N91192.AR.001011
NIROP FRIDLEY
5090.3a

GROUNDWATER MODELING SUMMARY DATED MAY 2011 NIROP FRIDLEY MN

5/1/2011

NIROP FRIDLEY

NIROP Fridley Groundwater Modeling Summary – May 2011

Objective The Navy has tasked Tetra Tech to evaluate and update the NIROP Fridley Groundwater Model (Report dated March 2002, calibrated to 1999 groundwater and pumping data) in order to be utilized as a potential tool for evaluations of the pumping system (e.g. impacts of AT-3A well replacements, optimization of pumping rates to attain maximum contaminant capture, etc.).

Considerations

- Since the Model was constructed over 10 years ago, many new borings and wells have been added to the project. As a consequence, greater resolution of the subsurface lithologies has been realized. Additionally, work done by USGS has realized low permeability zones (clay ridge) that also have hydraulic impacts on the groundwater system.
- Existing model grid and boundaries maintained – uniform 50 foot by 50 foot cells.
- Original model had 4 overburden layers and 2 bedrock layers.
- Most boundary conditions maintained (River cells, Constant Heads, No Flow cells and general heads).

Updates to the Existing NIROP Fridley Groundwater Model

1. **Changes to Model Layering**
    - Previous model had 4 layers in overburden. Model layers split, creating 8 model layers.
    - Additional model layer added to account for surface/topography (previous model top was approximately the water table elevation).
    - Total of 9 model layers in the overburden.
    - Total of 2 model layers in bedrock (unchanged).

2. **Changes to Model Layering Hydraulic Conductivities**
    - Multi-step process to set-up hydraulic conductivities based on observed lithologies from site-specific cross-sections.
        i. Based on 8 generalized lithologies ranging from generally clean gravels to sands to silts to clay (see Legend to compare to Model output).
    - Hydraulic conductivites for each lithology based first on site-specific values, then literature based values (primarily from *Groundwater* by Freeze & Cherry).

3. **Calibration of New Groundwater Model**
    - Calibrated to groundwater potentiometric data for 1999 and Annual data for 2009 and 2010.

    i. Data for 1999 represents higher pumping rates for extraction system while data from 2009 and 2010 represent lower rates (especially at AT-3A).
- Calibration efforts focused on area surrounding extraction system (not a site-wide re-calibration effort).
- Calibration focuses on modifying size, shape and value of hydraulic conductivites (lithologies) in this area to accurately predict large scale drawdown effects.
- Additional calibration efforts are needed over the entire site but do not significantly impact appropriateness of area of the extraction system.

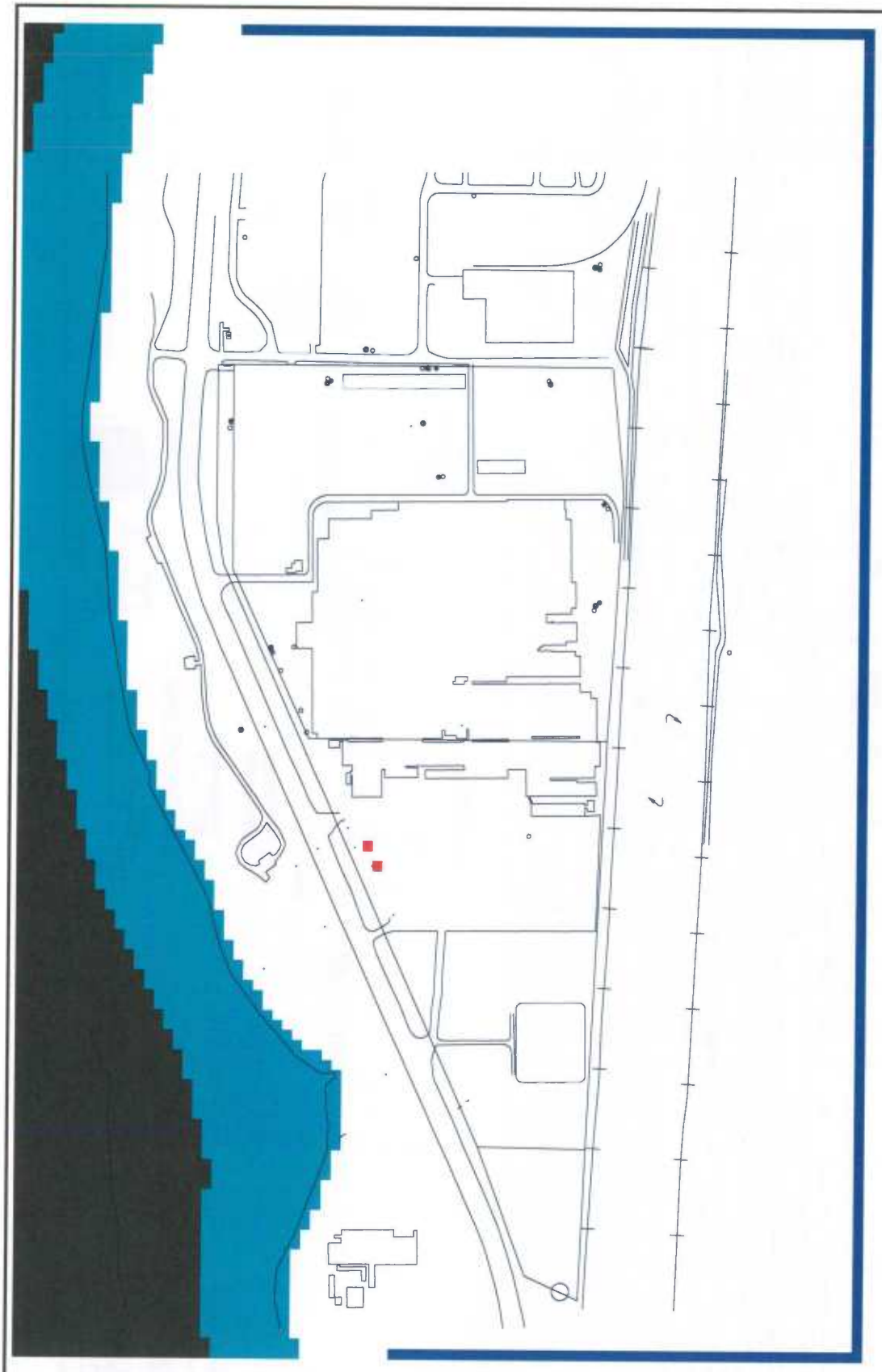
4. **Support for Replacement wells for AT-3A**
    - Based on calibrated model to the surrounding extraction system, a scenario was ran to verify the effect of placing the three proposed AT-3A replacement wells under the designed conditions.
    - Results do not indicate any significant de-watering/drawdown and generally show a more focused area of groundwater capture.
    - Results should be considered estimated (model does not account for long-term trends in reduced pumping capacity due to mechanical/physical degradation of the system).
    - Additional pumping rates and combination of rates may be performed.

5. **Additional Calibration, Verification and Scenarios (Potential Future Work)**
    - *Additional Calibration*
        i. Calibrate to site-wide conditions.
        ii. Update boundary conditions, especially constant heads observed upgradient (east) of the facility.
    - *Verification*
        i. Verify model calibration with new pumping and observation well data when replacement pumping wells installed.
    - *Additional Groundwater Scenarios for Evaluation*
        i. Evaluate various alternative pumping rates/strategies to optimize capture of contaminant plume that will provide less stress to operating system.

Legend for Hydrualic Conductivity Zonations
NIROP Fridley Groundwater Model
2011 Updated Model

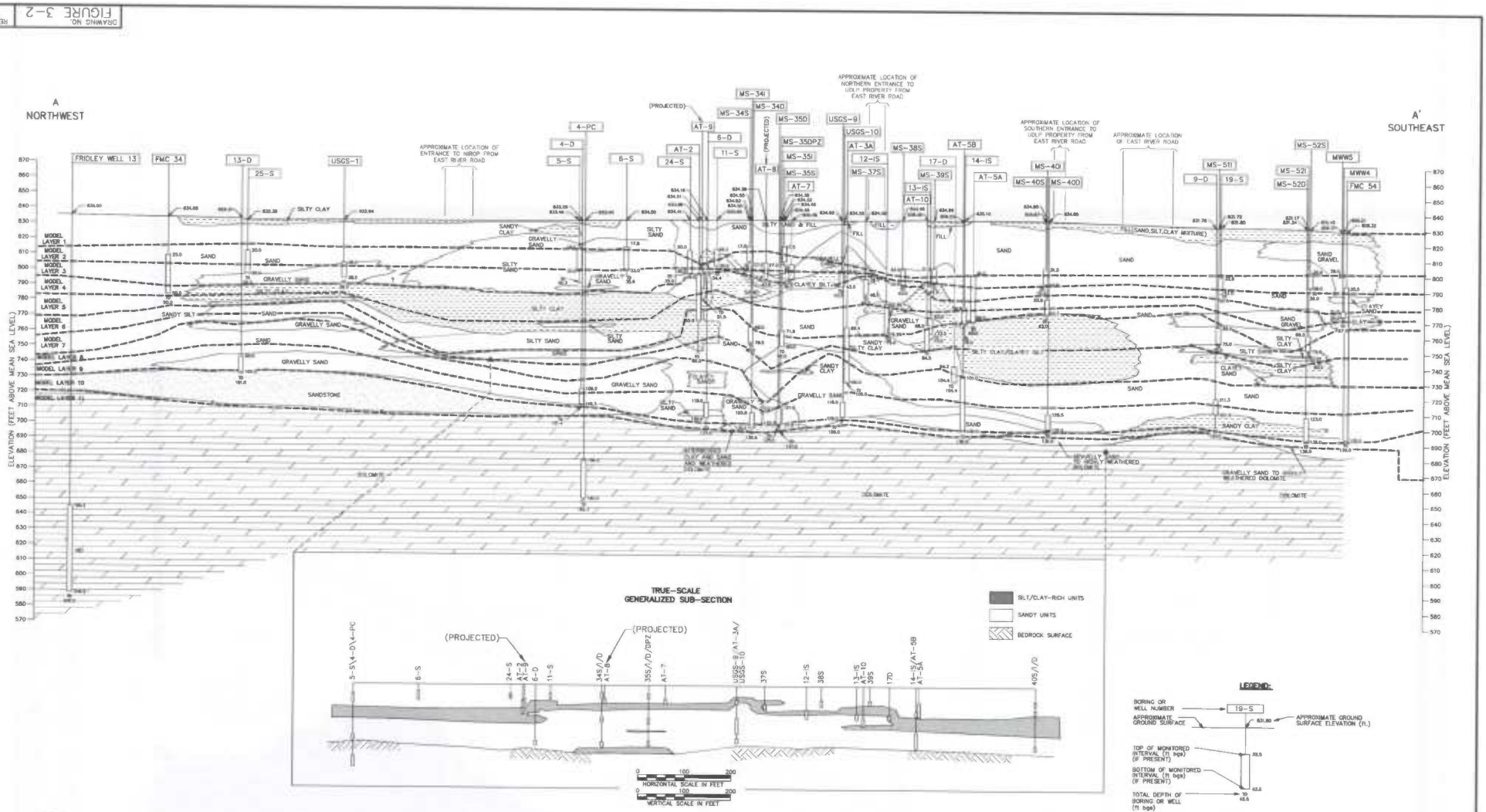
Color	Lithology	Hydraulic Conductivity (ft/day) used in Model
	Gravel	750
	Gravelly Sand	500
	Sand	8, 75, 90, 100, 150, 160, 200, 250, 300, 400
	Silty Sand	1, 10
	Sandy Clay	0.1, 0.25, 0.5
	Clayey Sand	1
	Silt	0.25, 1
	Clay	0.05

Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Boundary Conditions - River, General & Constant Heads, Wells



Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Boundary Conditions - River Cells, Constant Heads, Wells

DRAWING NO. FIGURE 3-2 | REV 1



NOTES:

1) LITHOLOGY SHOWN BETWEEN BORINGS WAS INTERPOLATED BASED ON BORING LOGS.
2) SAND SHOWN IN CROSS-SECTION RANGES FROM FINE TO COARSE SAND.
3) VERIFIED CROSS-SECTION A-A' LITHOLOGY USING FIGURE 10 OF PUBLICATION "HIGH RESOLUTION SEISMIC REFLECTION SURVEY TO MAP BEDROCK AND GLACIAL/FLUVIAL LAYERS AT THE U.S. NAVY NORTHERN ORDNANCE PLANT (NIROP) IN FRIDLEY, MINNESOTA; FEBRUARY 6, 1997.
4) WELLS AT-2, 6-D, 12-IS, 17-D, MS-40D, AND 9-D WERE GAMMA LOGGED. THE DATA GENERATED FROM THE GAMMA LOGS IN CONJUNCTION WITH THE GEOLOGIST'S LOGS WERE USED TO GENERATE THIS CROSS-SECTION. THERE WERE NOTICABLE DIFFERENCES BETWEEN THE GAMMA LOG AND GEOLOGIST'S LOG FOR WELLS 6-D AND MS-40D. IN THESE CASES, THE GAMMA LOGS WERE USED PRIMARILY.
5) EXTRACTION WELLS AT-9 & AT-8 WERE PROJECTED ONTO A-A' TRANSECT.

UNCONSOLIDATED MATERIAL

CLAY, SILTY CLAY, SANDY CLAY, SILT, CLAYEY SILT AND SANDY SILT AS SHOWN ON THE CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A LOWER PERMEABILITY)

SAND, CLAYEY SAND, SILTY SAND, GRAVELLY SAND, GRAVEL AND SANDY GRAVEL AS SHOWN ON CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A HIGH PERMEABILITY)

BEDROCK

SANDSTONE BEDROCK (ST. PETER SANDSTONE)

DOLOMITE BEDROCK (PRAIRIE DU CHIEN GROUP)

HORIZONTAL SCALE IN FEET: 0, 150, 300

VERTICAL SCALE IN FEET: 0, 30, 60

NOTE: ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (FT AMSL)

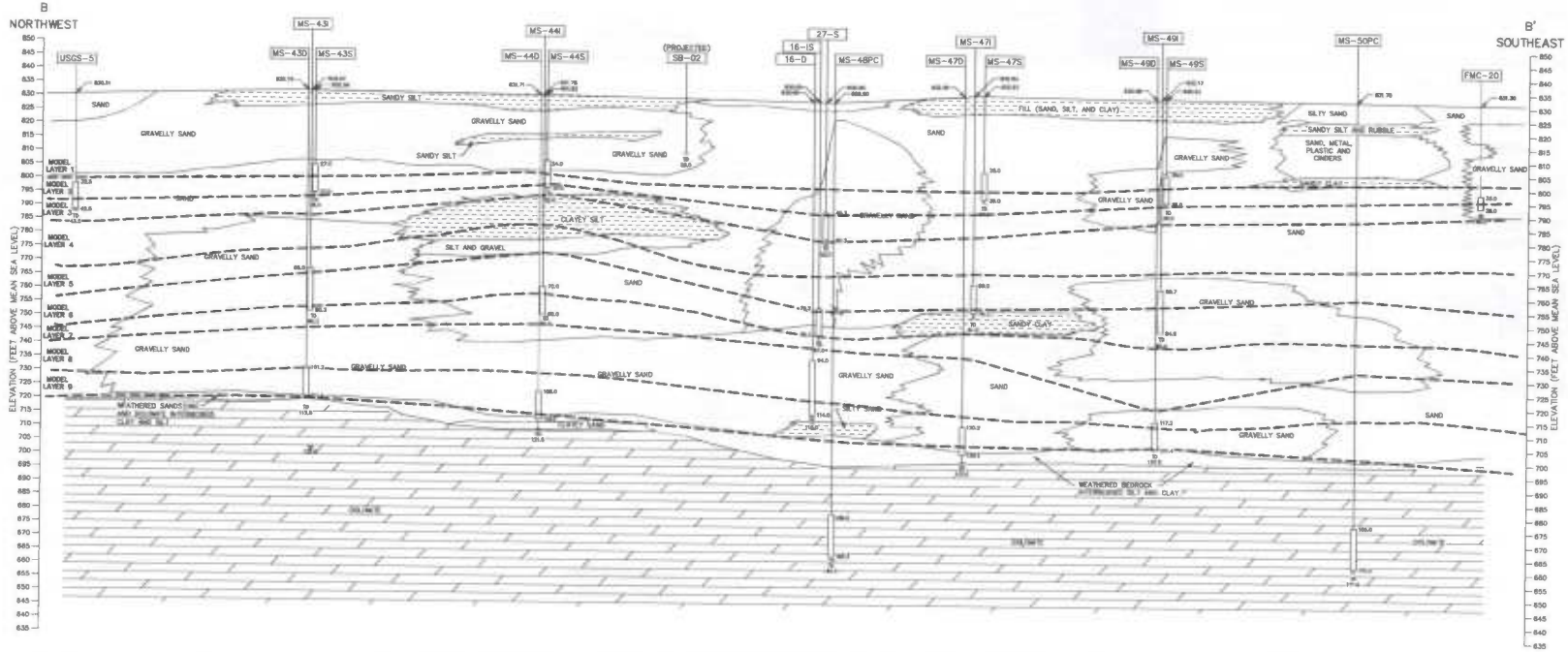
DRAWN BY ND	DATE 12/08/10
CHECKED BY	DATE
REVISED BY	DATE
SCALE AS NOTED	

NAVFAC

GENERALIZED GEOLOGICAL CROSS-SECTION A-A'
2009 ANNUAL MONITORING REPORT
NIROP FRIDLEY, MINNESOTA

CONTRACT NO.	2583
OWNER NO.	F27C
APPROVED BY	DATE
DRAWING NO.	FIGURE 3-2
REV.	0

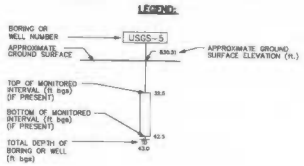
DRAWING NO. FIGURE 3-3 REV. 1



HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN FEET

LEGEND:



NOTES:

1) SAND SHOWN IN CROSS SECTION RANGES FROM FINE TO COARSE GRAINED SAND
2) LITHOLOGY SHOWN BETWEEN BORINGS WAS INTERPOLATED BASED UPON THE BORING LOGS.
3) WELL MS-49D WAS GAMMA LOGGED. THE DATA WERE GENERATED FROM THE GAMMA LOG IN CONJUNCTION WITH THE GEOLOGIST'S LOG WAS USED TO GENERATE THIS CROSS-SECTION.

UNCONSOLIDATED MATERIAL

CLAY, SILTY CLAY, SANDY CLAY, SILT, CLAYEY SILT AND SANDY SILT AS SHOWN ON THE CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A LOWER PERMEABILITY)

SAND, CLAYEY SAND, GRAVELLY SAND, GRAVEL AND SANDY GRAVEL AS SHOWN ON CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A HIGH PERMEABILITY)

BEDROCK

DOLOMITE BEDROCK (PRAIRIE DU CHIEN GROUP)

NOTE: ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (FT AMSL)

DRAWN BY ND	DATE 12/08/10
CHECKED BY	DATE
REVISED BY	DATE
SCALE AS NOTED	

NAVFAC

GENERALIZED GEOLOGICAL CROSS-SECTION B-B'
2009 ANNUAL MONITORING REPORT
NIROP FRIDLEY, MINNESOTA

CONTRACT NO.	2583
OWNER NO.	F27C
APPROVED BY	DATE
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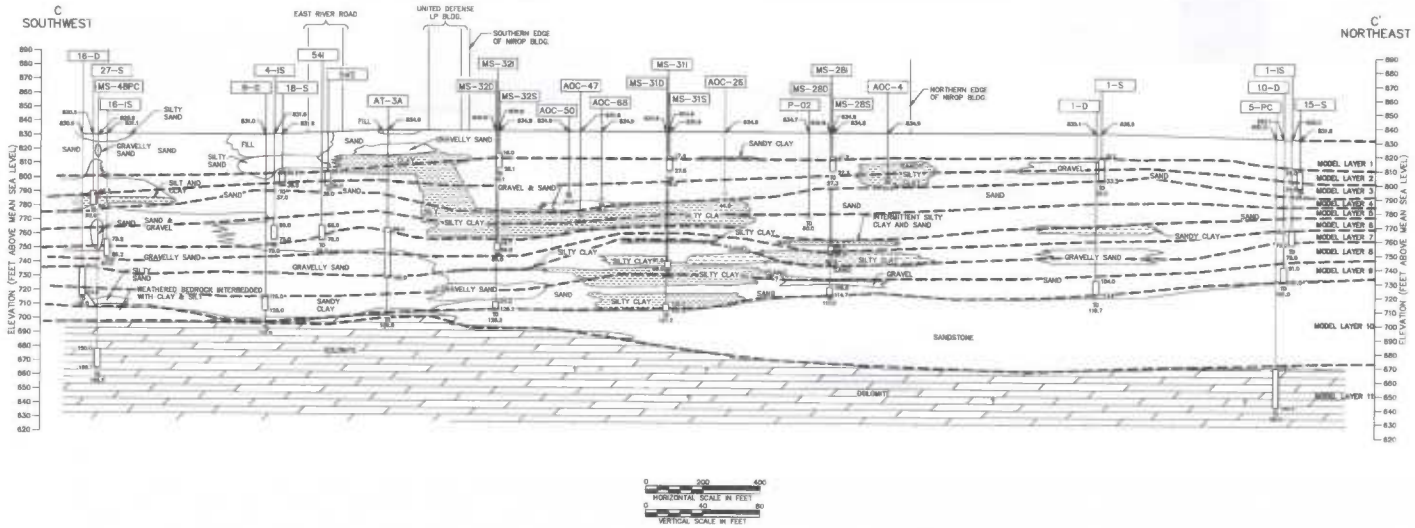
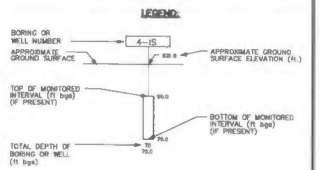
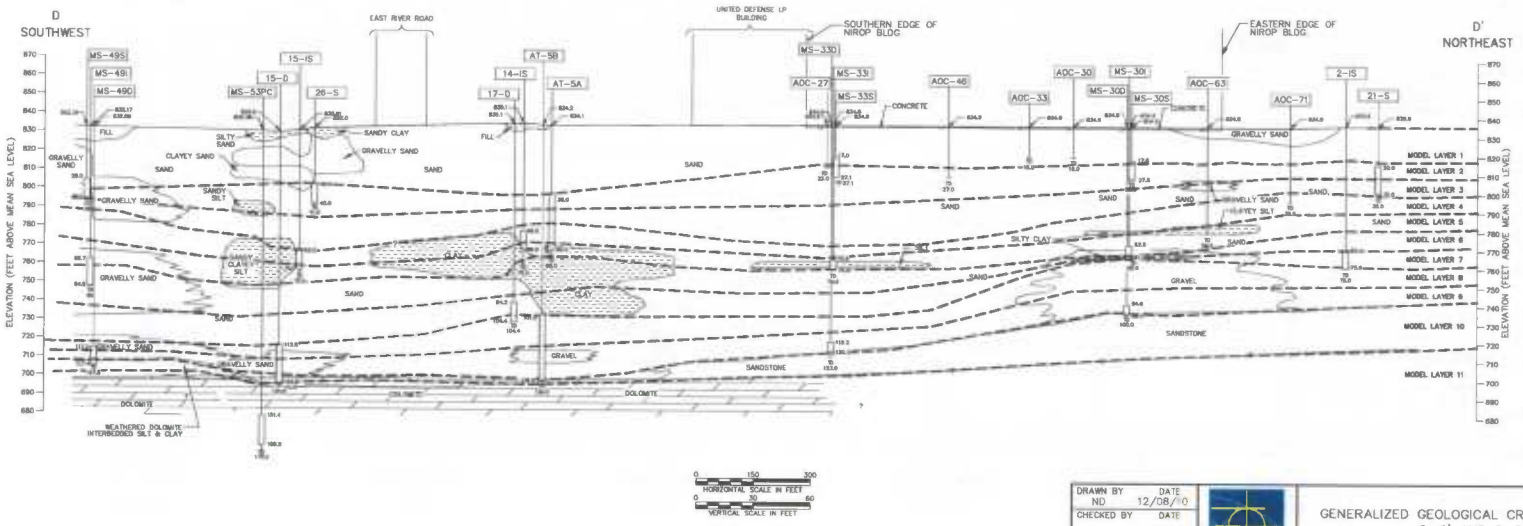
REV.	0

