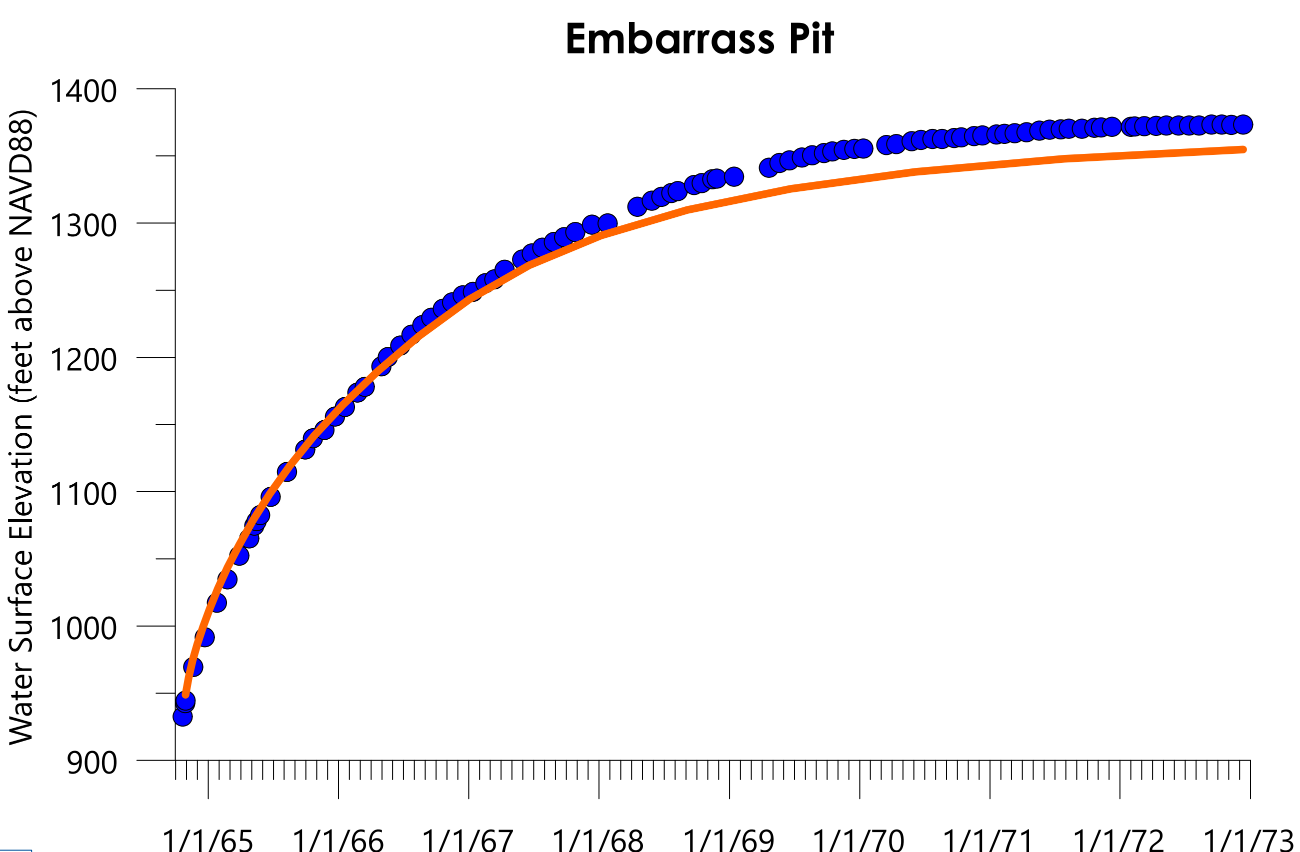
STEADY-STATE RECALIBRATION
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

FIGURE 6

P:\Hibbing\23 MN\69\23692735 Embarrass Pit GW Model Update\WorkFiles\Tech Memo\figures\grapher\Figure 6 - Steady-State Recalibration.grf







Lake Level Measurement
Calibrated Model

Lake level data source: MnDNR Lake Finder
All elevation data collected in NGVD29 datum
NAVD88 = NGVD29 + 0.68 feet

