Borehole Mining of Manganese at Emily, MN

Or…Mn in MN

by

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This talk will cover:

- Geology of the Manganese Deposit in Emily
- Proposed Mining Methods
- Bulk Sample Collection Project
  - Permitting Requirements
  - Hydrogeologic Evaluation

Overview of the Project

- Collect a "bulk sample" (>12,000 cubic yards) of manganese-rich iron formation from 1 borehole
- Evaluate borehole mining technology
  - Uses high-pressure water jet to mine *in situ*
  - Ore-water slurry is pumped out, filtered and re-injected
- Filtered material (ore) is trucked to U of M minerals research facility in Coleraine for processing
- EAW developed **ONLY** for collecting the bulk sample – EIS will be required if full-scale operation is implemented

Who is proposing to do the project?

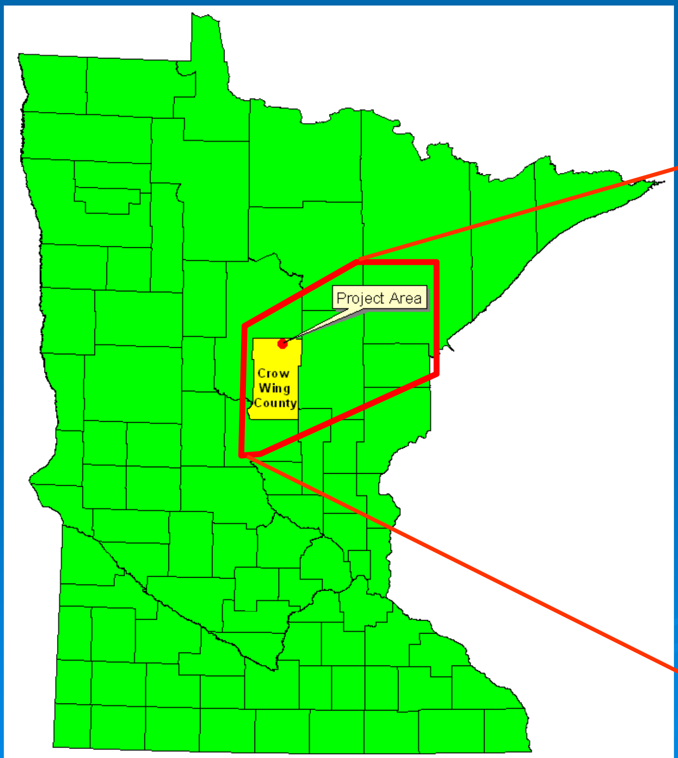
- Cooperative Minerals Resources (CMR) – a wholey-owned subsidiary of Crow Wing Power Cooperative
  - Profits will be shared with their 36,000 members – mostly in Crow Wing County
- Environmental permitting & hydrologic evaluations by Barr Engineering Co.
- Bulk sample collection to begin in August 2010

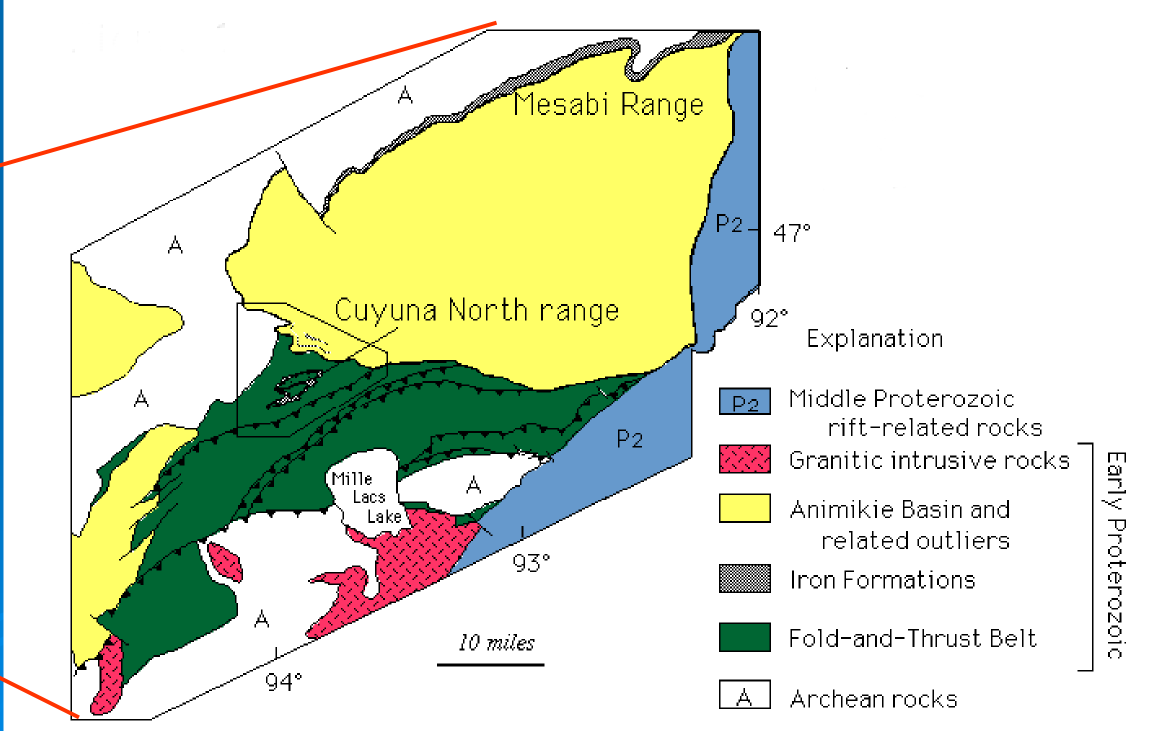
Geology of the Manganese Deposit at Emily, MN

Photo of Borehole Mining Site (by Ellen Considine, Barr Engineering Co.)

The Cuyuna or “Old” Iron Range

- Iron mining from 1904 to 1984
- 106 million tons for iron ore mined



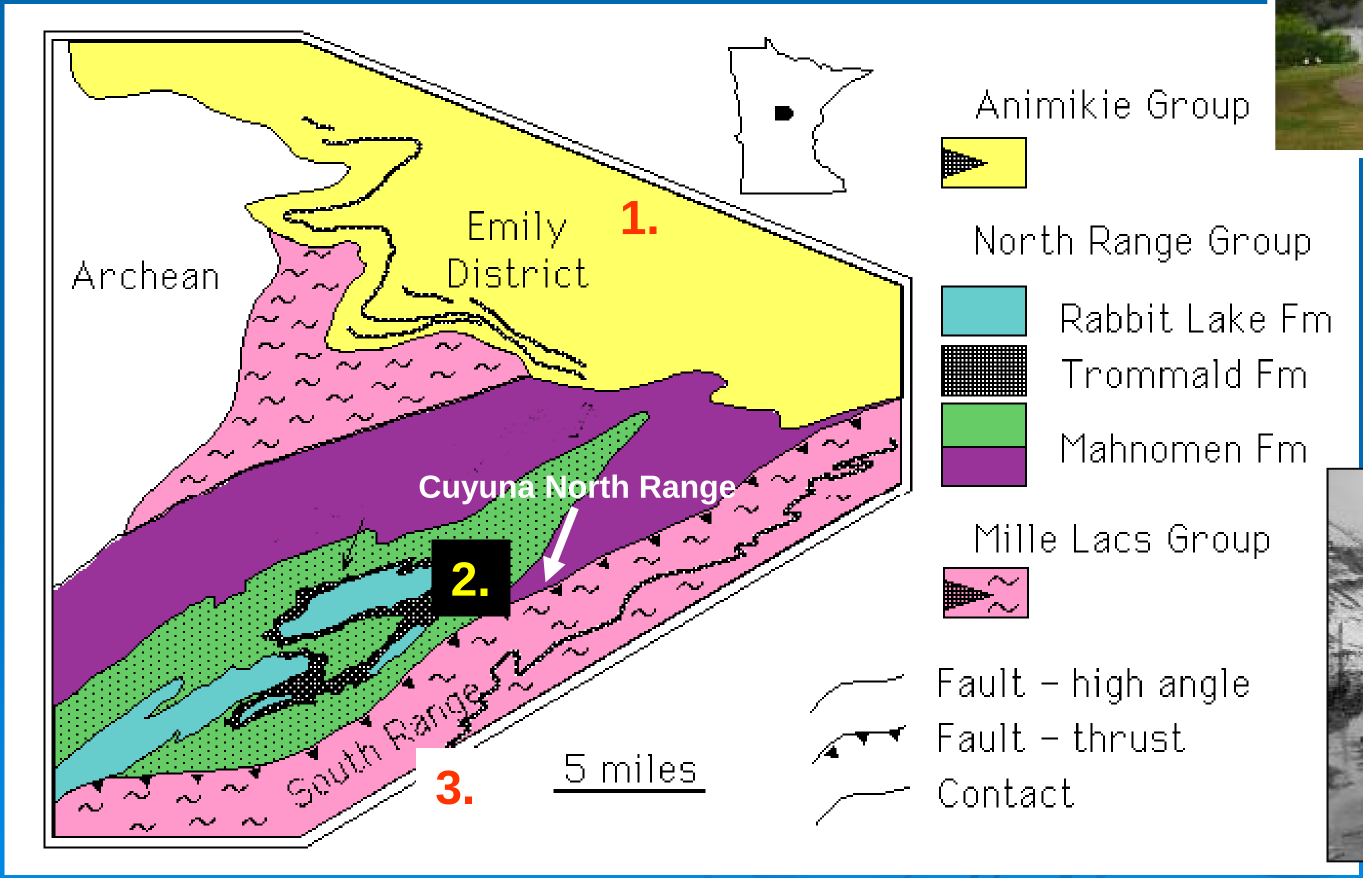


After Southwick et al., 1988

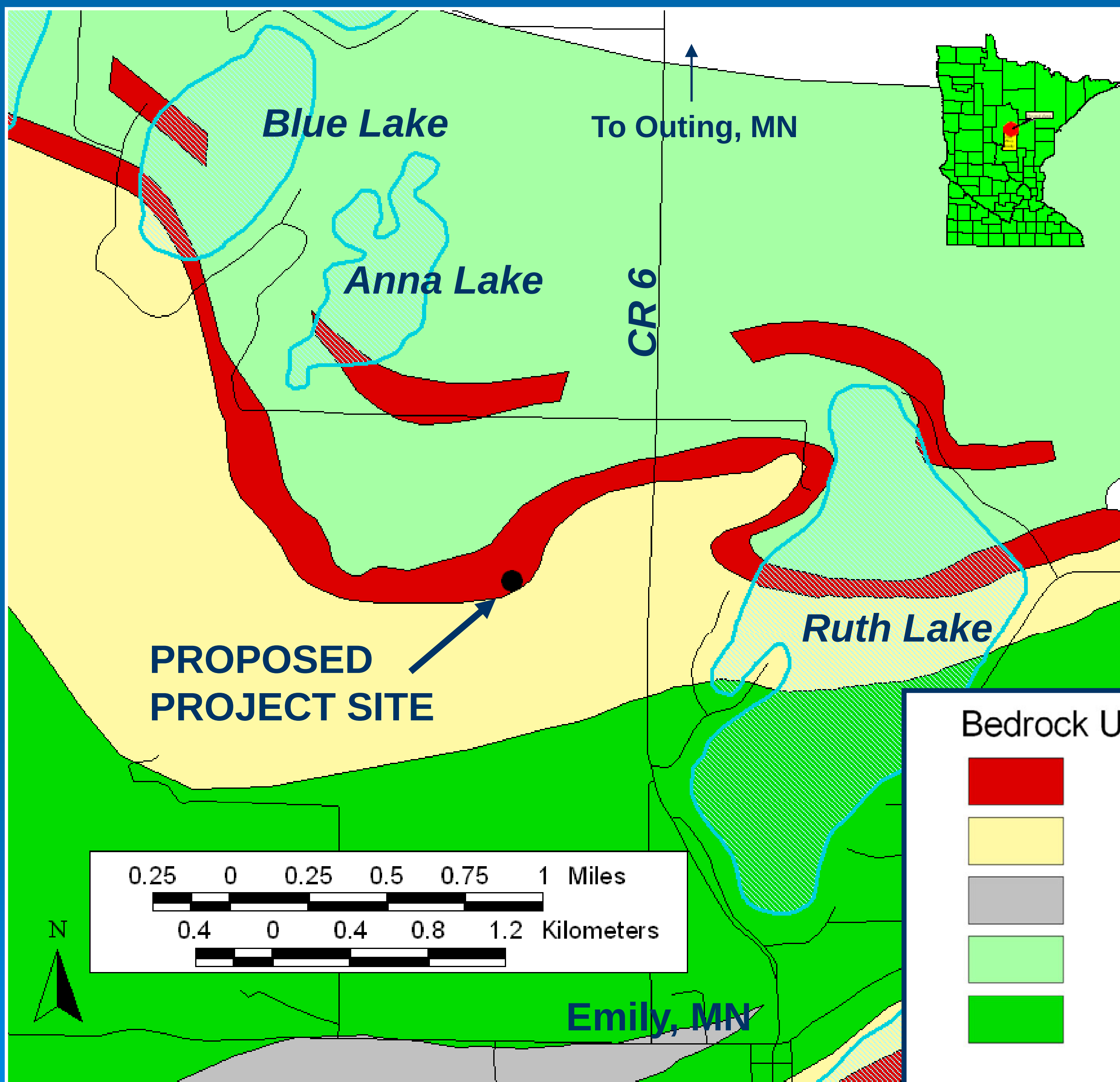
Cuyuna Range is Divided Into 3 Districts