DRAWING NO. FIGURE 3-4 REV. 1







NOTES:

1) SAND SHOWN IN CROSS-SECTION RANGES FROM SILTY SAND TO FINE AND COARSE GRAINED SAND.

2) LITHOLOGY SHOWN BETWEEN BORINGS WAS INTERPOLATED BASED ON BORING LOGS.

3) WELLS MS-49C, 5-D, AND 15-D WERE GAMMA LOGGED. THE DATA GENERATED FROM THE GAMMA LOGS IN CONJUNCTION WITH THE GEOLOGISTS LOGS WERE USED TO GENERATE THIS CROSS-SECTION. THERE WERE NOTICEABLE DIFFERENCES BETWEEN THE GAMMA LOG AND GEOLOGISTS LOG FOR 15-D AND 5-D. IN THESE CASES, THE GAMMA LOGS WERE USED PRIMARILY.

UNCONSOLIDATED MATERIAL

CLAY, SILTY CLAY, SANDY CLAY, SILT CLAYEY SILT AND SANDY SILT AS SHOWN ON THE CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A LOWER PERMEABILITY.)

SAND, CLAYEY SAND, GRAVELLY SAND, GRAVEL AND SANDY GRAVEL AS SHOWN ON CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A HIGH PERMEABILITY)

BEDROCK

SANDSTONE BEDROCK (ST PETER SANDSTONE)

DOLOMITE BEDROCK (PRAIRIE DU CHEIN GROUP)

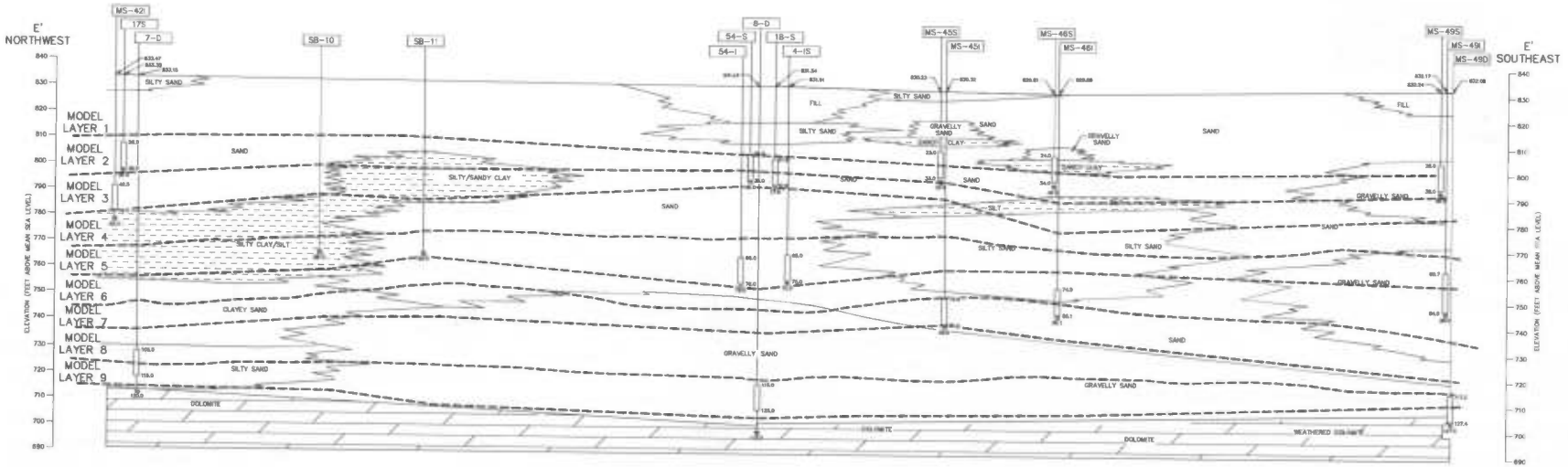
DRAWN BY ND	DATE 12/08/10
CHECKED BY	DATE
REVISED BY	DATE
SCALE AS NOTED	

NAVFAC

GENERALIZED GEOLOGICAL CROSS-SECTIONS
C-C' AND D-D'
2009 ANNUAL MONITORING REPORT
NIROP FRIDLEY, MINNESOTA

CONTRACT NO.	2583
OWNER NO.	F27C
APPROVED BY	DATE
DRAWING NO.	FIGURE 3-4
REV.	0

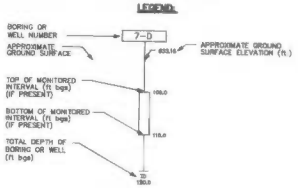
DRAWING NO. FIGURE 3-5 REV 1



NOTES:

1. LITHOLOGY SHOWN BETWEEN BORINGS WAS INTERPOLATED BASED ON THE BORING LOGS.
2. SAND SHOWN IN CROSS-SECTION RANGES FROM FINE TO COARSE SAND.

LEGEND:



NOTE: ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (FT AMSL)

UNCONSOLIDATED MATERIAL

CLAY, SILTY CLAY, SANDY CLAY, SILT, CLAYEY SILT AND SANDY SILT AS SHOWN ON THE CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A LOWER PERMEABILITY)

SAND, CLAYEY SAND, SILTY SAND, GRAVELLY SAND, GRAVEL AND SANDY GRAVEL AS SHOWN ON CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A HIGH PERMEABILITY)

BEDROCK

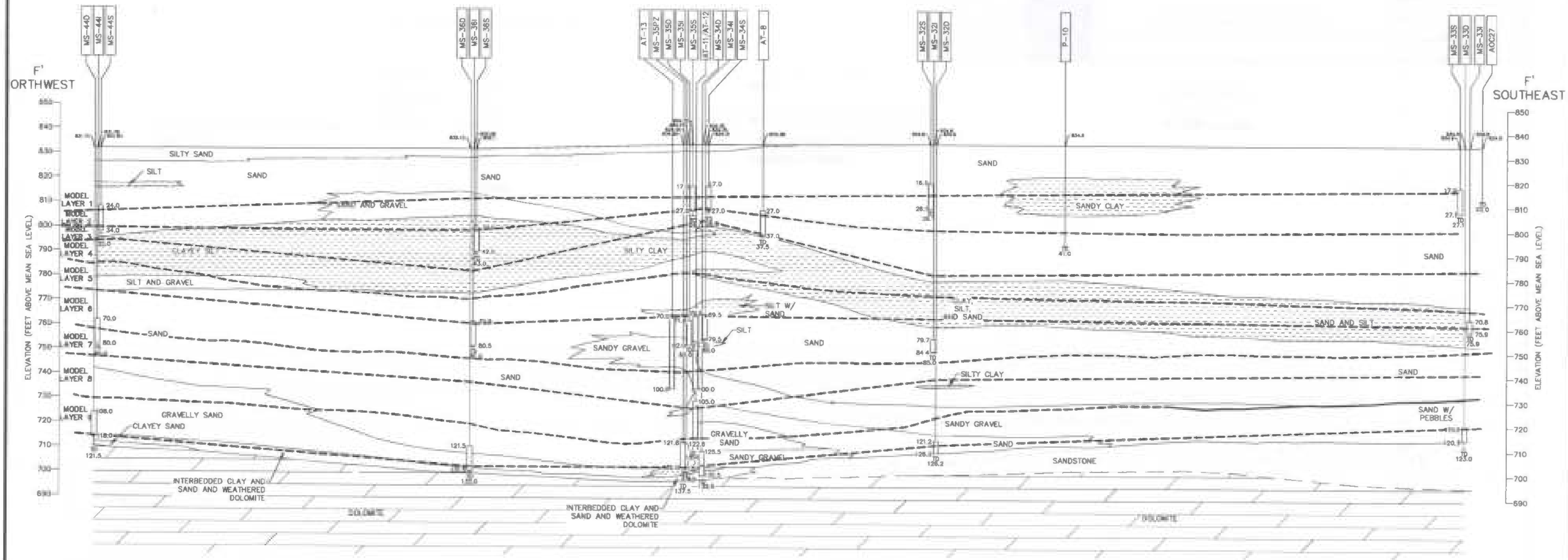
DOLOMITE BEDROCK (PRAIRIE DU CHIEN GROUP)

0 60 120
HORIZONTAL SCALE IN FEET

0 20 40
VERTICAL SCALE IN FEET

DRAWN BY ND DATE 12/09/10	GENERALIZED GEOLOGICAL CROSS-SECTION E-E'
CHECKED BY DATE	2009 ANNUAL MONITORING REPORT
REVISED BY DATE	NIROP, FRIDLEY, MINNESOTA
SCALE AS NOTED	NAVFAC

CONTRACT NO. 2583	
OWNER NO. F27C	
APPROVED BY --	DATE --
DRAWING NO. FIGURE 3-5	REV. 0



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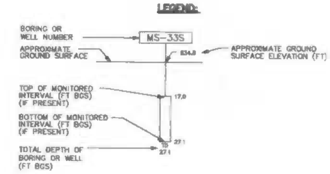

NOTE: ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (FT AMSL)

0 50 100
HORIZONTAL SCALE IN FEET
0 20 40
VERTICAL SCALE IN FEET

NOTES:

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3) VERIFIED CROSS-SECTION A-A' LITHOLOGY USING FIGURE 10 OF PUBLICATION "HIGH RESOLUTION SEISMIC REFLECTION SURVEY TO MAP BEDROCK AND GLACIAL/FLUVIAL LAYERS AT THE U.S. NAVY NORTHERN ORDNANCE PLANT (NIROP) IN FRIDLEY, MINNESOTA, FEBRUARY 6, 1997.