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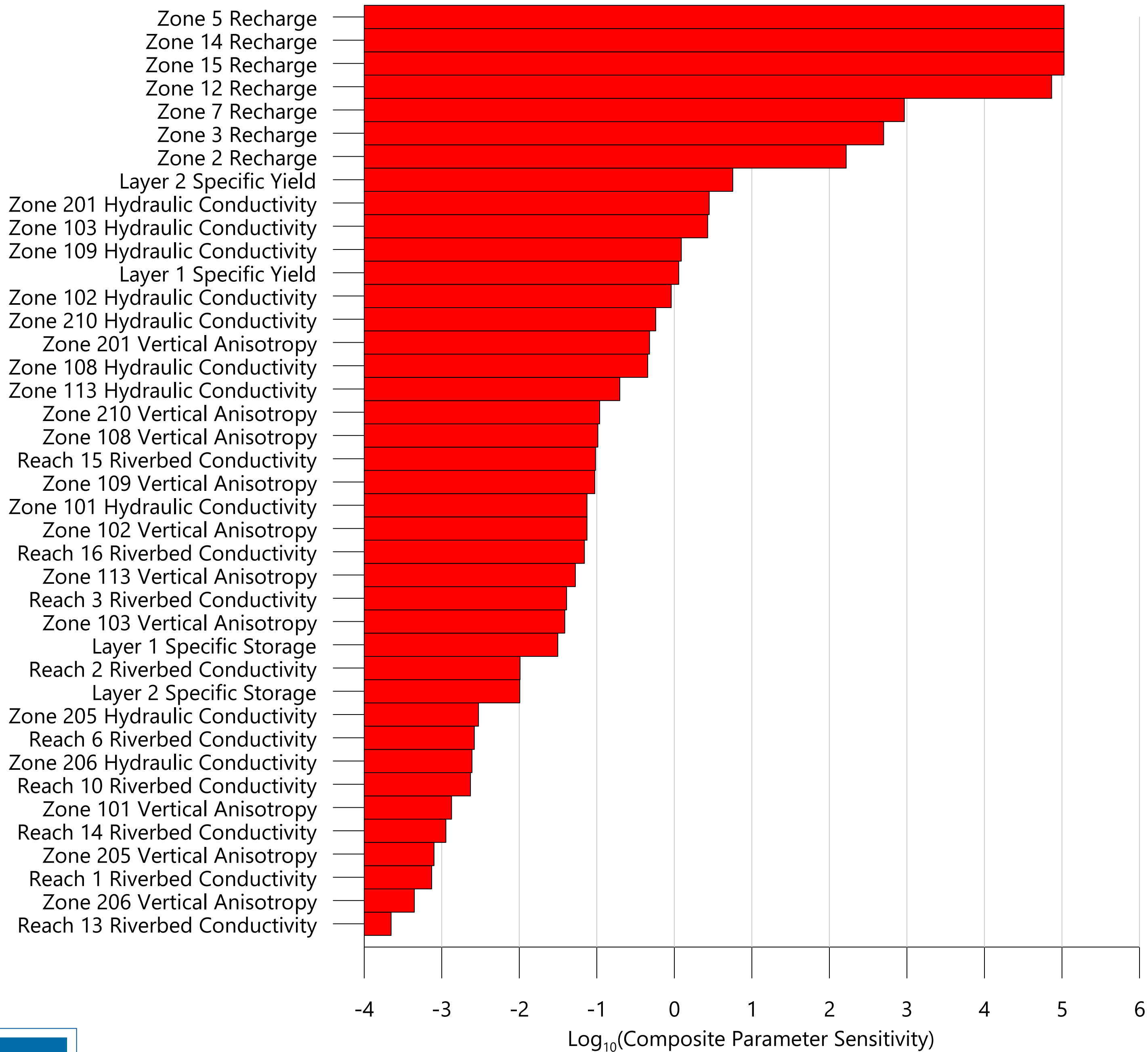
TRANSIENT RECALIBRATION
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