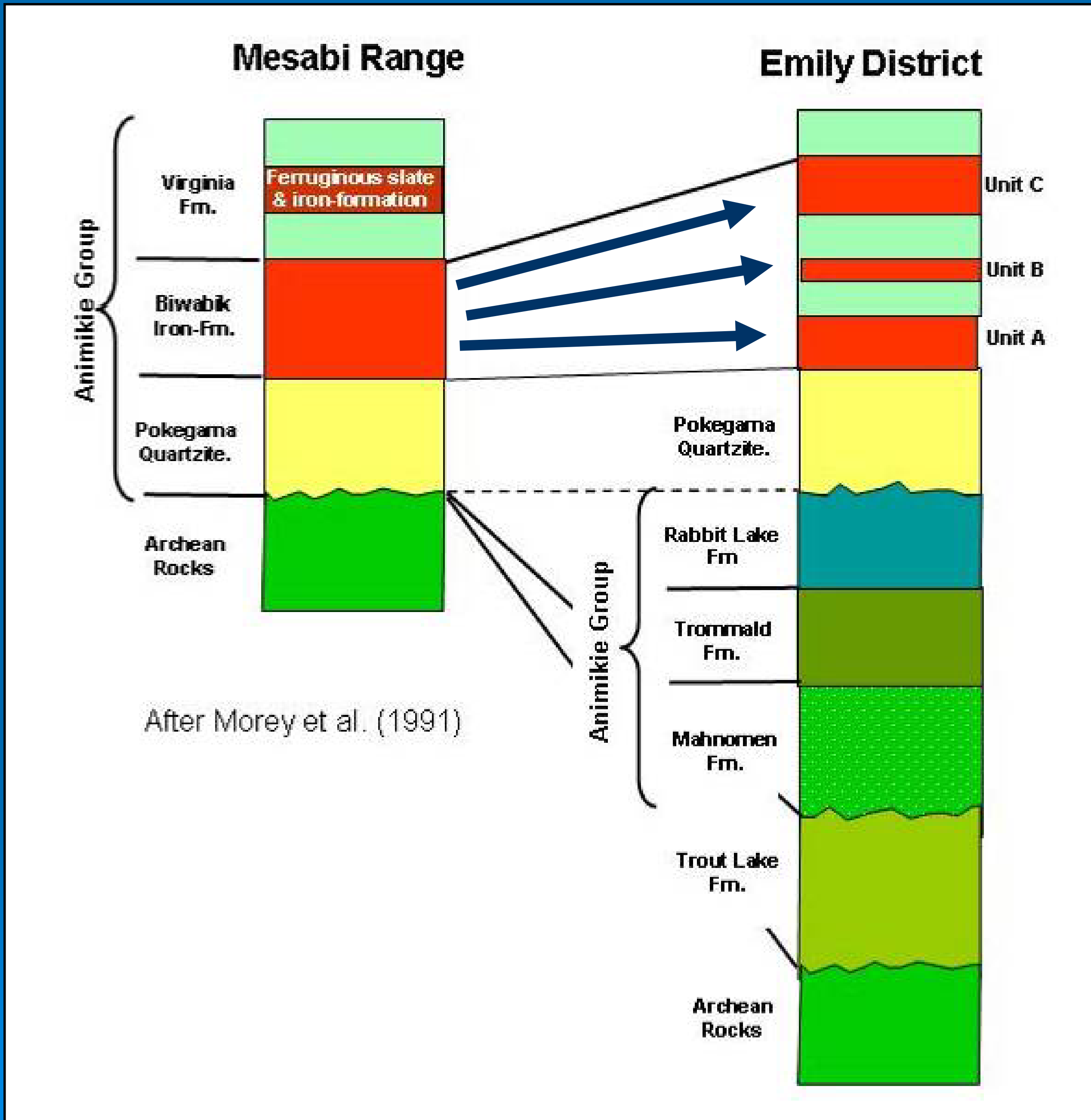
- Emily District
- North Range
- South Range

Croft Mine Historical Park, Crosby, MN



Emily District Iron-Formation is a thin band on the limb of a north-plunging anticline

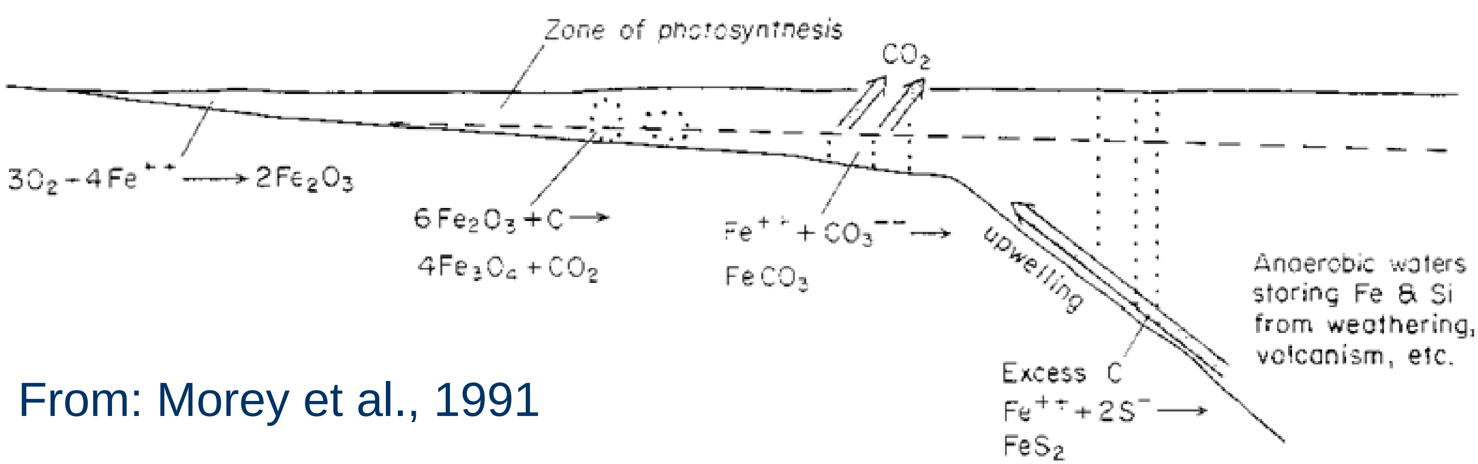




Emily District Iron-Formation Units A, B, & C correlate with the Biwabik Iron-Formation of the Mesabi Range

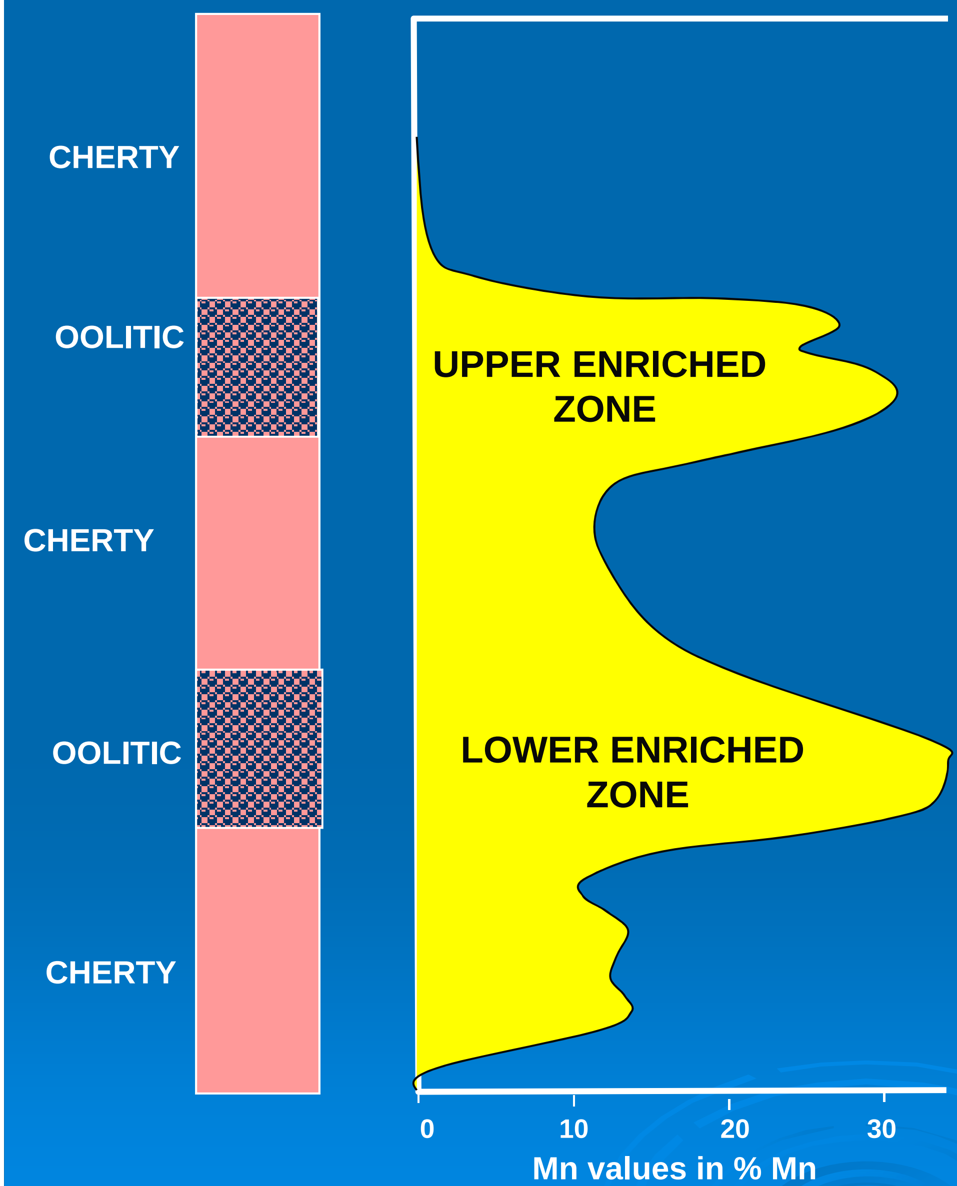
Depositional History

- Similar to Biwabik Iron Formation – chemical precipitation of iron and silica in a shallow Precambrian sea
- Abundance of oolitic hematite indictes wave-action reworking



From: Morey et al., 1991

Manganese Enrichment is Present in Two Zones Corresponding to Oolitic Zones



After Morey et al., 1991

Reflux Model of Enrichment

Manganese and barium were carried to their final depositional site by anaerobic water systems.