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5) EXTRACTION WELLS AT-9 & AT-8 WERE PROJECTED ONTO A-A' TRANSECT

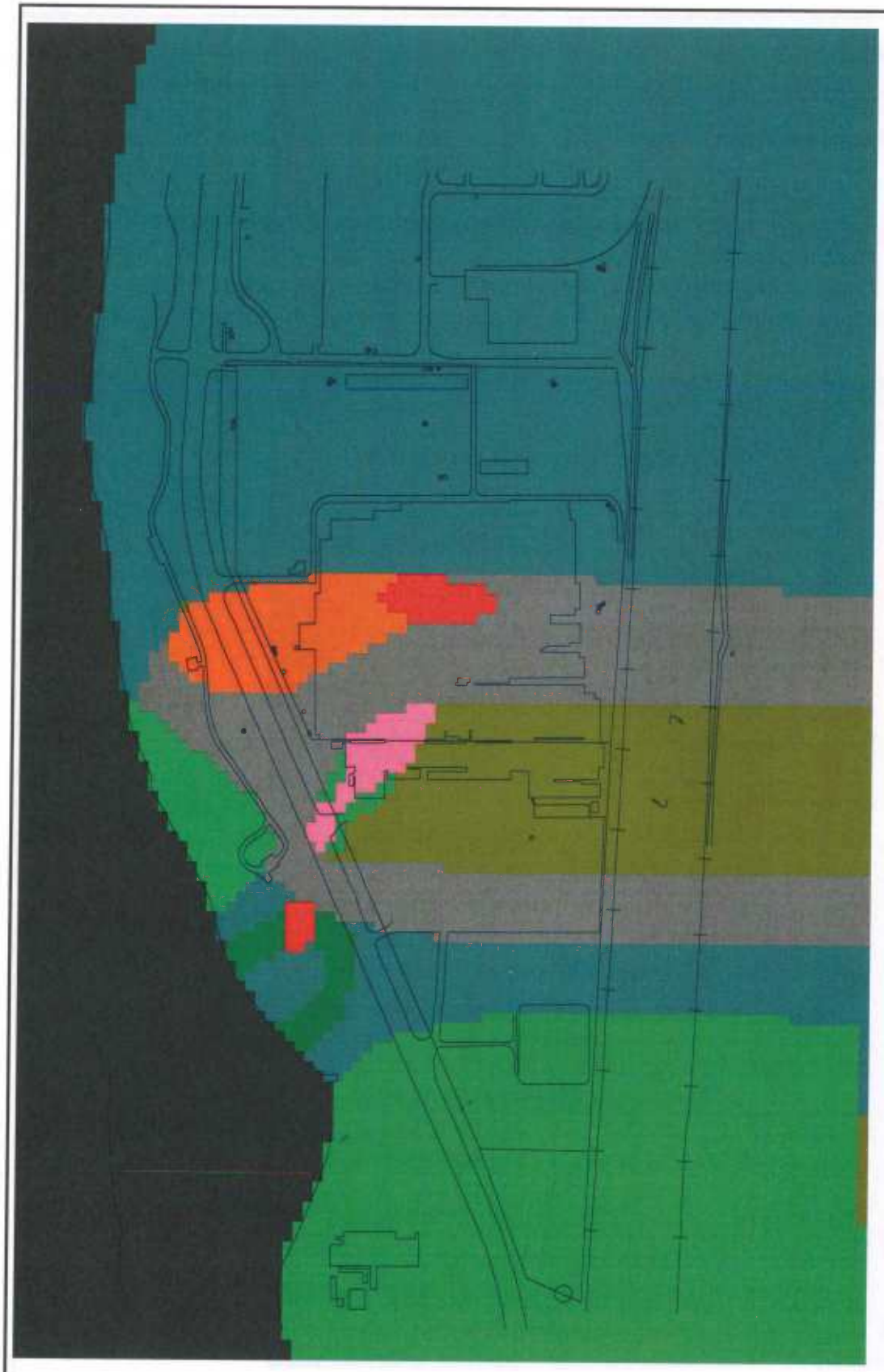
UNCONSOLIDATED MATERIAL

- CLAY, SILTY CLAY, SANDY CLAY, SILT, CLAYEY SILT AND SANDY SILT AS SHOWN ON THE CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A LOWER PERMEABILITY)
- SAND, CLAYEY SAND, SILTY SAND, GRAVELLY SAND, GRAVEL AND SANDY GRAVEL AS SHOWN ON CROSS-SECTION (UNCONSOLIDATED MATERIAL HAVING A HIGH PERMEABILITY)

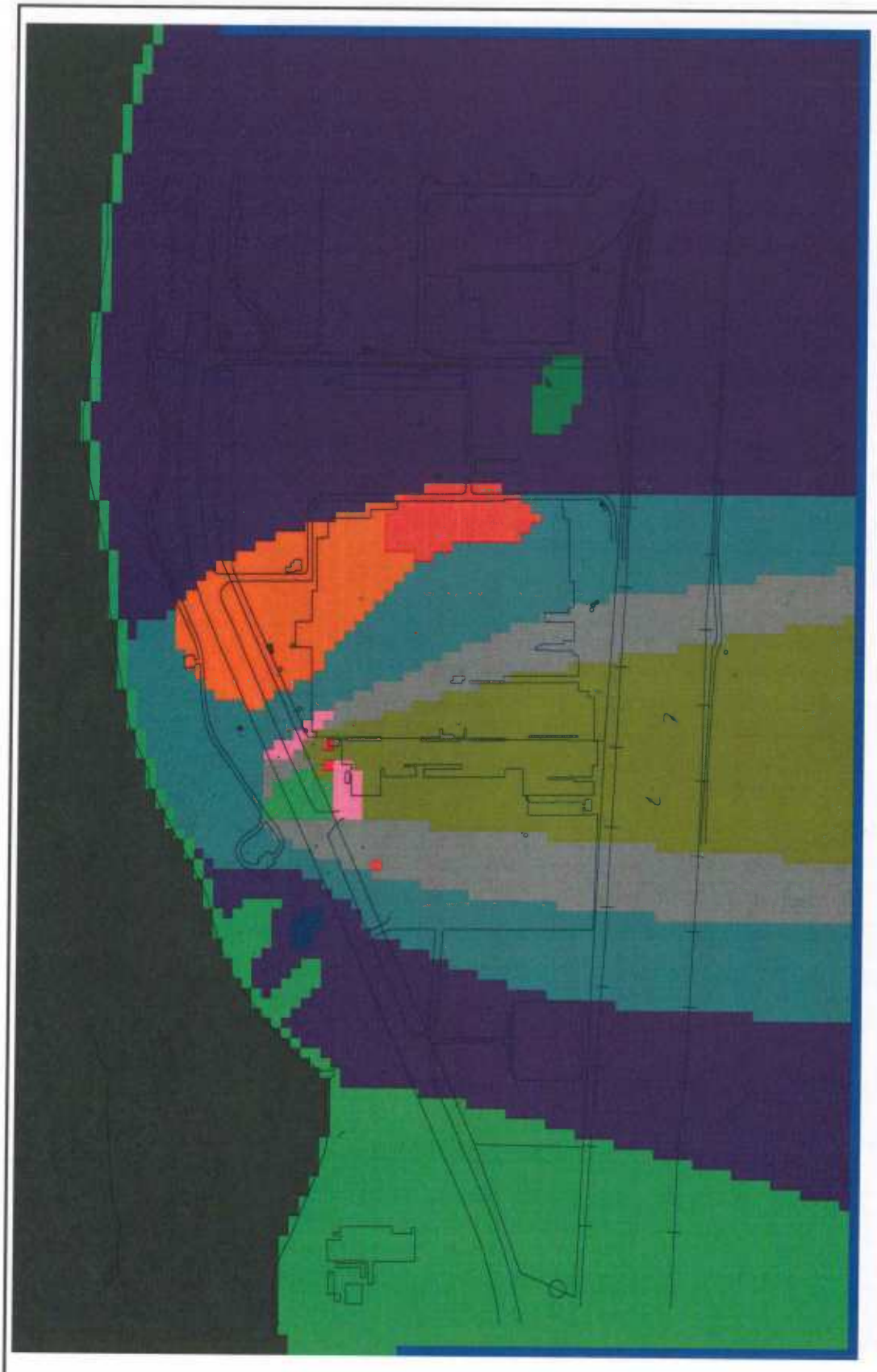
BEDROCK

- SANDSTONE BEDROCK (ST. PETER SANDSTONE)
- DOLOMITE BEDROCK (PRAIRIE DU CHIEN GROUP)

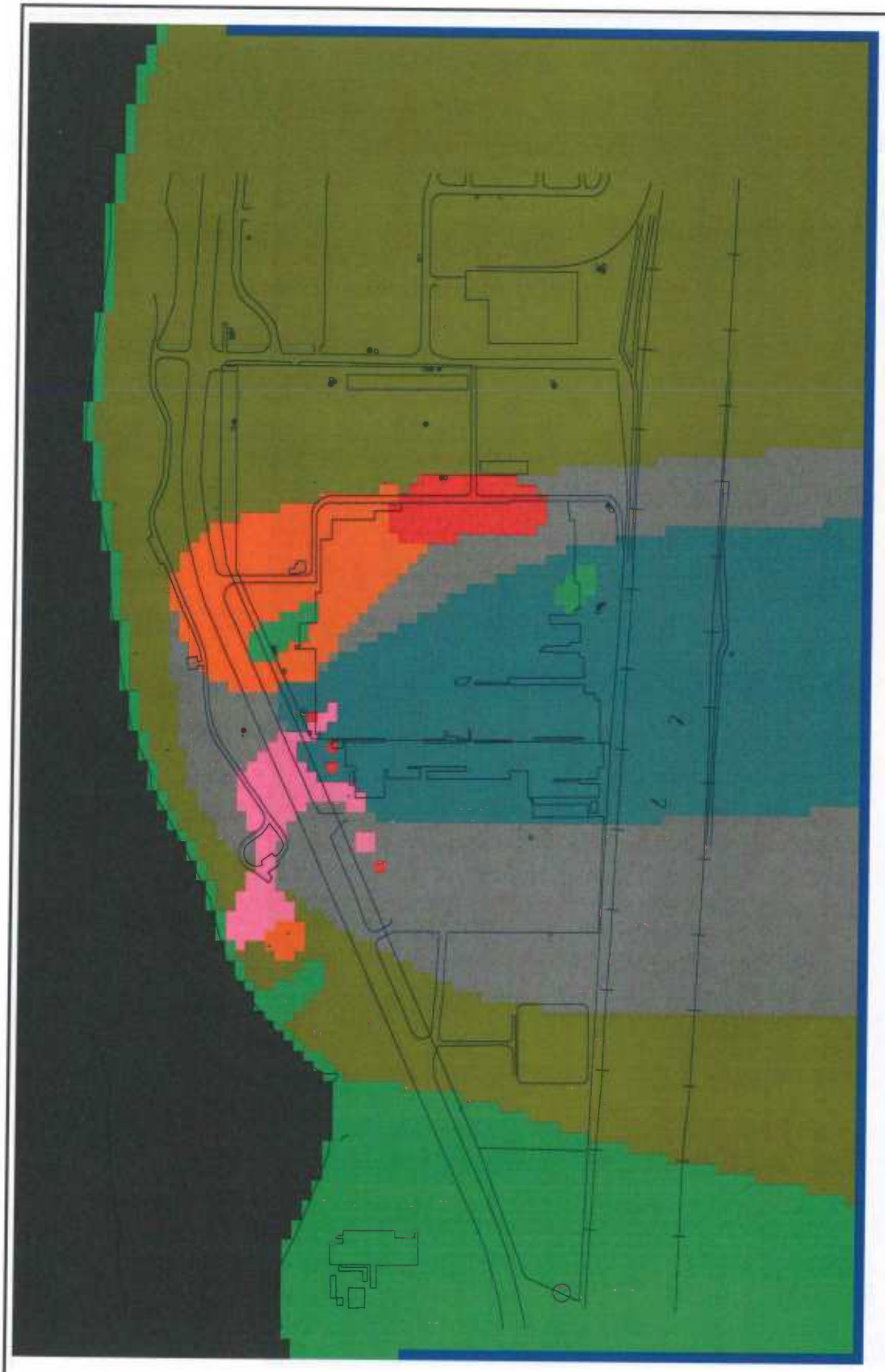
DRAWN BY ND	DATE 12/9/10	NAVFAC	GENERALIZED GEOLOGICAL CROSS-SECTION F-F' GROUNDWATER AND TCE ISOCONCENTRATIONS NIROP, FRIDLEY, MINNESOTA	CONTRACT NO. ---
CHECKED BY	DATE			OWNER NO. ---
REVISED BY	DATE			APPROVED BY / DATE
SCALE AS NOTED				DRAWING NO. FIGURE 3-2 / REV. 0



Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 1 - Hydraulic Conductivities

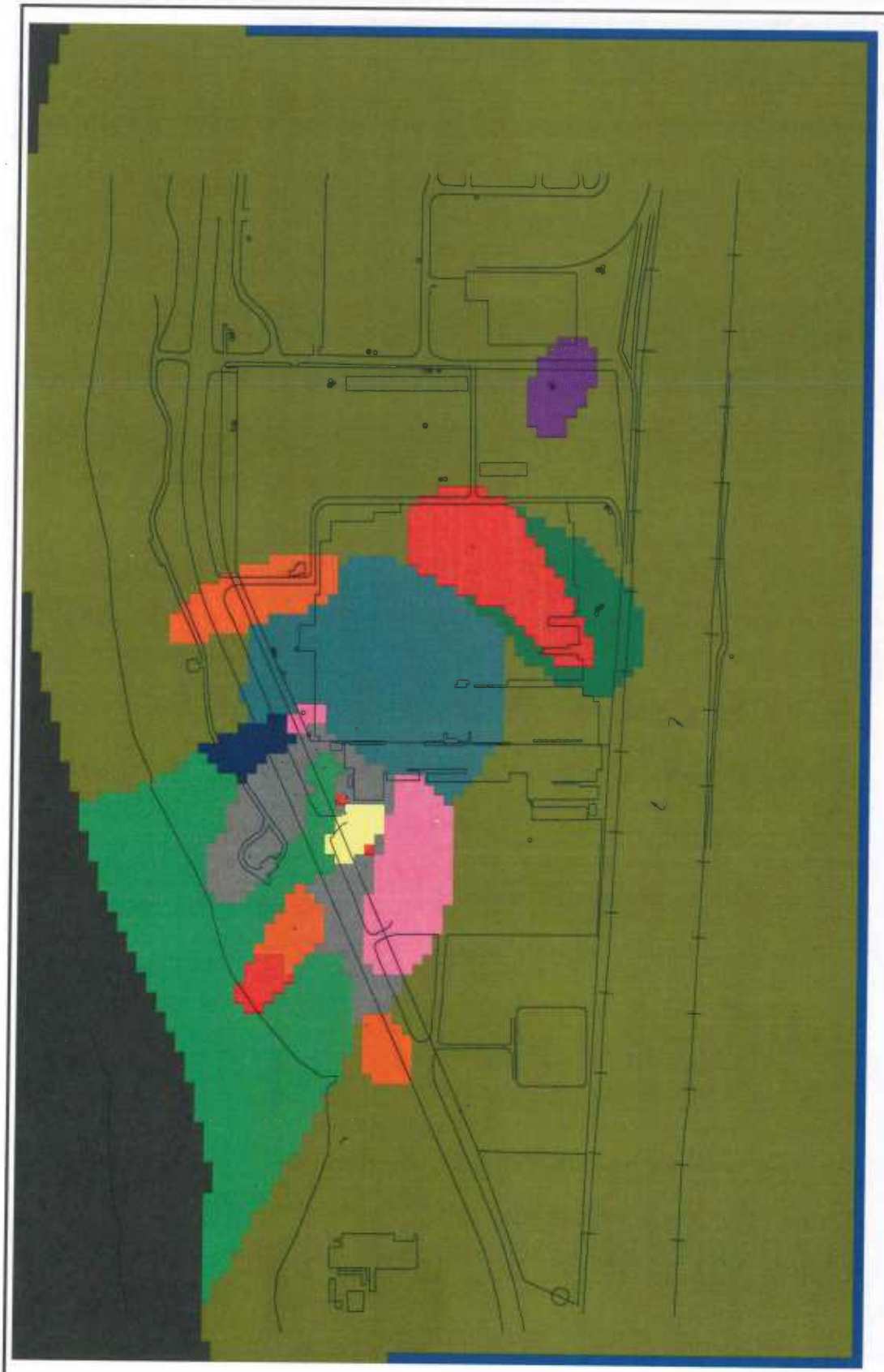


Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 2 - Hydraulic Conductivities

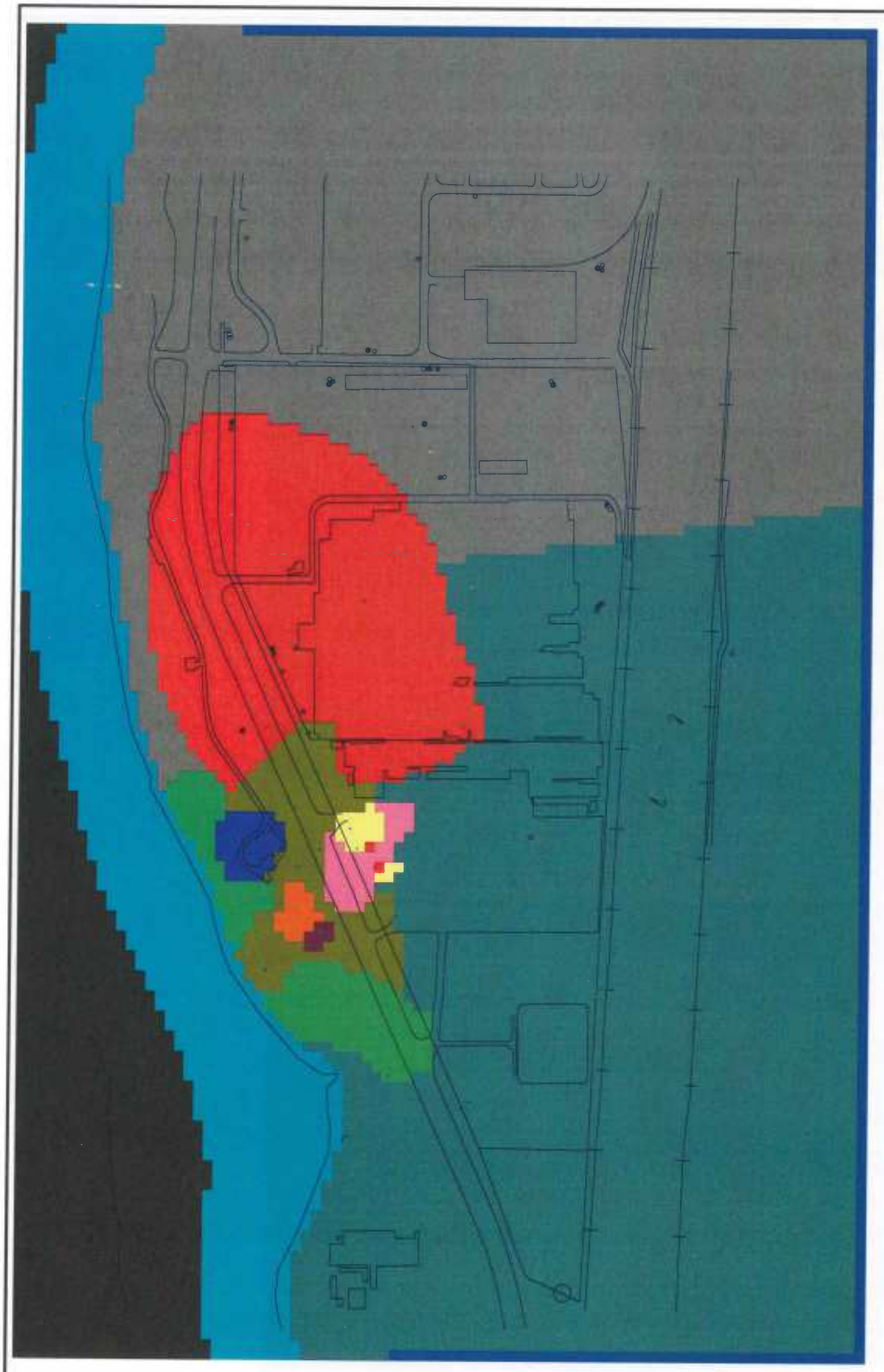


Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 3 - Hydraulic Conductivities

Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 4 - Hydraulic Conductivities