FIGURE 7

P:\Hibbing\23 MN\69\23692735 Embarrass Pit GW Model Update\WorkFiles\Tech Memo\figures\grapher\Figure 7 - Transient Recalibration.grf



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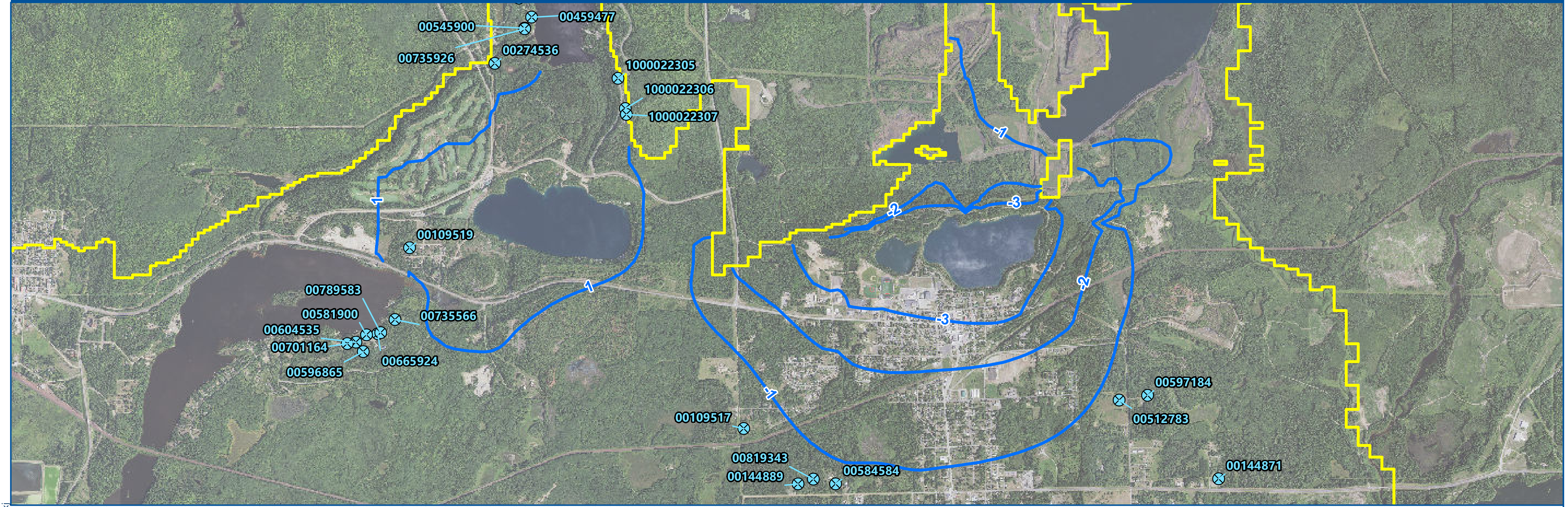
PARAMETER SENSITIVITY
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