Both precipitated when the anaerobic water met and mixed with aerated water in uncemented iron-formation on the seafloor.

Manganese Mineralogy of the Deposit

- Manganite - MnO(OH) – primary ore mineral
- Psilomelane – $(Ba,Mn)_3(O, OH)_6Mn_8O_{16}$
- Cryptomelane - $K(Mn)_8O_{16}$

- Manganese Concentration (by weight) greater than 50% in 2 zones (i.e. "high-grade" ore)
- Hematite is dominant iron mineral
- Almost zero sulfur

What is Manganese Used For?

- Essential to iron and steel production by virtue of its sulfur-fixing, deoxidizing, and alloying properties (there is no substitute)
- Alloying agent in aluminum (especially in beer cans – really!)
- New generation batteries
- Pollutant removal from coal-fired power plant emissions (Pahlman process)

World Sources of Manganese

- High-grade (> 44% Mn)
  - 680 million tons ore world-wide
  - Mostly in southern hemisphere – countries using for internal use (limited export)
- Low-grade (<44% Mn)
  - Russia’s low-grade ores are depleting
  - China has very low-grade ore for internal use
  - Thin layers of 25% Mn in nodules on ocean floor (not yet mined)

Total world production and consumption of Mn ore in 2003 was 23 million tons

U.S. Manganese Sources

- The US imports ALL its manganese from Gabon, South Africa, France, and Brazil (692,000 tons in 2003)
- The US currently has no high-grade (>44%) Mn reserves
- Strategic stockpiles of Mn in the U.S. are essentially depleted
- Manganese from recyled materials is negligible
- Recent price of Mn: @ $1.30/lb

How much Manganese is Available at Emily?

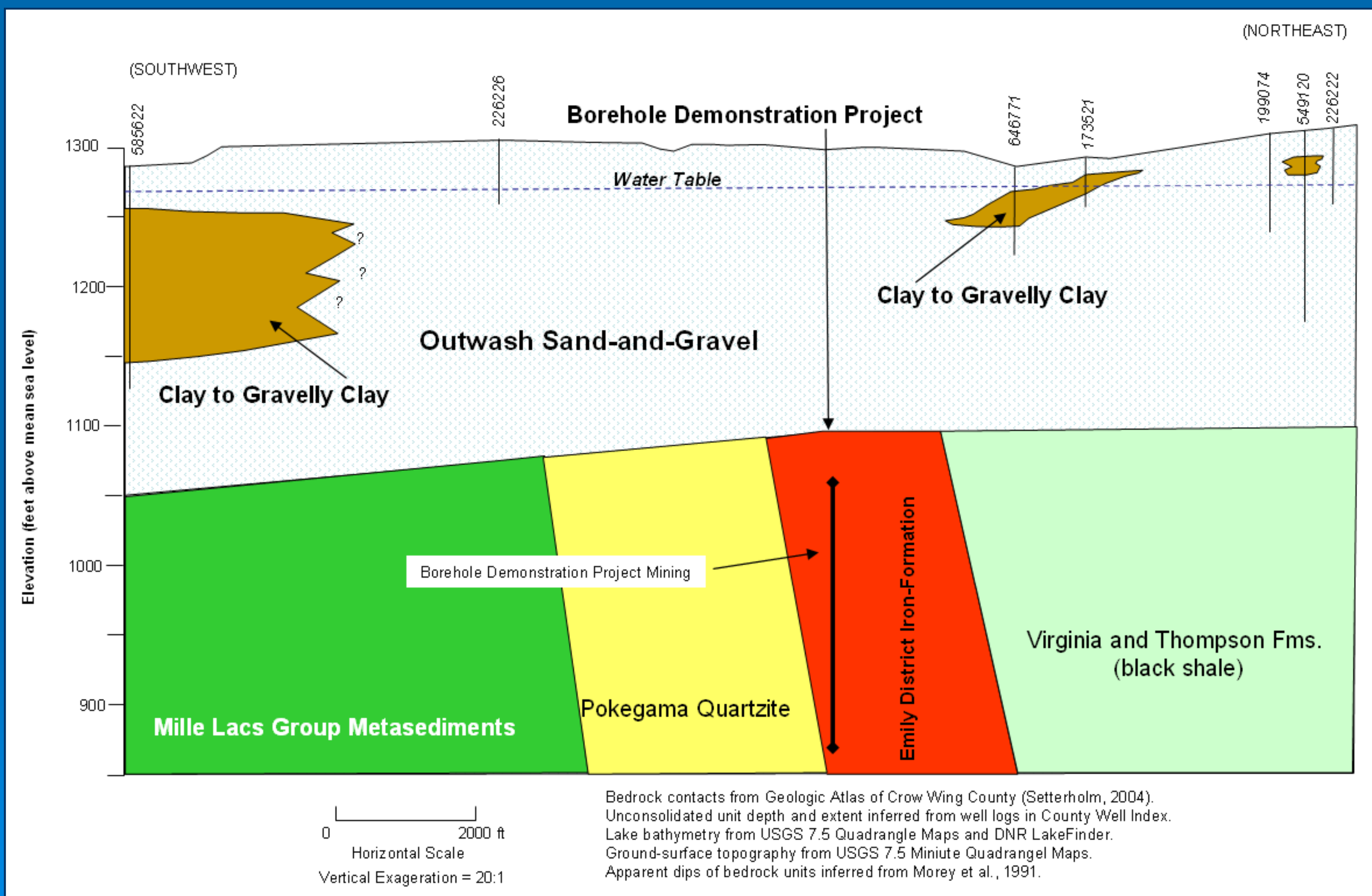
- Bureau of Mines estimated @ 2 billion pounds (1 million tons) in a 9 acre area within 2 zones (50 feet and 70 feet thick) (Pahlman, 1995)
- The deepest of these zones is @ 400 feet below ground surface
- Likely the largest high-grade Manganese deposit in the Northern Hemisphere.

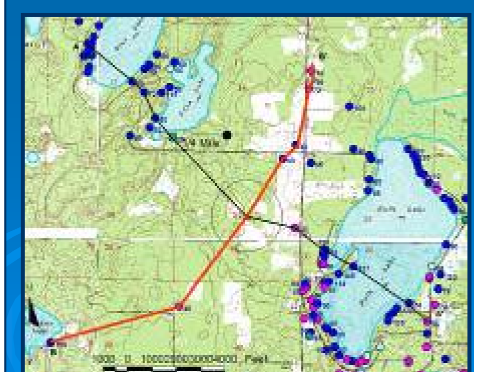
Mn-Rich Sections of Iron-Formation are Very Friable

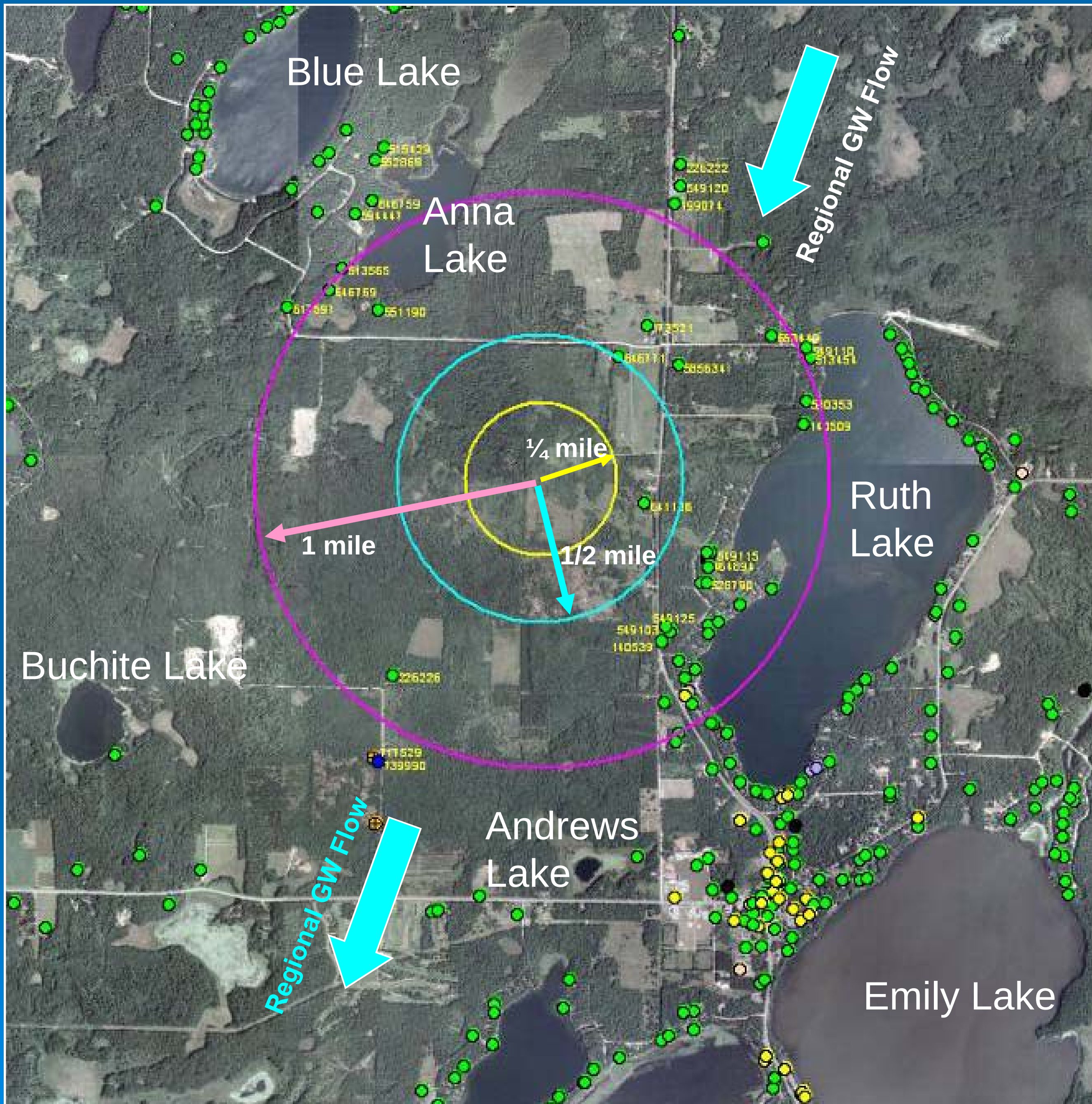
This is very important in determining whether or not this formation can be mined in an environmentally friendly manner

Rotosonic core of iron-formation

Bedrock is Overlain by @ 180 – 200 Feet of Sand-and-Gravel Outwash







Depth to Groundwater is @ 35 Feet at the Project Site

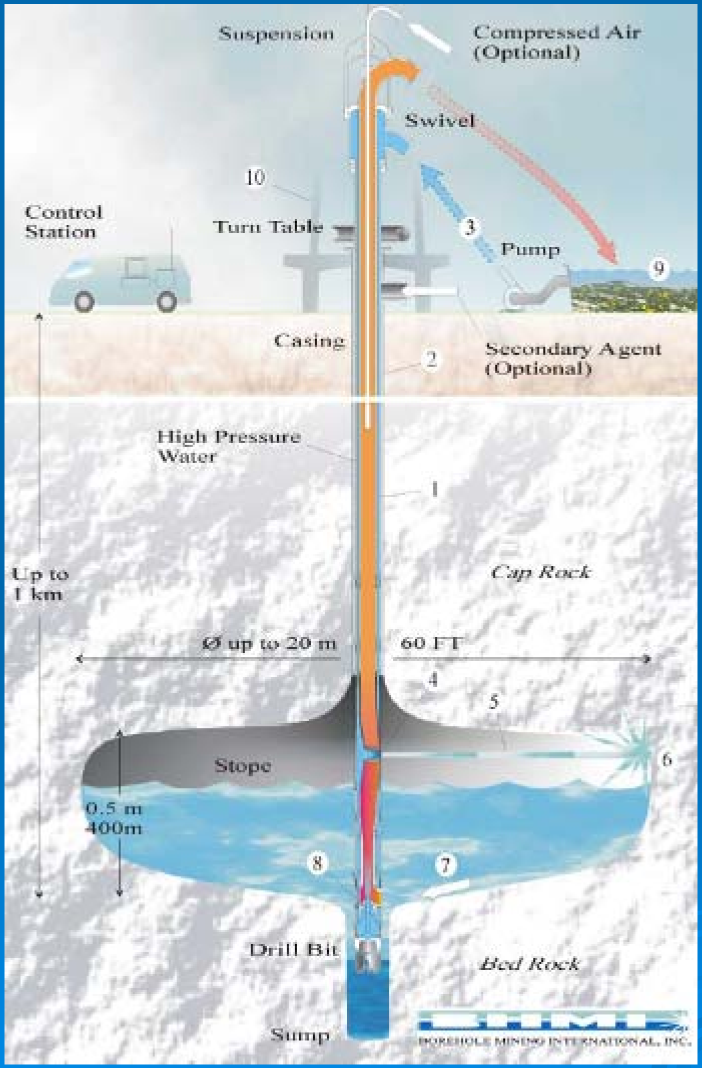
The soils are VERY sandy.