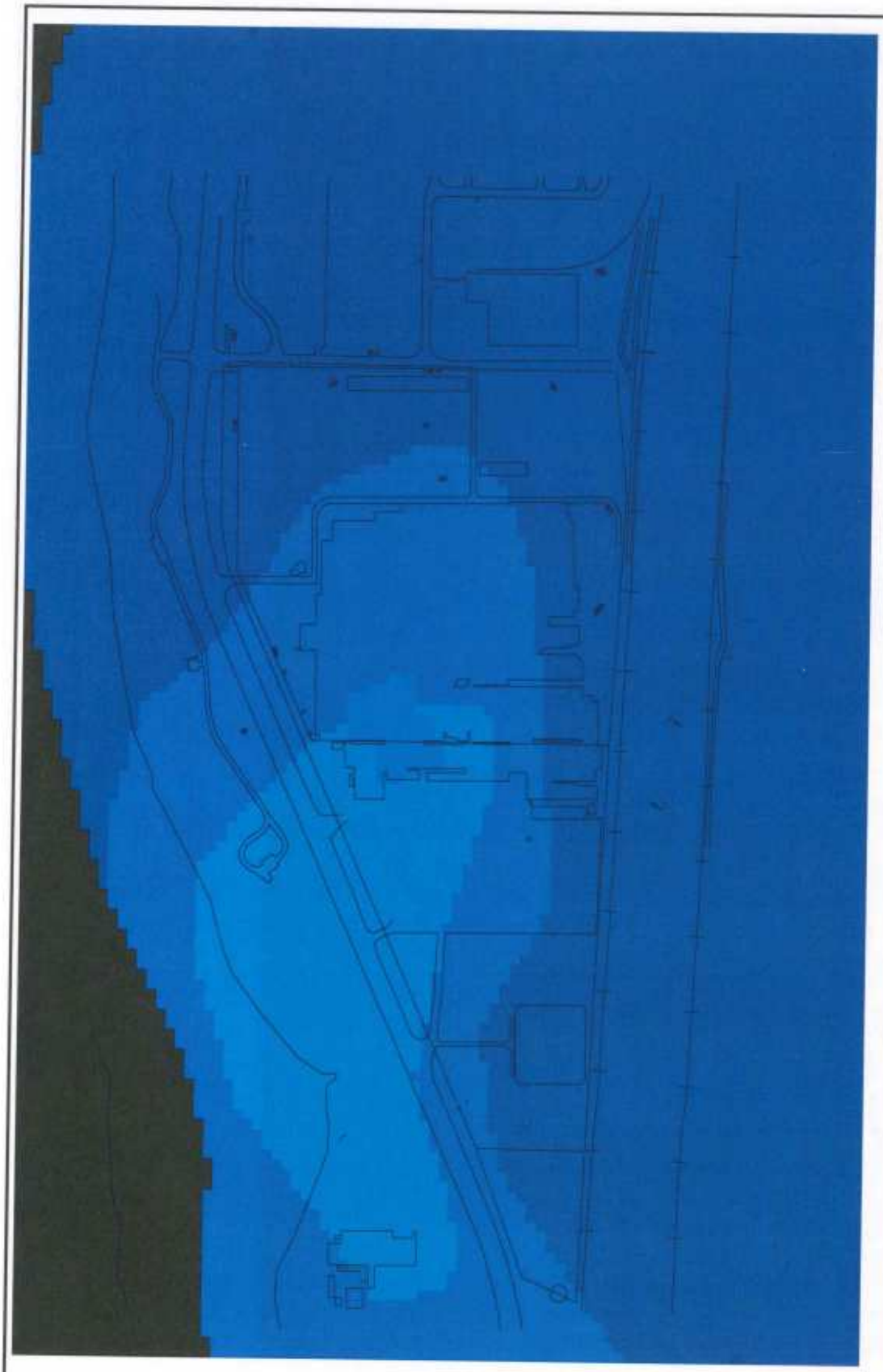
Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 6 - Hydraulic Conductivities



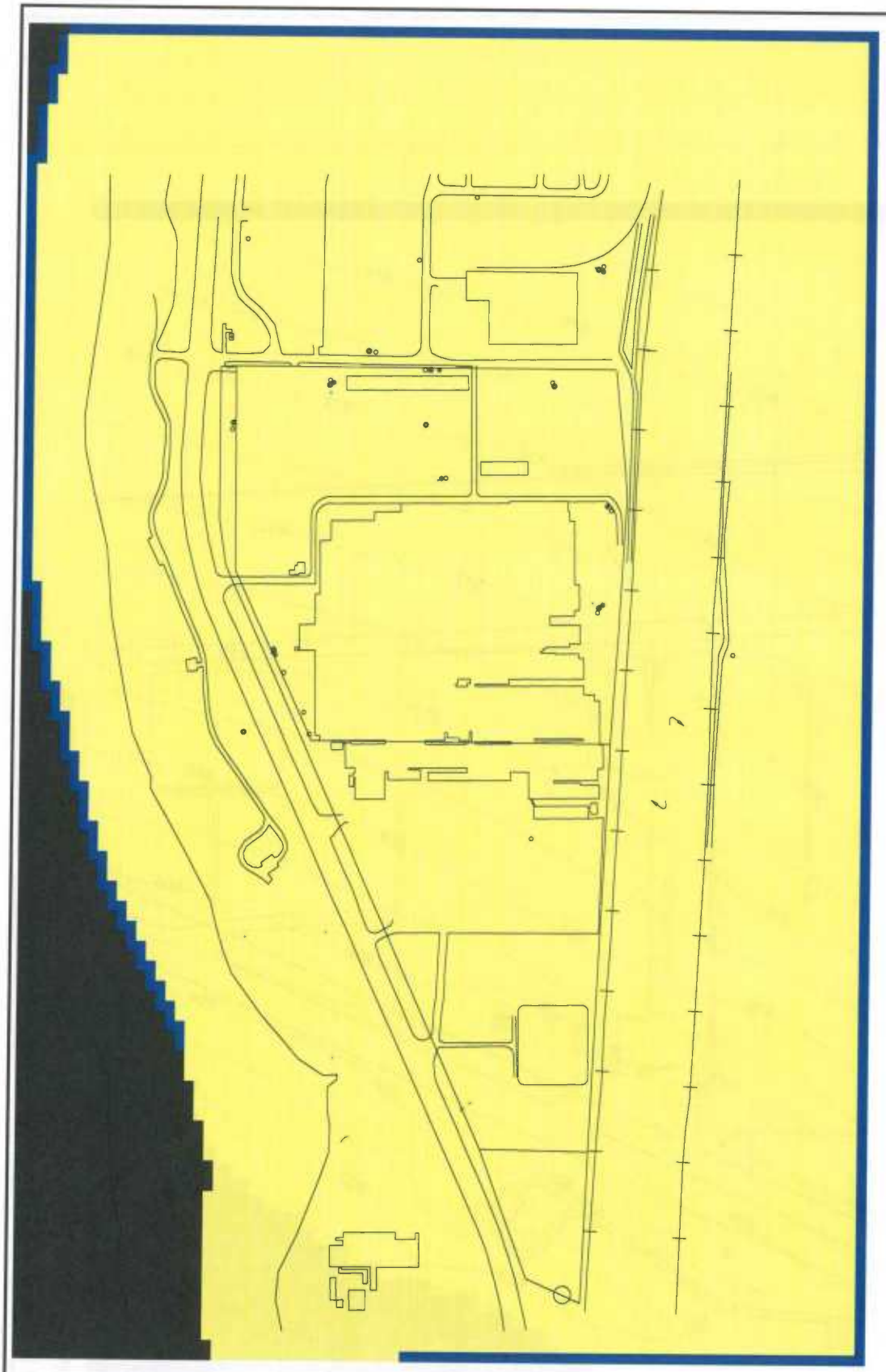
Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 5 - Hydraulic Conductivities

Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 7 - Hydraulic Conductivities

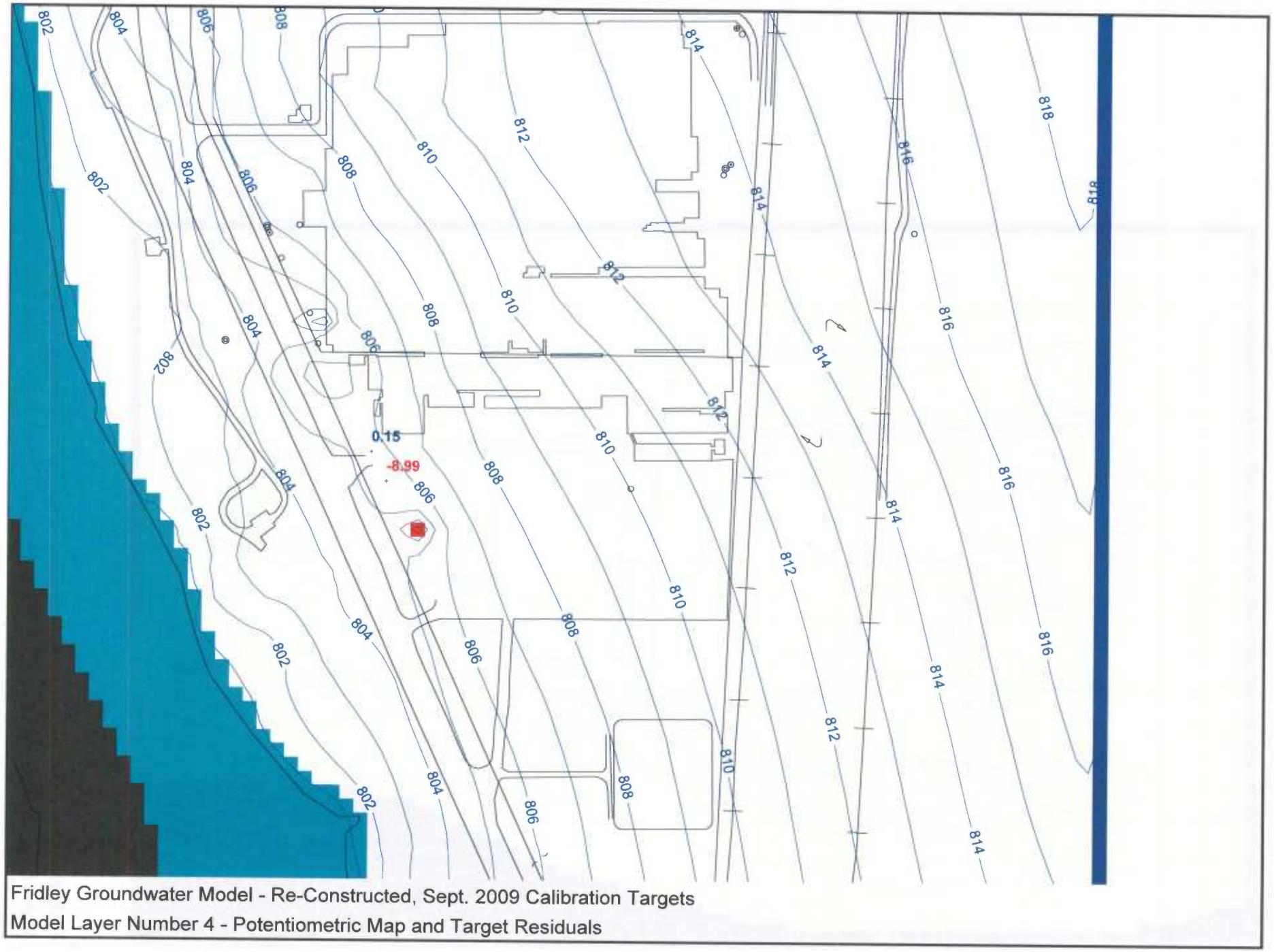
Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 9 - Hydraulic Conductivities