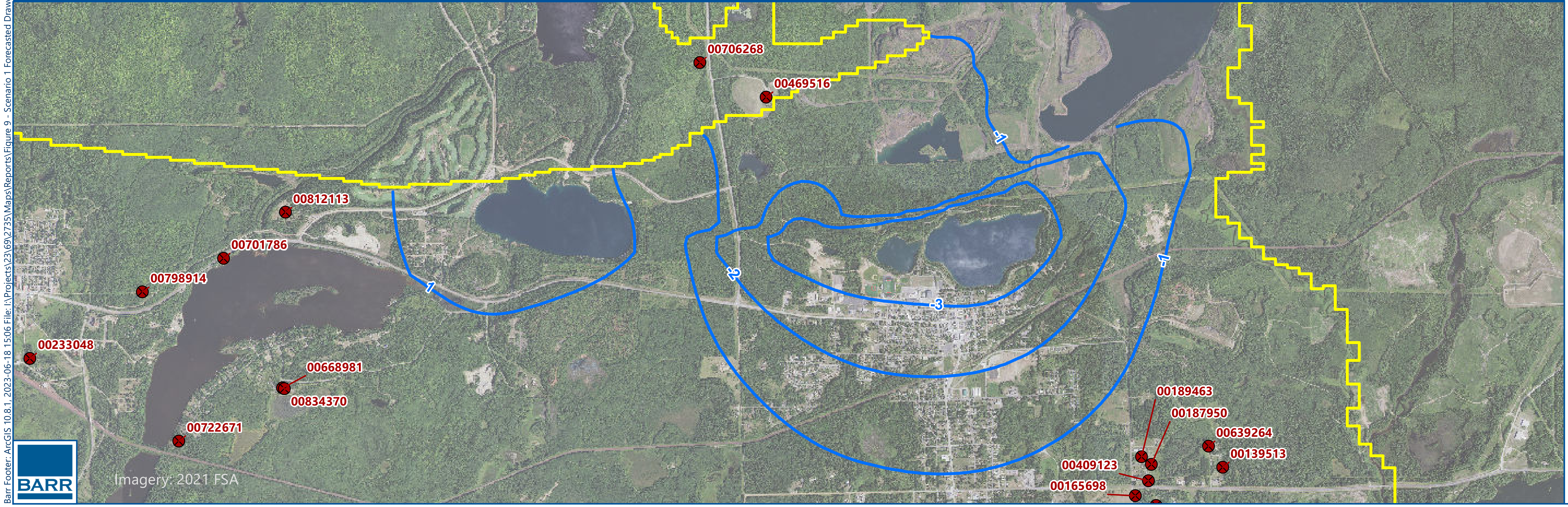
FIGURE 8

P:\Hibbing\23 MN\69\23692735 Embarrass Pit GW Model Update\WorkFiles\Tech Memo\figures\grapher\Figure 8 - Parameter Sensitivity.grf

Layer 1 - Unconsolidated Aquifer



Layer 2 - Bedrock Aquifer



Drawdown (feet)