Lakes are in direct hydraulic connection with the sand-and-gravel aquifer.

All wells in the area completed in sand-and-gravel aquifer

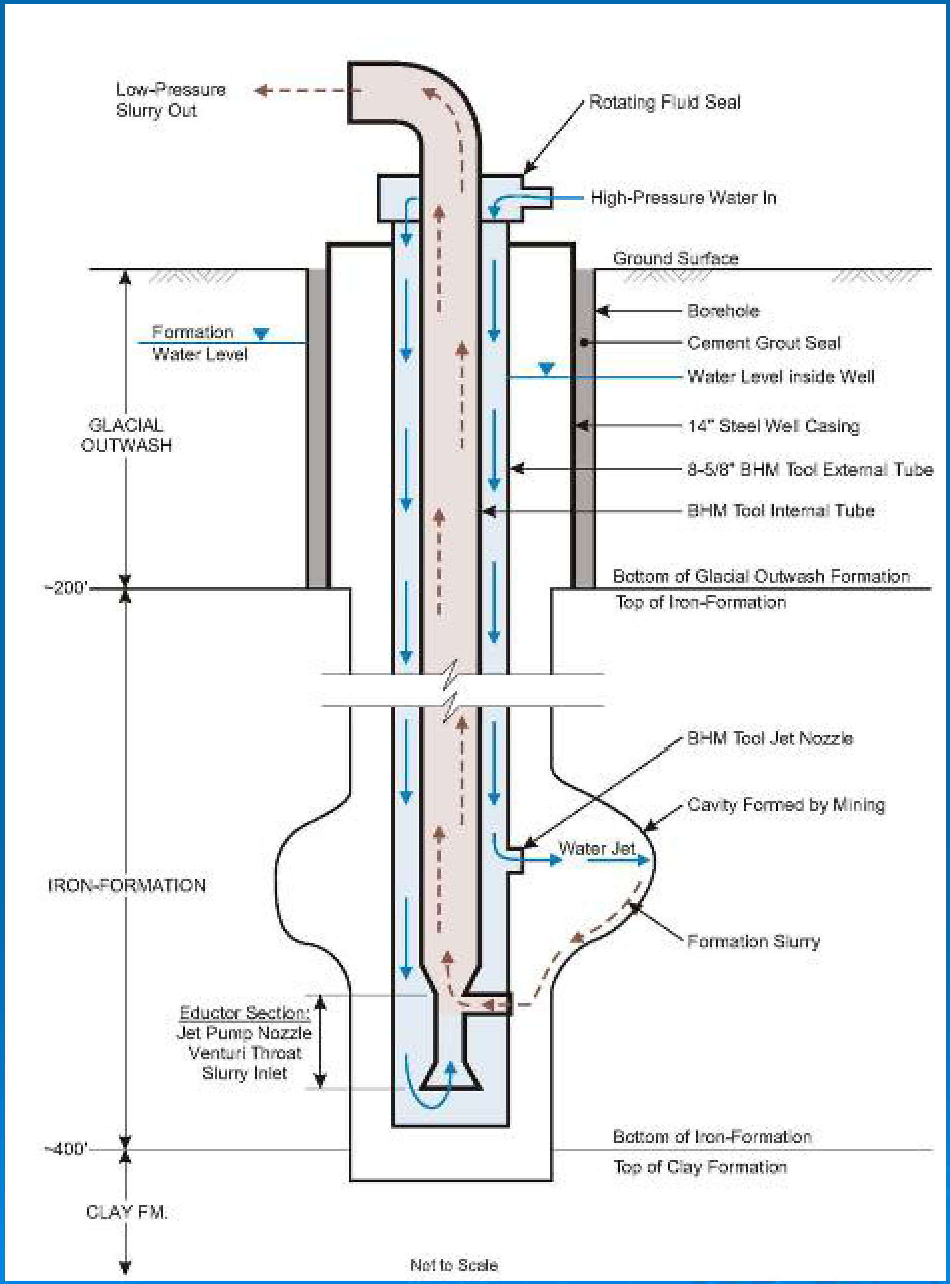
Dots show CWI well locations

The Borehole Mining Process



Possible Mining Approaches

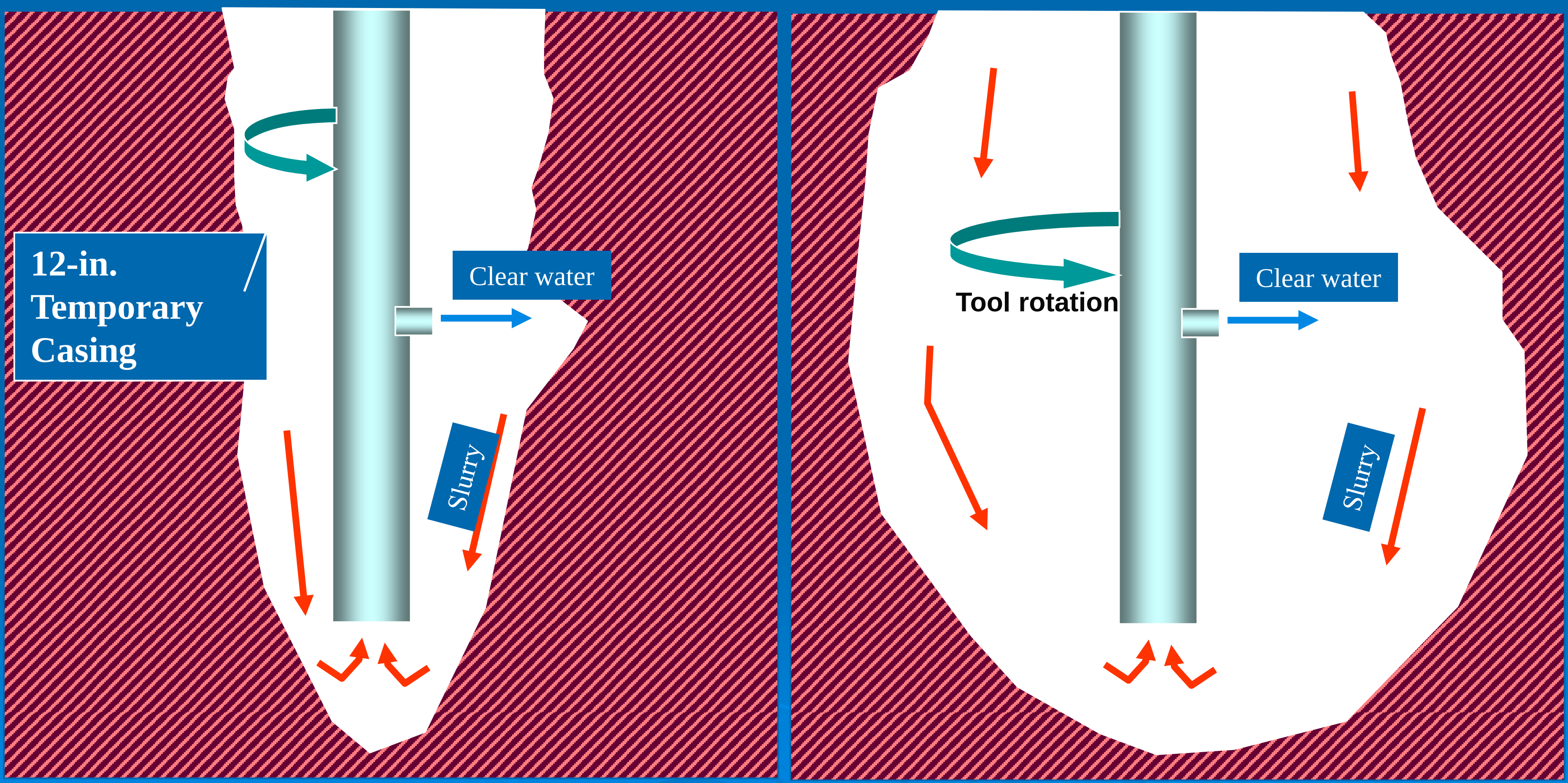
- Open-Pit mining: Have to deal with 200 feet of saturated overburden and dewatering.
- Underground mining: Likely extensive dewatering and expensive.
- *In situ* leach mining: Studied by Bureau of Mines and deemed practical – but probably environmentally unacceptable



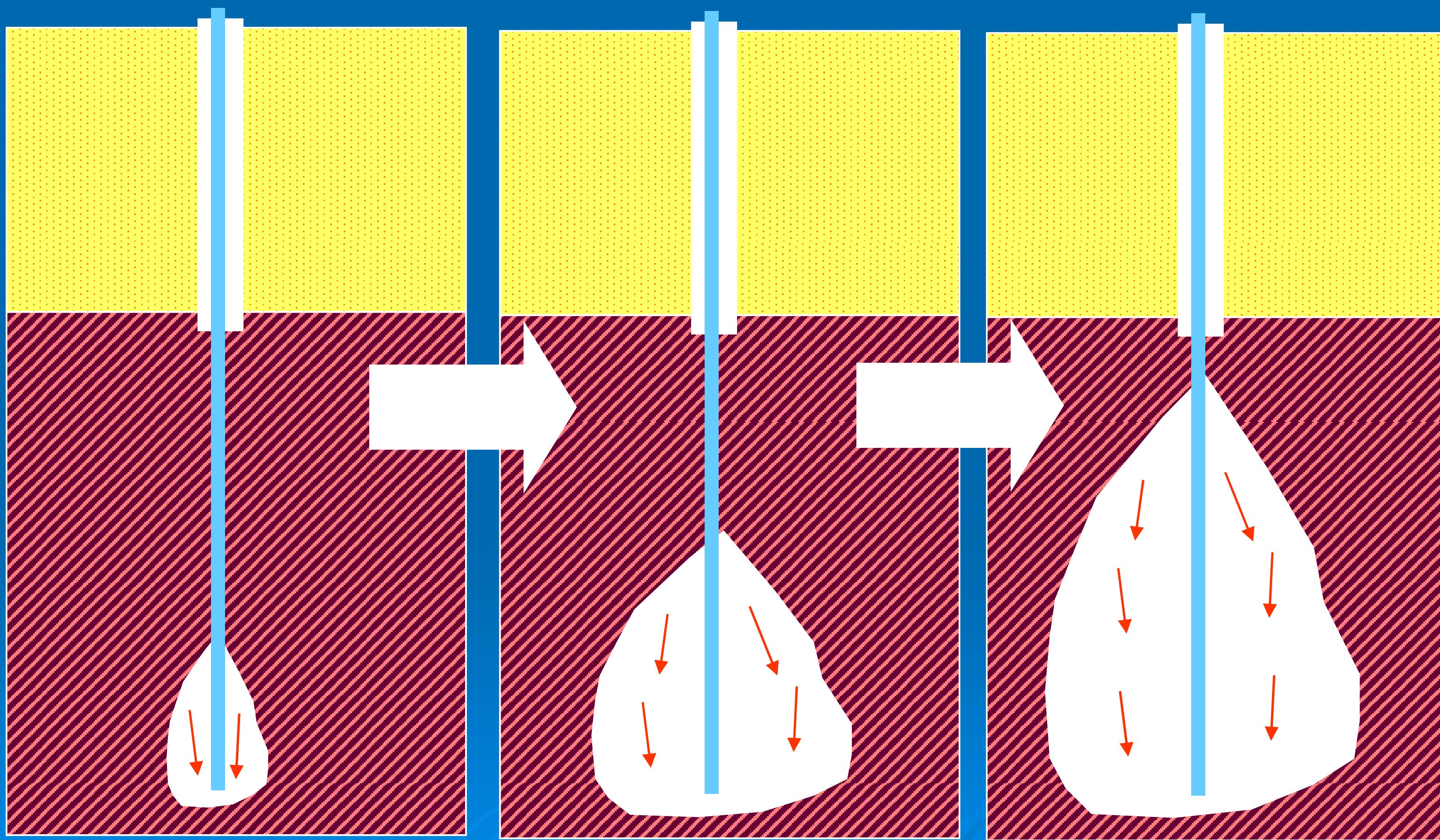
Borehole Mining is performed hydraulically