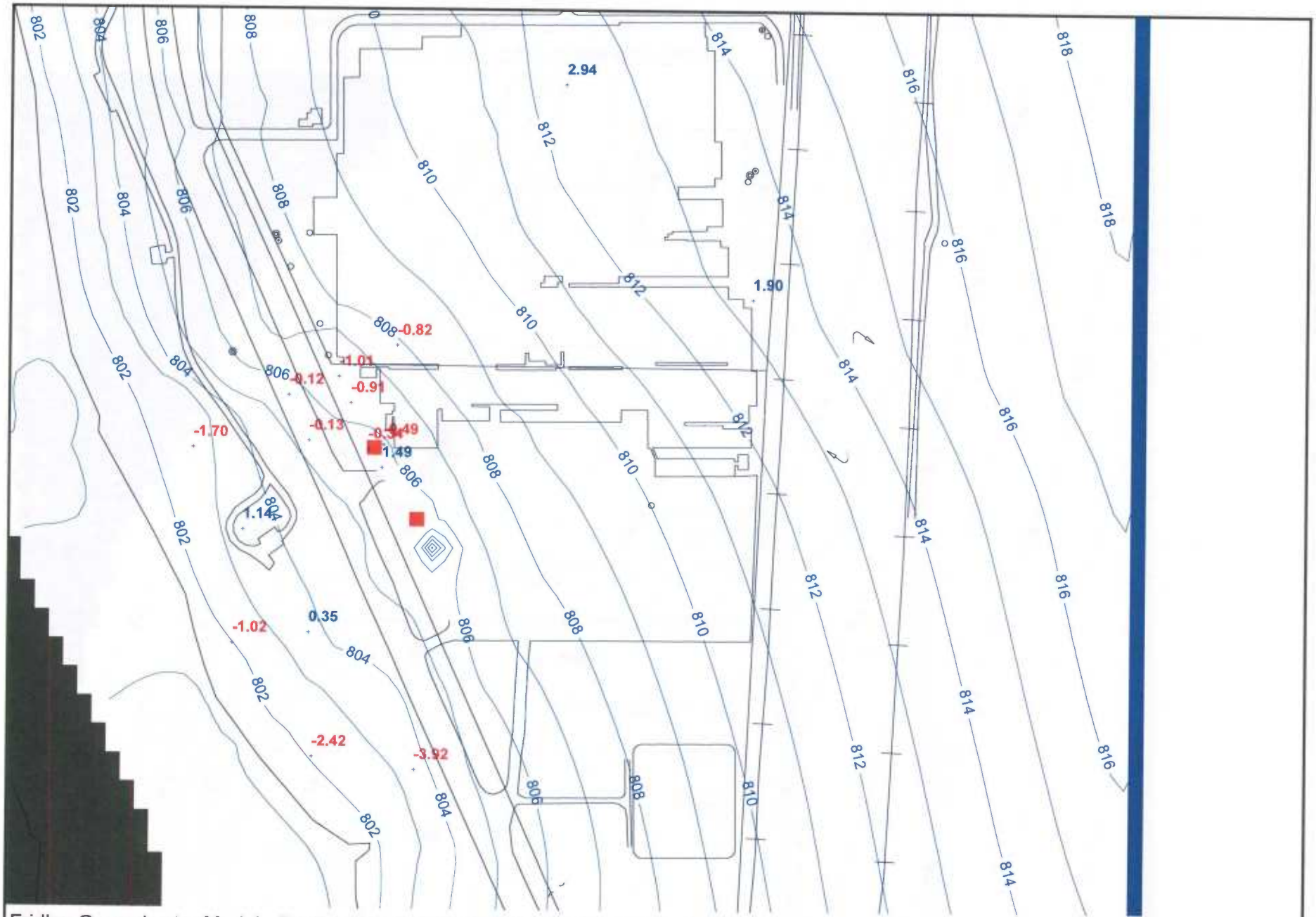
Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 10 - Hydraulic Conductivities



Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 11 - Hydraulic Conductivities

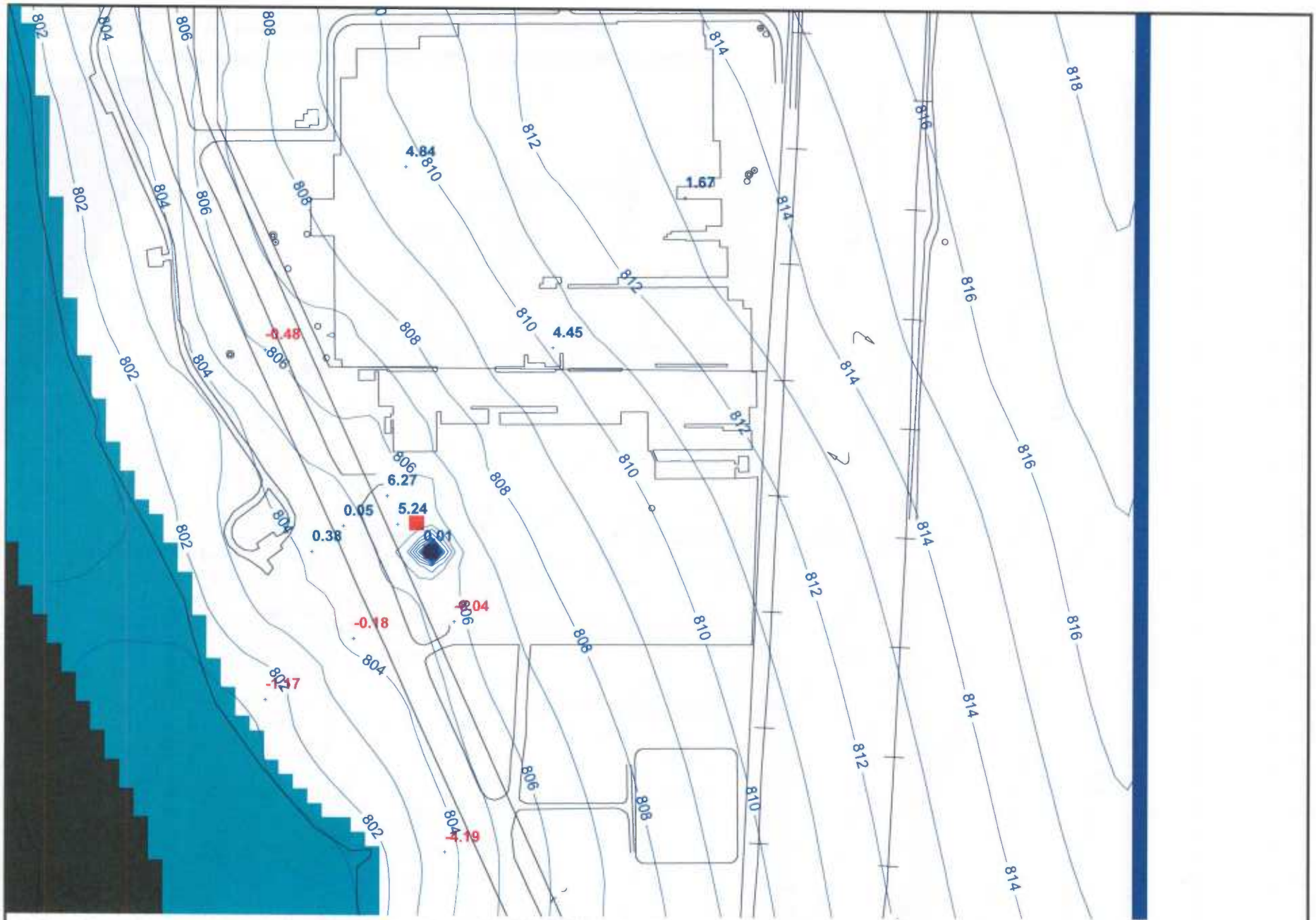


Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 4 - Potentiometric Map and Target Residuals



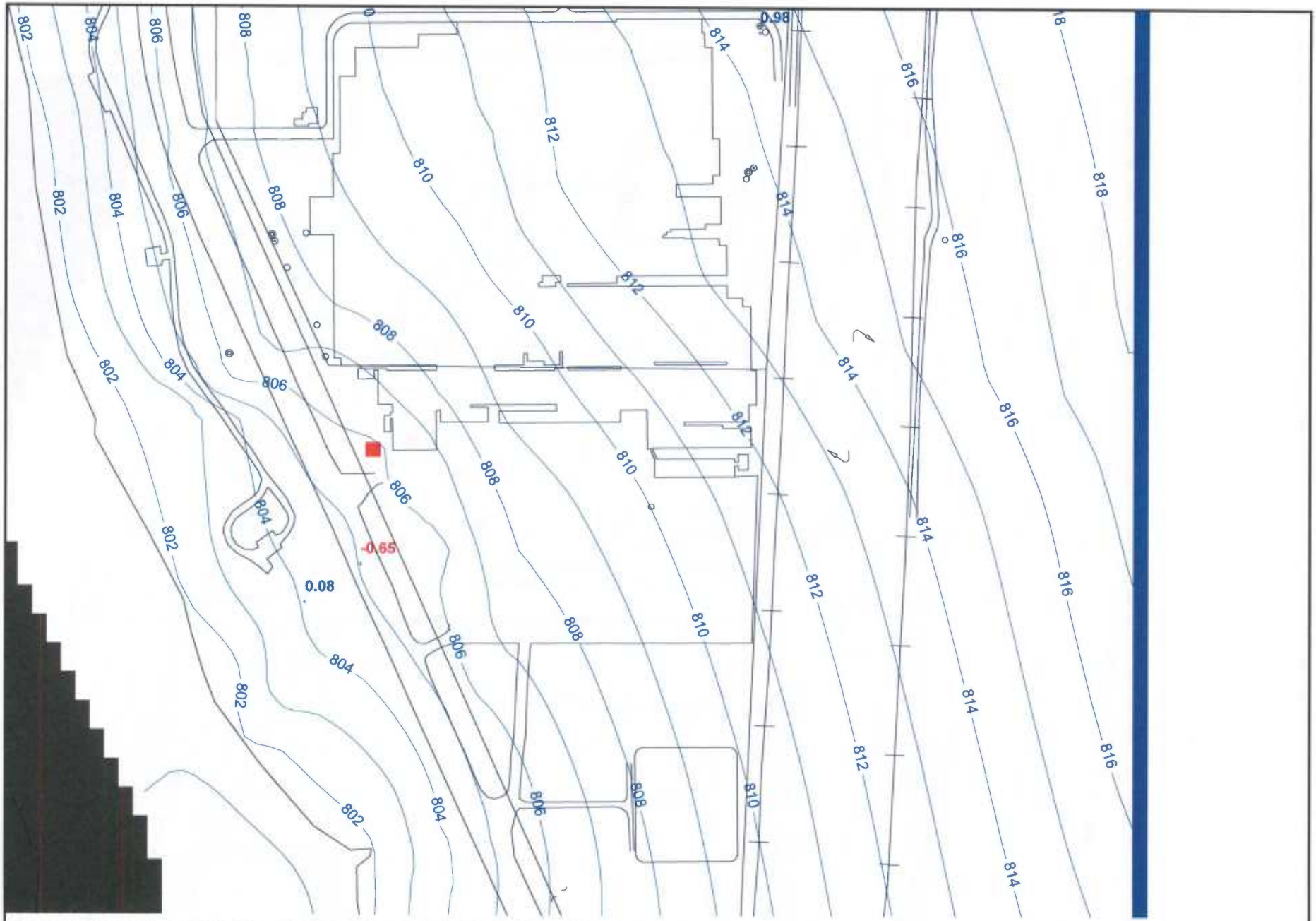
Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets

Model Layer Number 6 - Potentiometric Map and Target Residuals



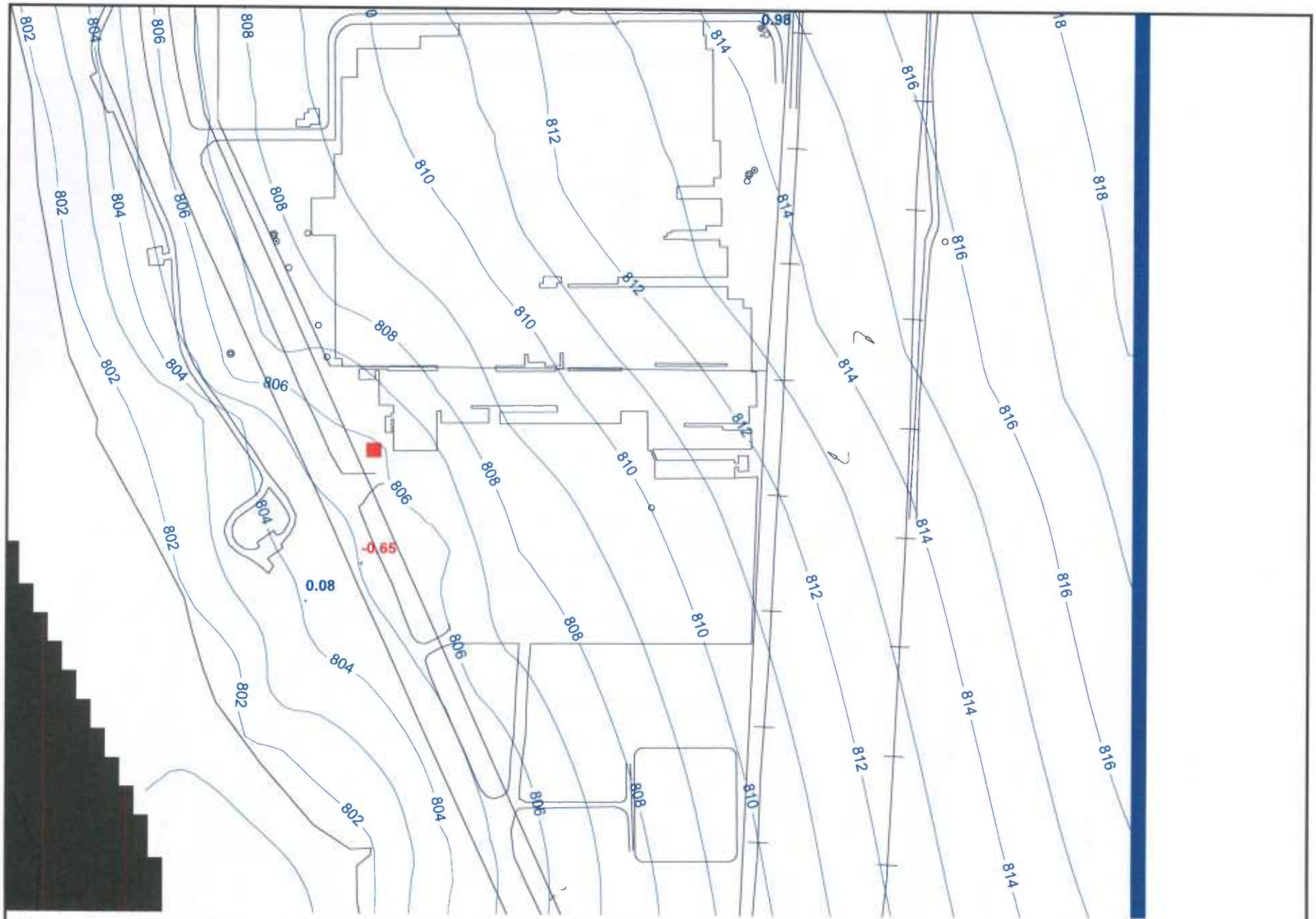
Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets

Model Layer Number 5 - Potentiometric Map and Target Residuals

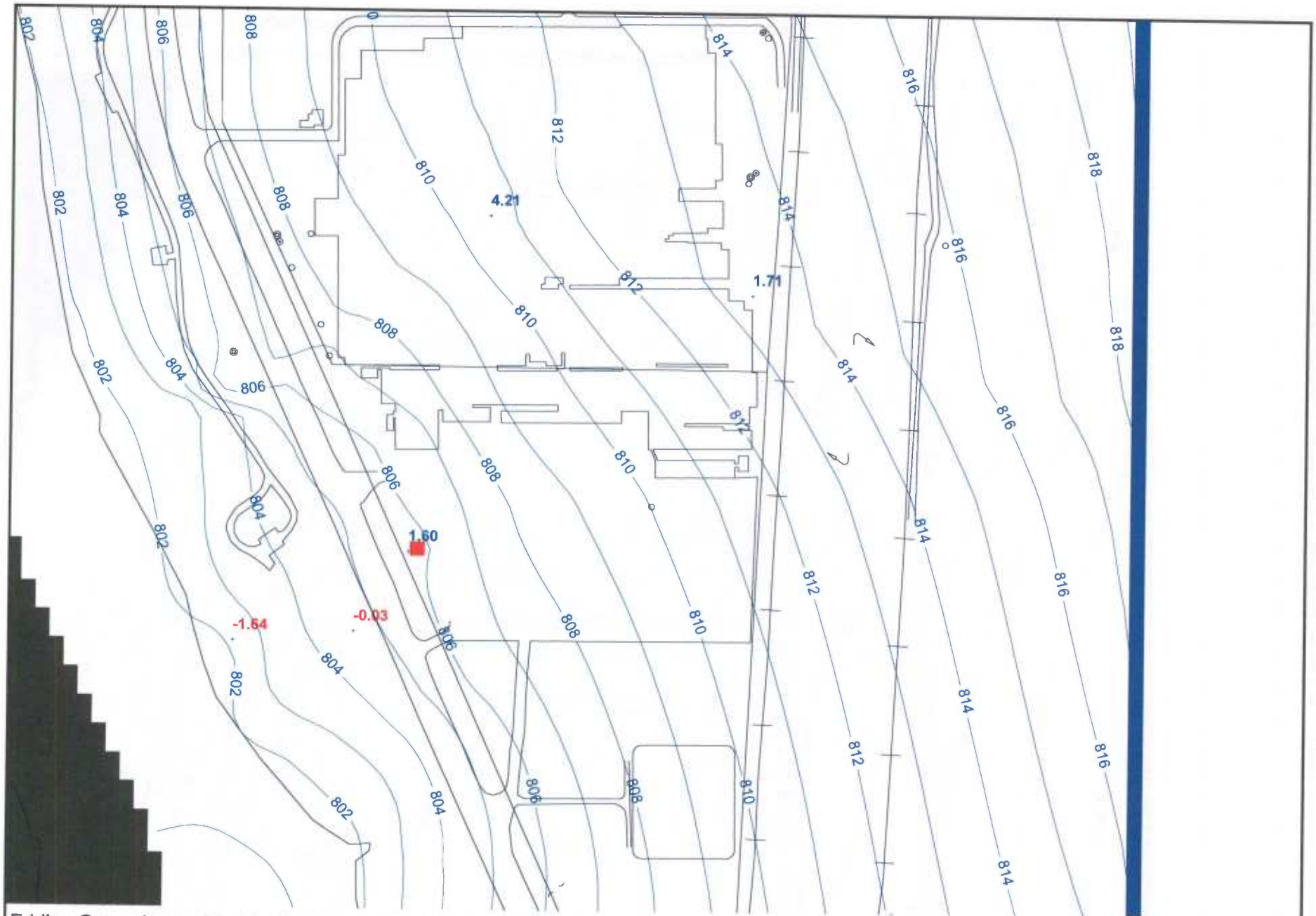


Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets

Model Layer Number 7 - Potentiometric Map and Target Residuals

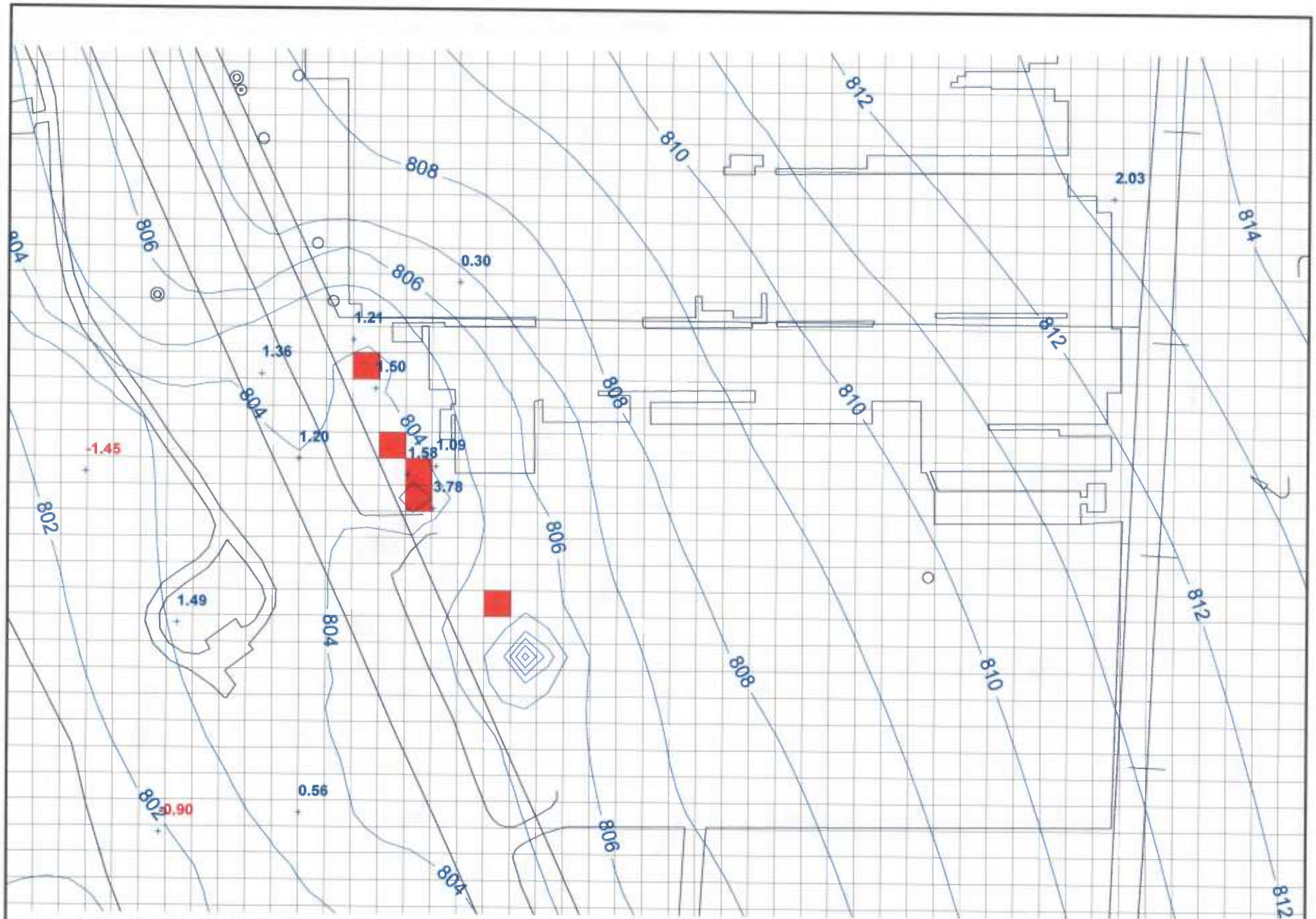


Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets
Model Layer Number 7 - Potentiometric Map and Target Residuals



Fridley Groundwater Model - Re-Constructed, Sept. 2009 Calibration Targets

Model Layer Number 8 - Potentiometric Map and Target Residuals



Fridley Groundwater Model - Future Scenario - Run 1

Model Layer Number 6 - Contours (1 foot interval) and Target Residuals

Fridley Groundwater Model - Future Scenario - Run 1

Model Layer Number 7 - Contours (1 foot interval) and Target Residuals