Active Model Domain

MWI Water Supply Well

Aquifer

Unconsolidated

Bedrock

Wells shown have active or unknown status

Exploration borings and observation/monitoring wells not shown

Unlocated wells not shown

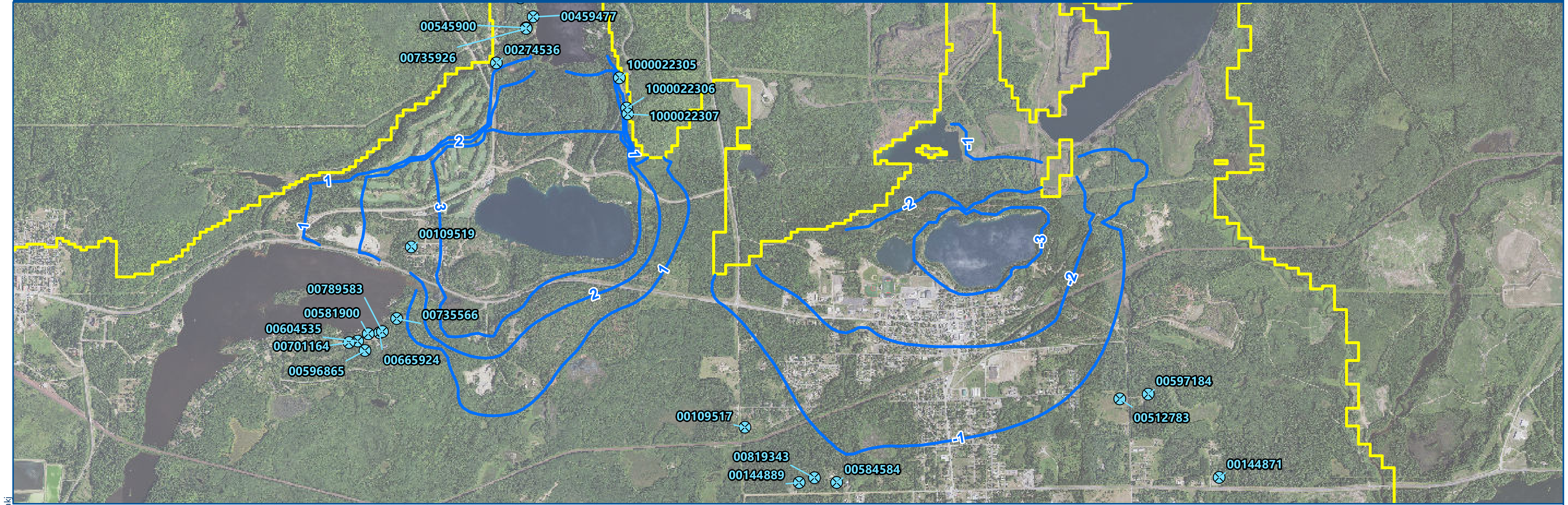
0 3,000
Feet

FORECASTED DRAWDOWN
SCENARIO 1
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

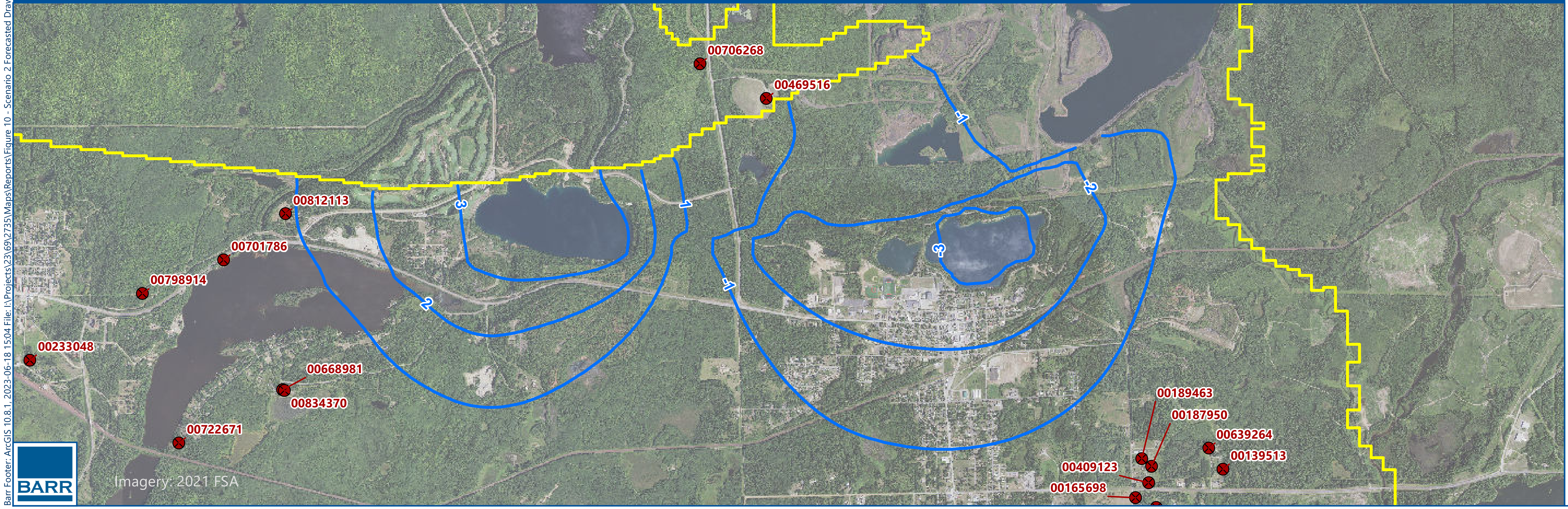
FIGURE 9

BARR

Layer 1 - Unconsolidated Aquifer



Layer 2 - Bedrock Aquifer



Drawdown (feet)

Active Model Domain

MWI Water Supply Well

Aquifer

Unconsolidated

Bedrock

Wells shown have active or unknown status

Exploration borings and observation/monitoring wells not shown

Unlocated wells not shown

0 3,000
Feet

FORECASTED DRAWDOWN
SCENARIO 2
Embarrass Pit Model Update
East Range Water Board
St. Louis County, MN

FIGURE 10