1. Water is jetted into the formation at @ 1,200 – 1,800 psi. The tool head rotates.
2. Sloughed deposit settles to the bottom of the borehole.
3. The slurry is pumped out, screened, and filtered at the surface.
4. Clear water is re-injected as water jet

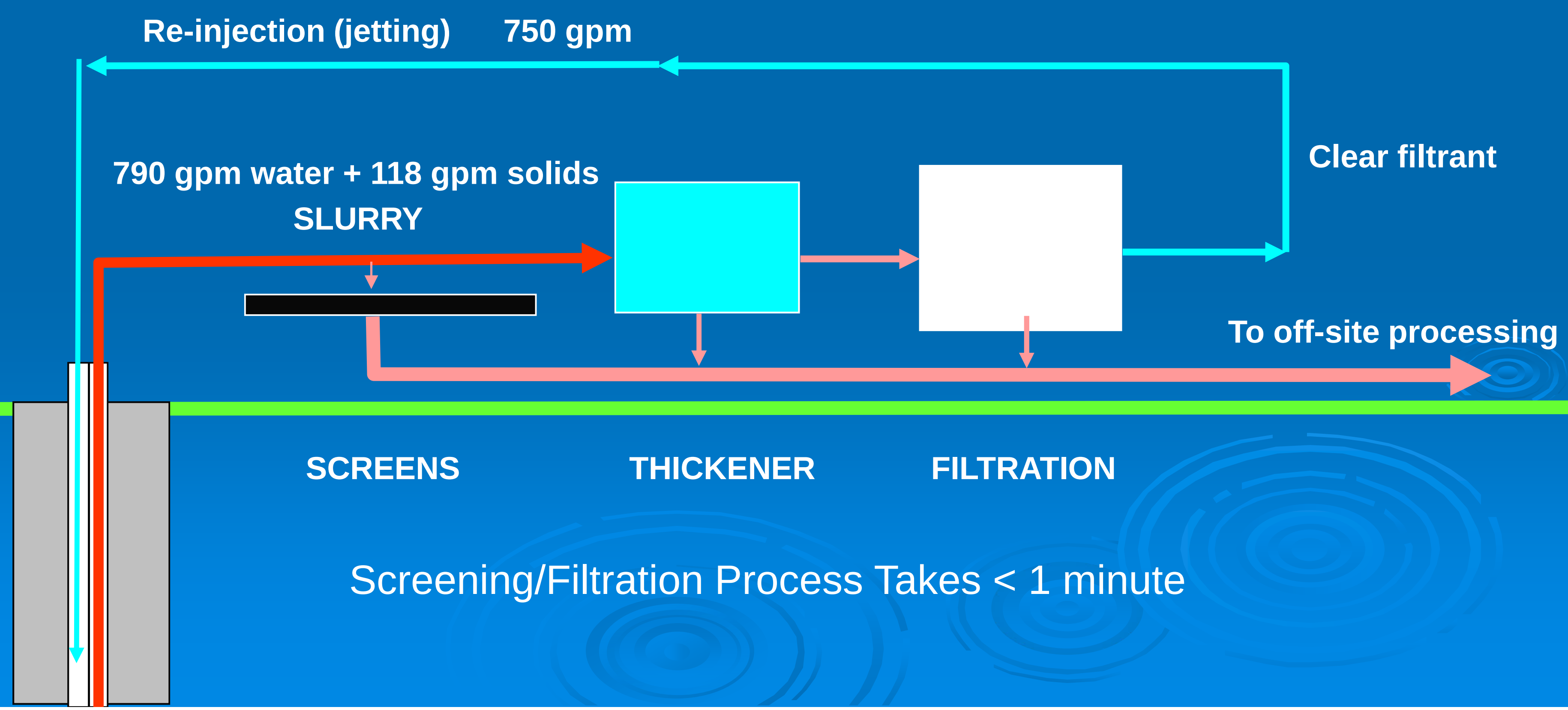
Water Cycling in Borehole



Borehole Mining Progression



General Filtration Process at Ground Surface



Screening/Filtration Process Takes < 1 minute

Expected Operation and Water Pumping

- Net instaneous withdrawal rate = 40 gpm
- 8 hours operation, 5 days a week
- Total estimated withdrawal during collection of the bulk sample = 1.15 MG
- Estimated operation days = @ 45

Environmental Evaluations for Permitting the Collection of the Bulk Sample

Required Permits & Environmental Reviews

- Environmental Assement Worksheet (DNR is RGU)
- Water Appropriations Permit – DNR
- Operation & Reclamation Plan – DNR
- State Disposal System Permit (for stormwater rapid infiltration basin) – MPCA
- Conditional Use Permit – City of Emily
- Underground Injection Control Permit – EPA

Aquifer Testing and Modeling

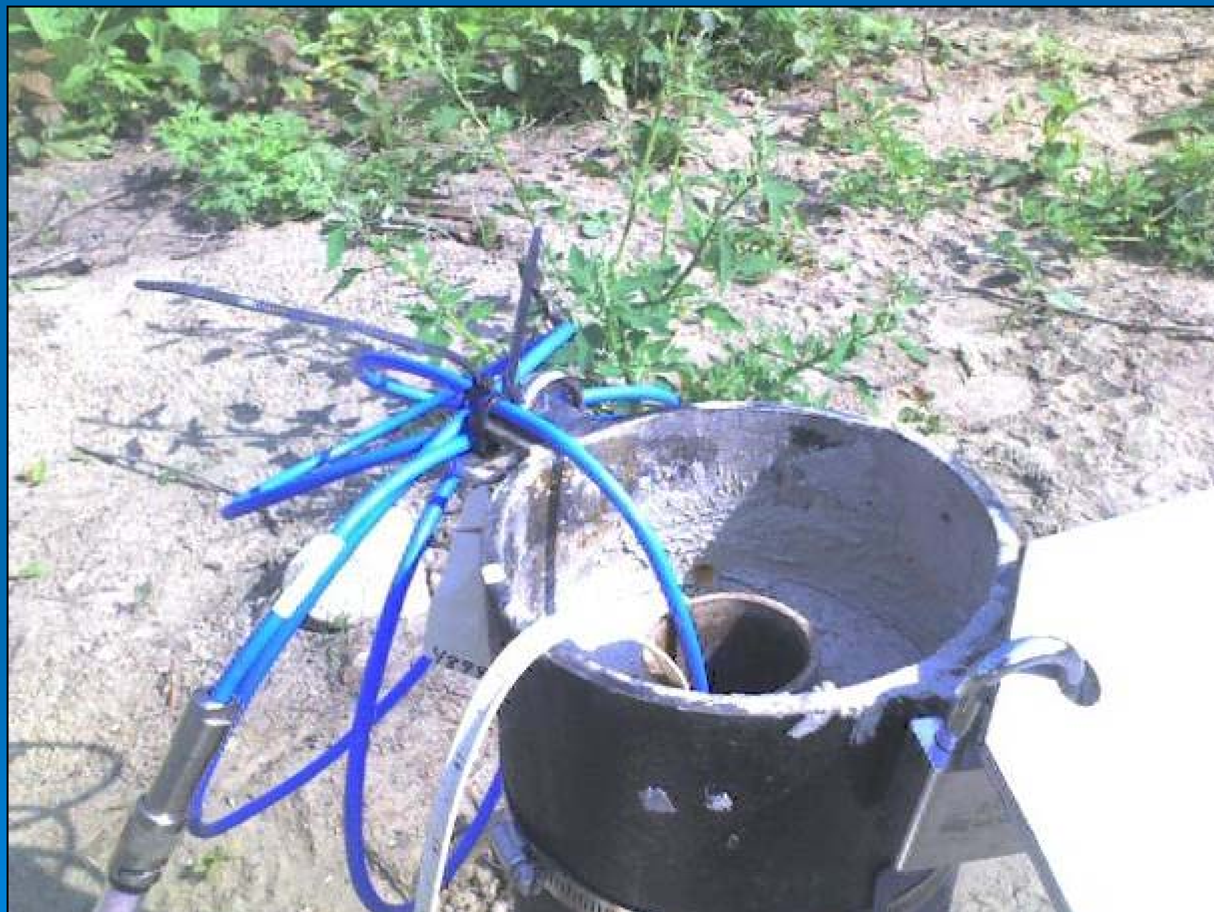


Photo by Tonia O'Brien, Barr Engineering Co.

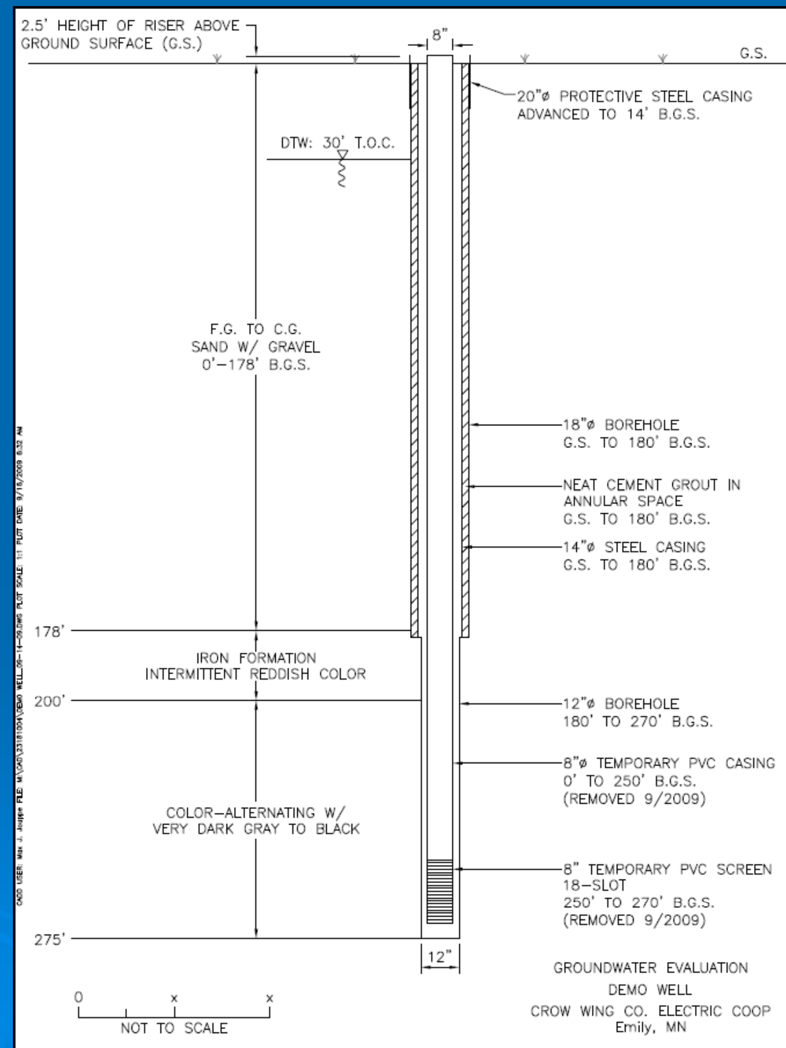
Drilling 18-inch Borehole

14-inch Steel Casing

Photo by Ellen Considine, Barr Engineering Company

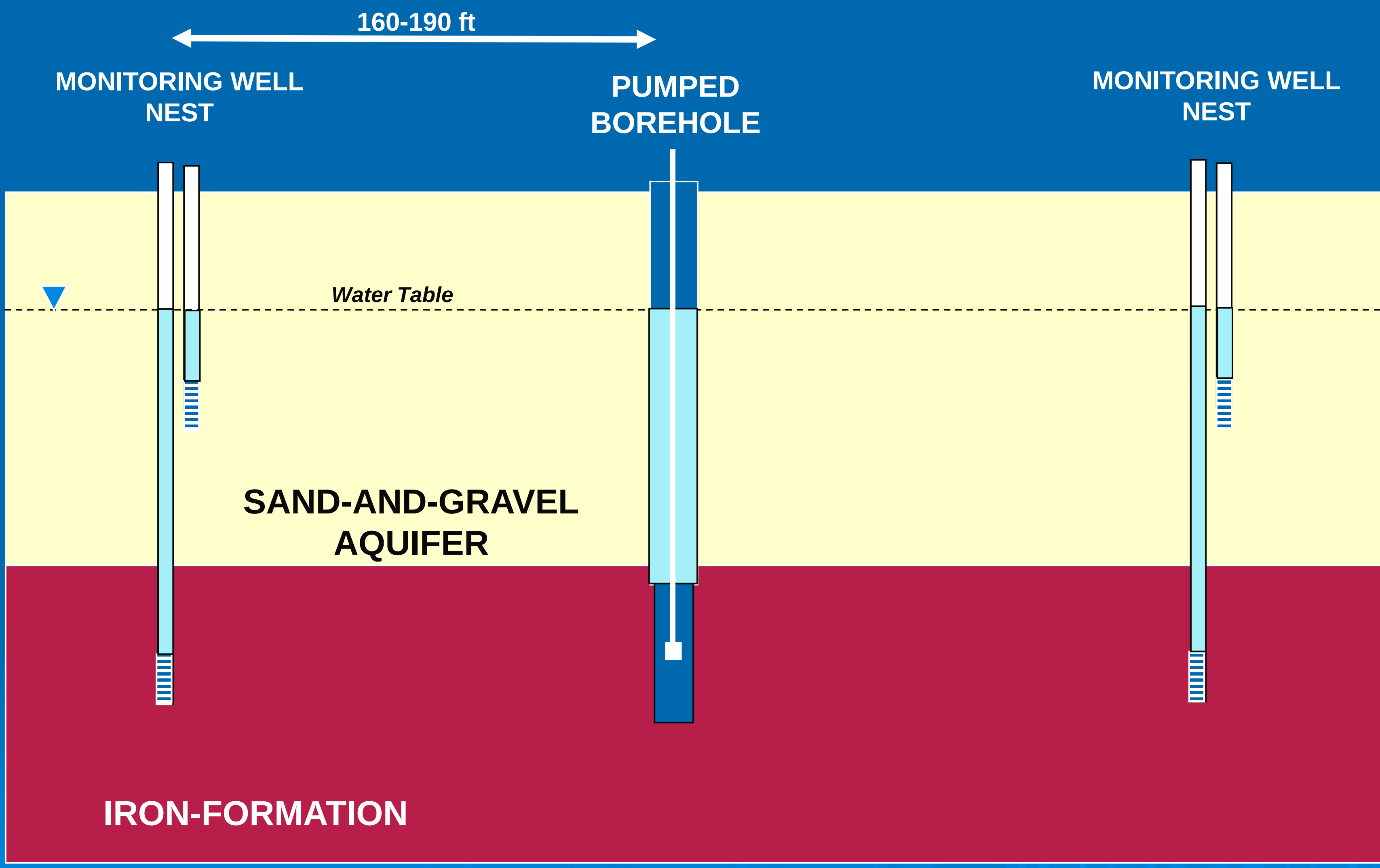
8-inch Temporary Casing Installed in Borehole

Photo by Ellen Considine, Barr Engineering Company

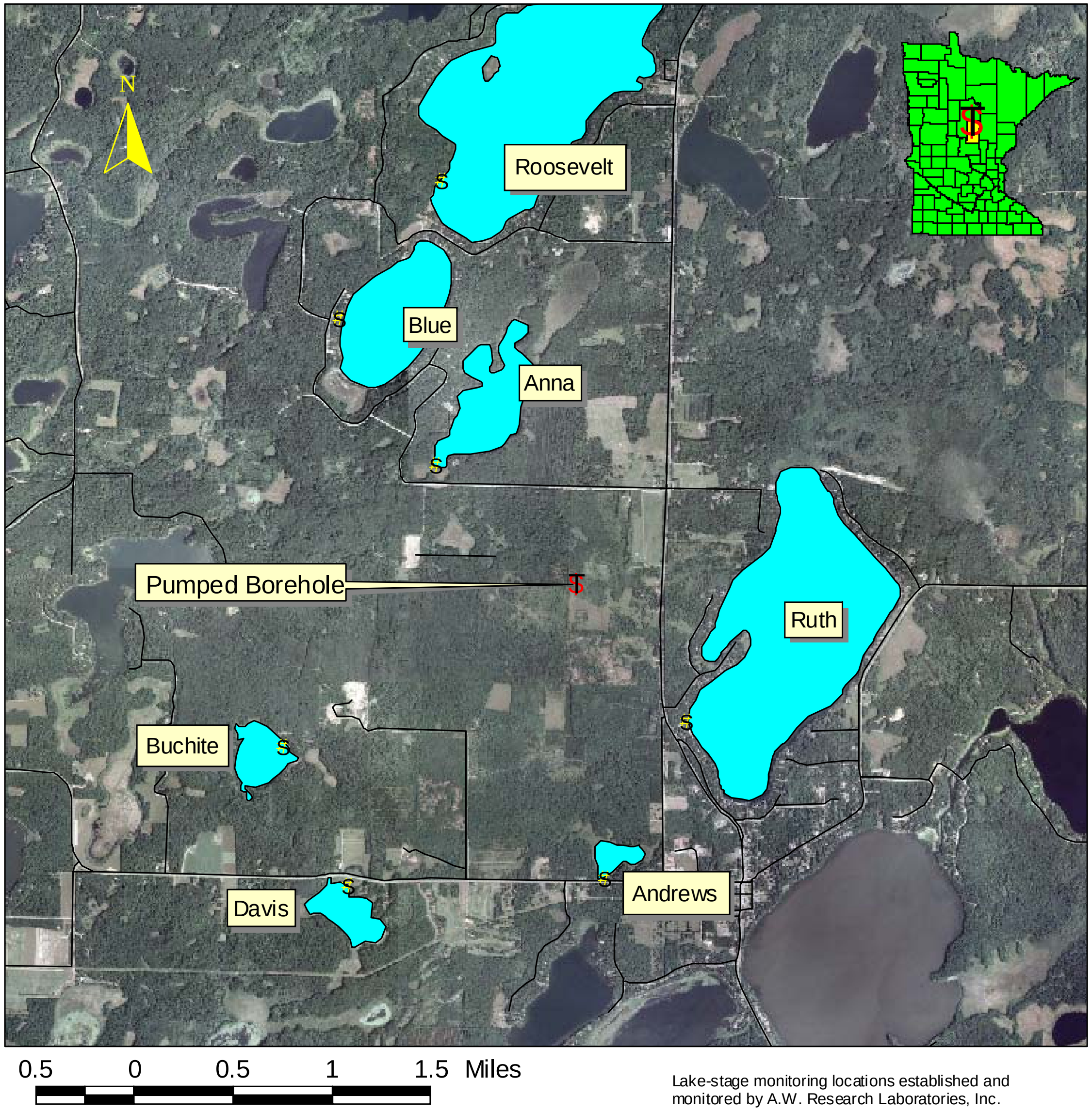


Location of Monitoring Wells

Non-Pumping Condition



SCHEMATIC CROSS SECTION THROUGH AQUIFER TEST AREA



Lake-stage monitoring locations established and monitored by A.W. Research Laboratories, Inc.

S Monitoring Location

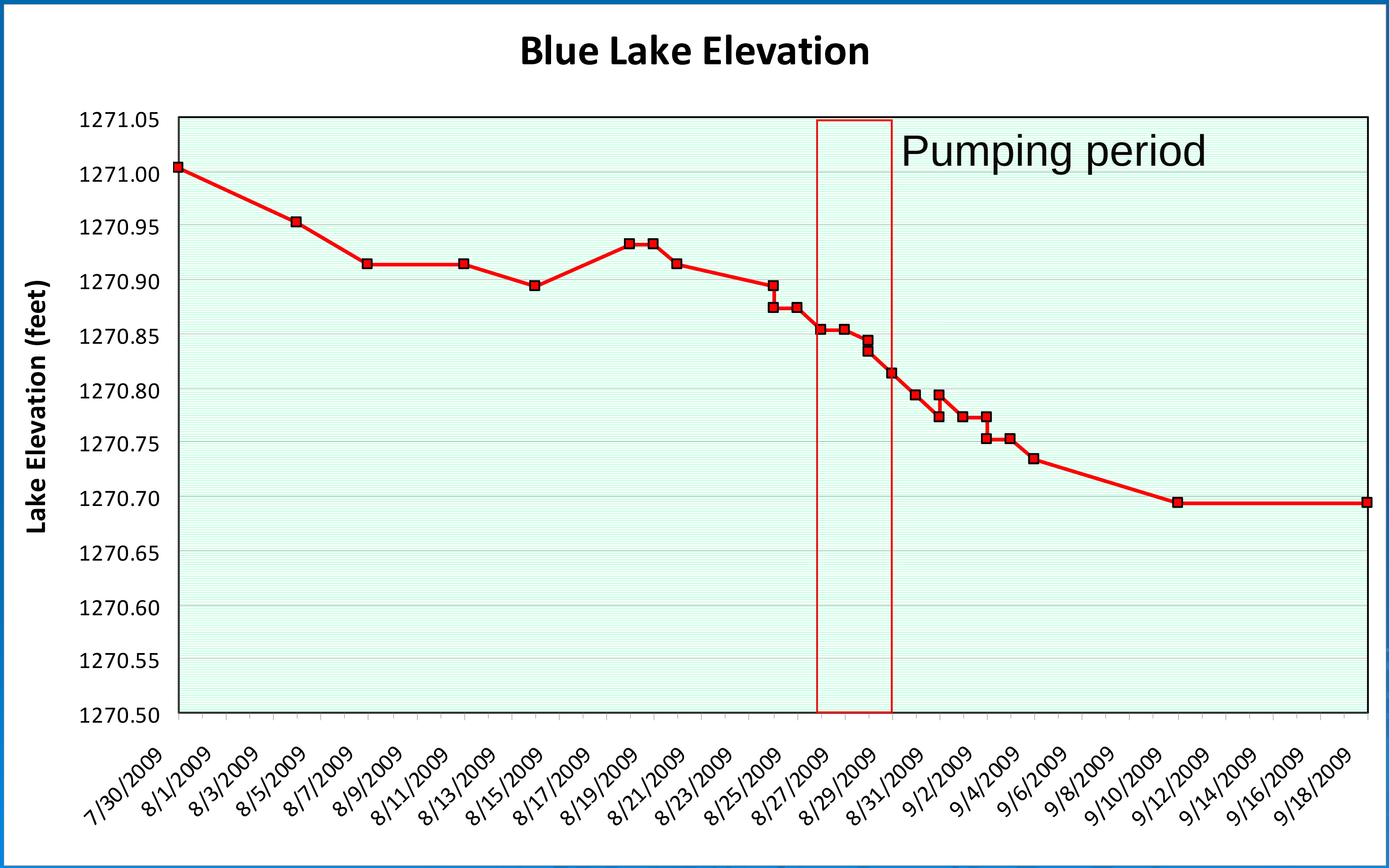
Lake Stage and Pan Evaporation were also monitored before, during, and after test

Photo by A.W. Research, Inc.

Water chemistry in both units are very similar

- Dissolved Iron – 0.02 to 23 mg/L – typically higher in sand-and-gravel aquifer
- Dissolved Mn – 0.086 to 1.4 mg/L - typically higher in sand-and-gravel aquifer
- Major ions @ similar concentrations in both units
- Trace metals non-detect to a few ppb
- pH @ 6.5 to 7
- Eh @ -140 mv in both units

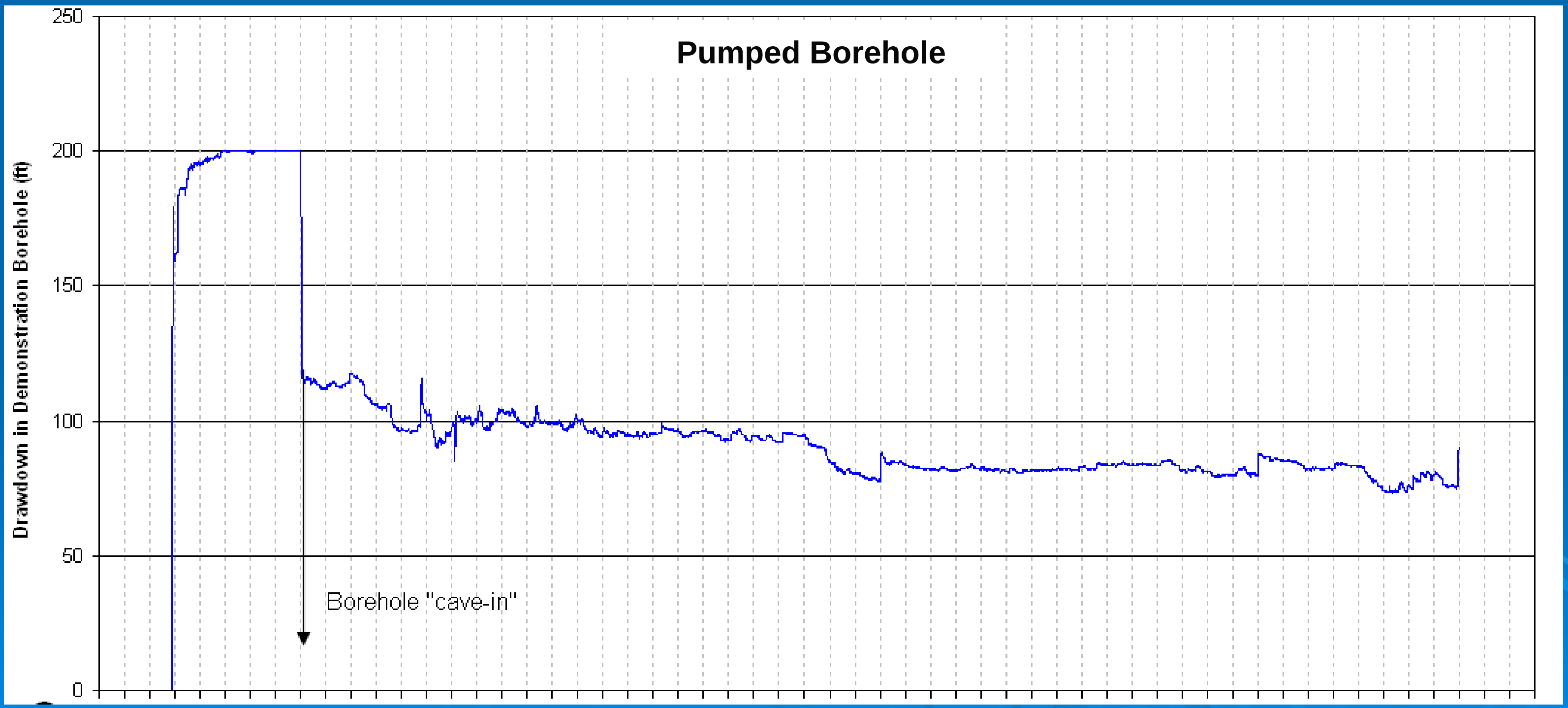
Example of Lake Stage Trends



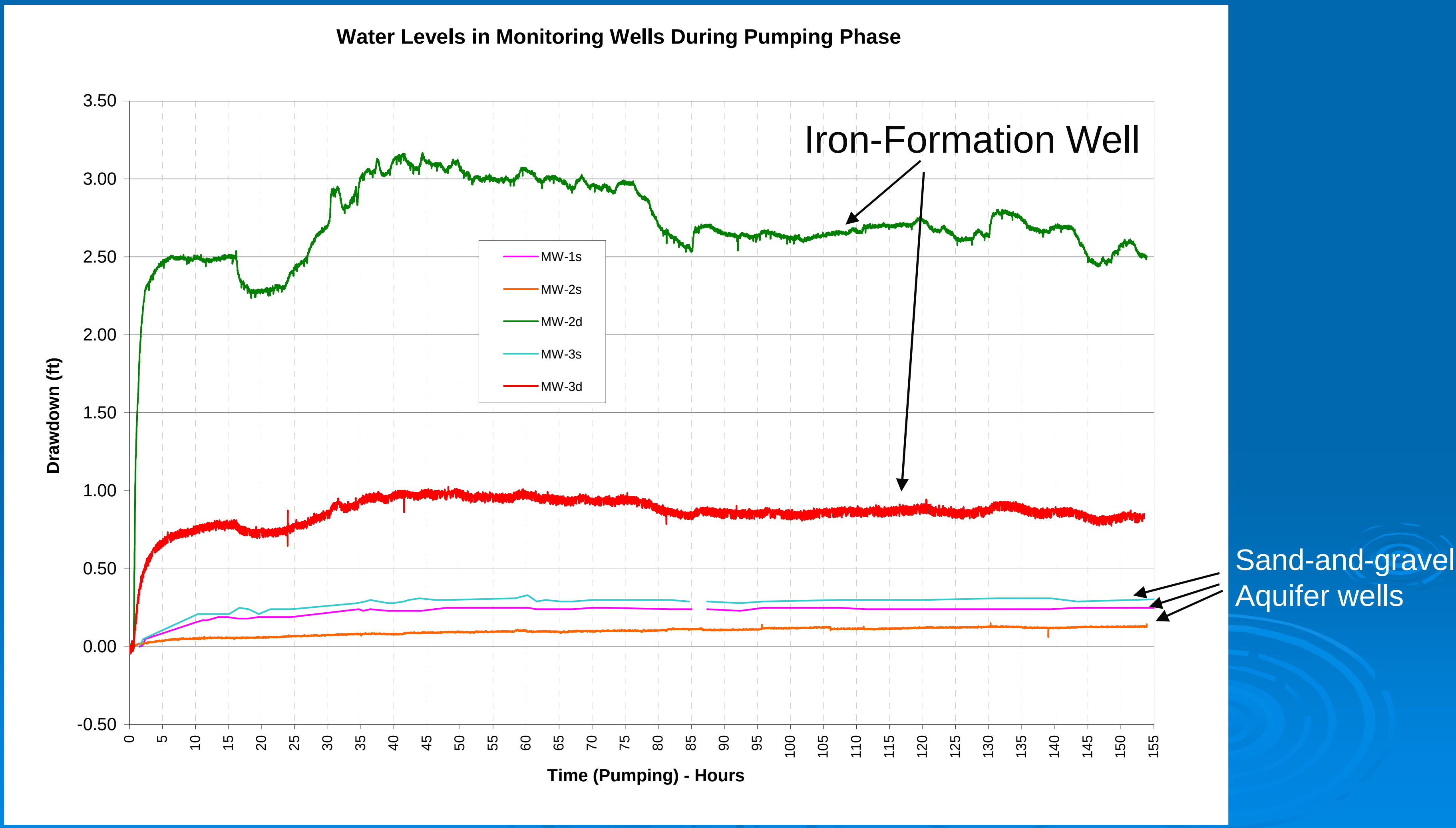
Aquifer Test

- 162.7 hours of continuous pumping @ +/- 200 gpm
- 1.95 million gallons of water
- That's about 0.8 million gallons <u>more</u> than will likely be pumped by the entire Bulk Sample Collection Project

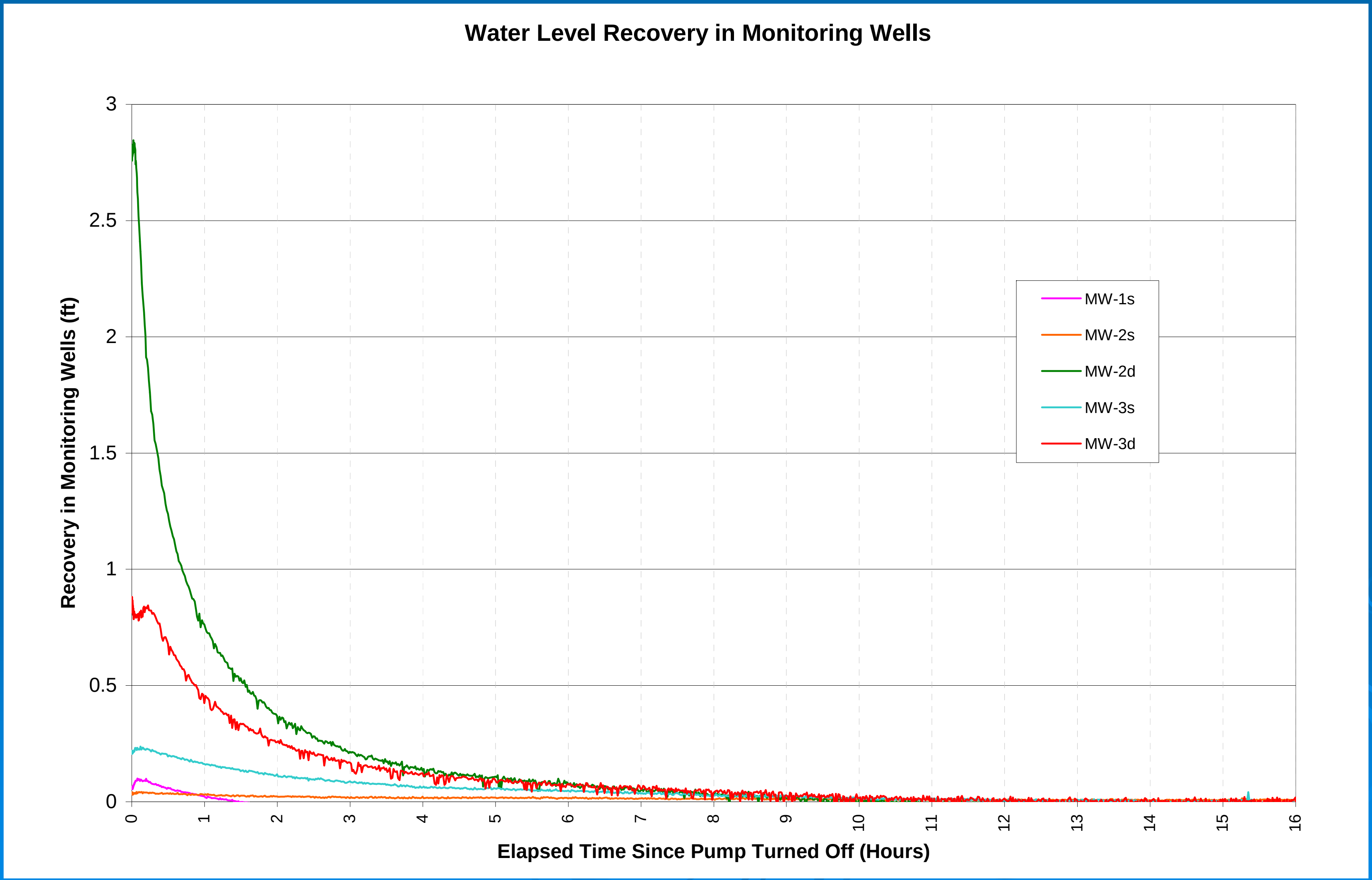
Borehole Cave-In Resulted in Huge Improvement in Well Efficiency

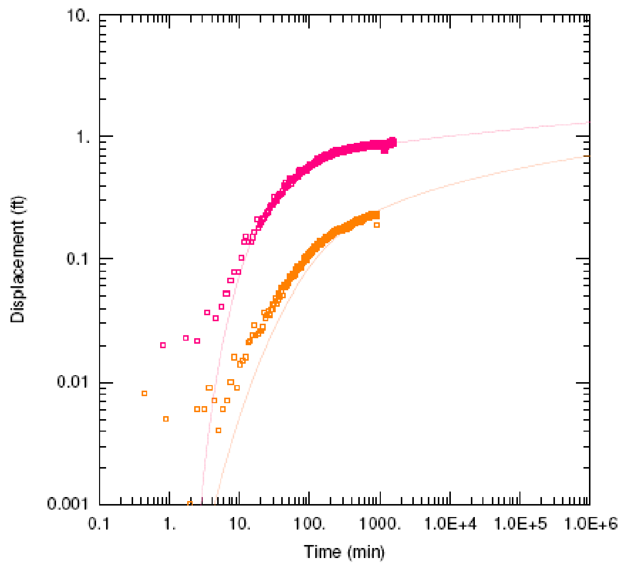


Maximum Drawdown in the Sand-and-Gravel Aquifer Monitoring Wells was less than 0.5 feet



Water-Level Recovery was Rapid





WELL TEST ANALYSIS

Data Set: P:\...\Recovery_MW3_djd.aqt
Date: 09/24/09 Time: 21:46:54

PROJECT INFORMATION

Company: Barr Engineering
Client: CMR
Project: 23/18-1004
Location: Emily, MN
Test Well: Demo Well
Test Date: 8/24/2009

AQUIFER DATA

Saturated Thickness: 241. ft
Anisotropy Ratio (Kz/Kr): 0.05
Aquitard Thickness (b'): 20. ft
Aquitard Thickness (b"): 1. ft

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
Demo Well	0	0

Observation Wells

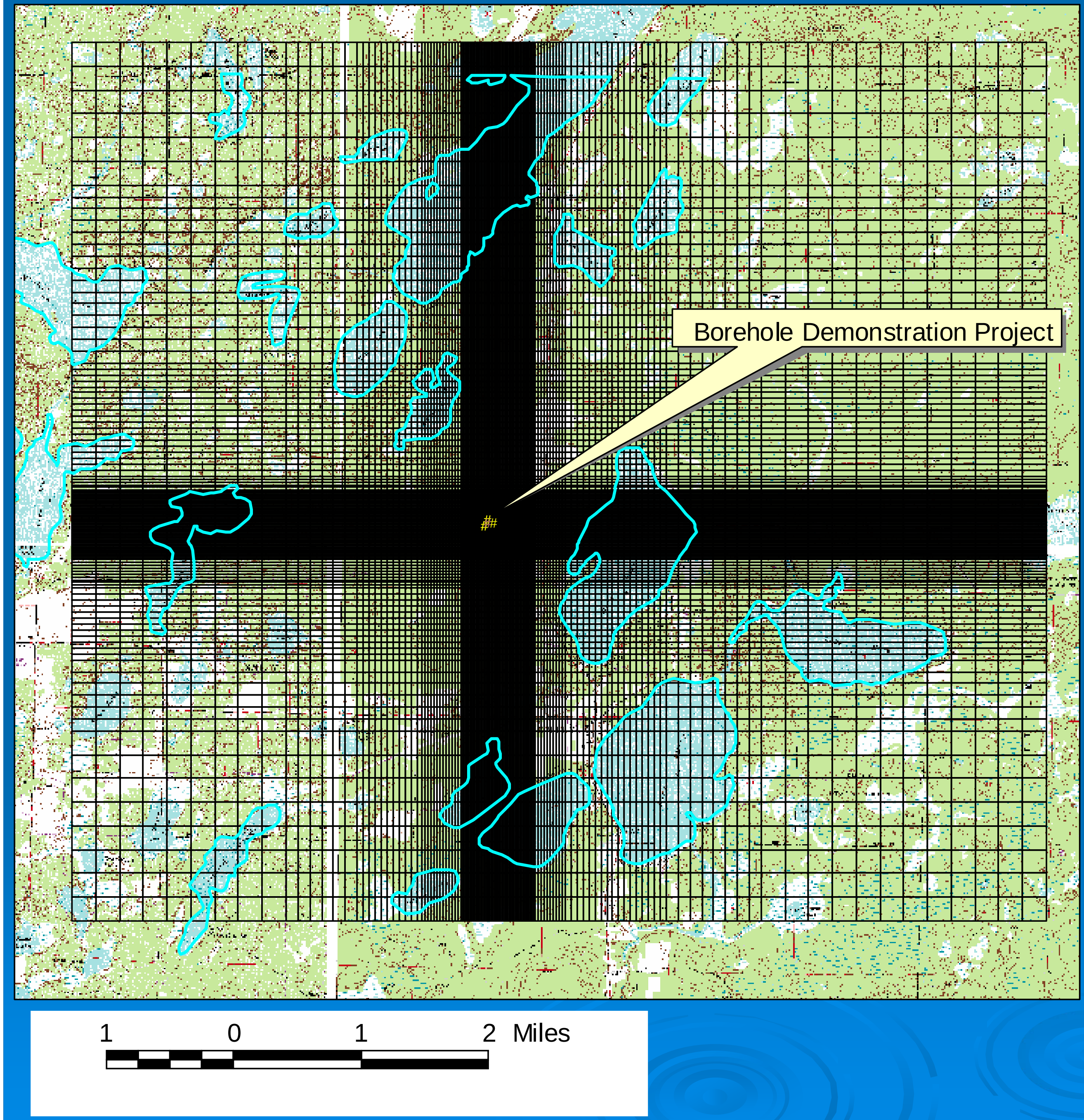
Well Name	X (ft)	Y (ft)
□ MW-3d	-50	150
□ MW-3s	-50	150

SOLUTION

Aquifer Model: Leaky
Solution Method: Neuman-Witherspoon

T = 5794.6 ft^2/day
S = 0.007913
1/B = 0.00467 ft^{-1}
ß/r = 6.325E-8 ft^{-1}
T2 = 4.152E+4 ft^2/day
S2 = 0.01

Well pairs were analyzed for aquifer parameters using conventional analytic methods

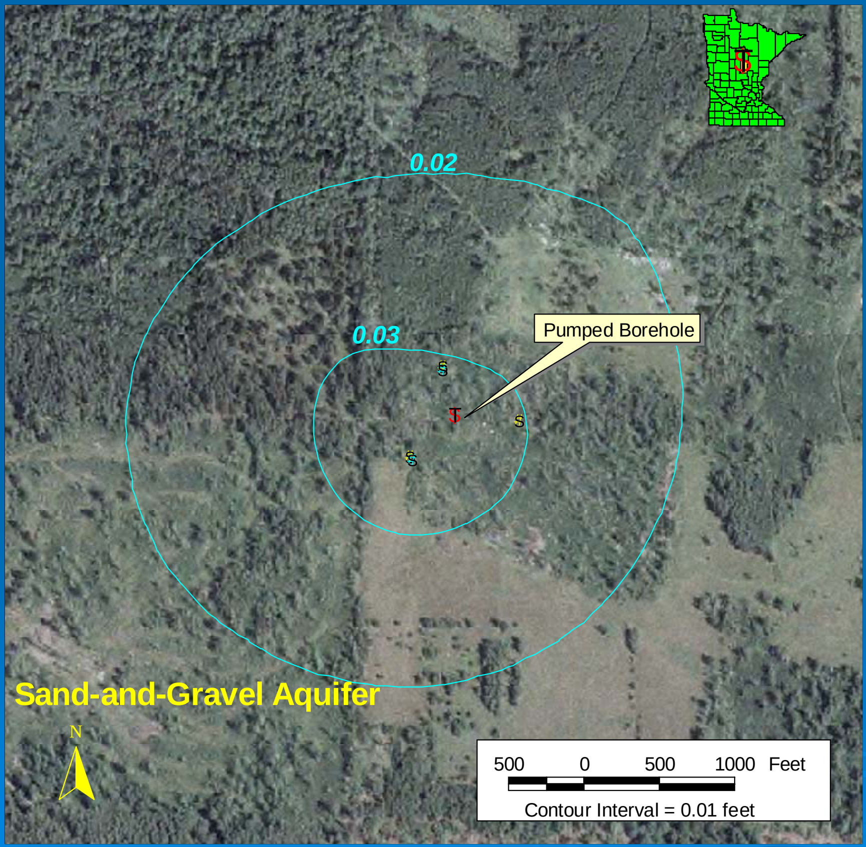


A 2-Layer MODFLOW model was developed and calibrated to the aquifer test data

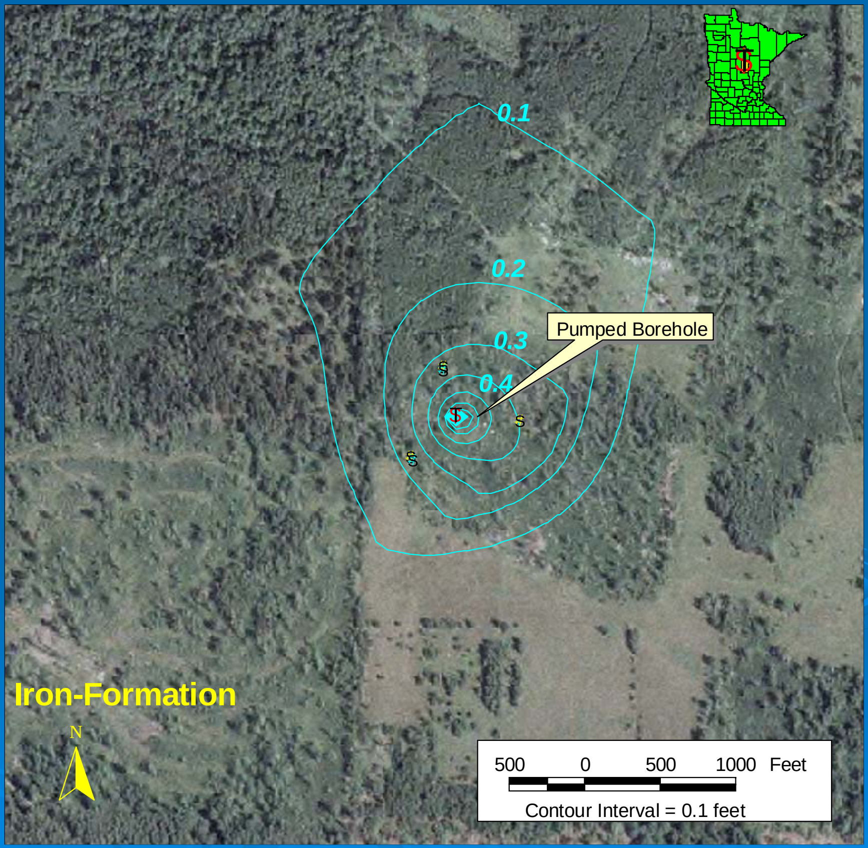
Model Calibration Designed to "Honor" Analytic Solution Results

Model Parameter	Parameter Type	Model Calibration Value	Neuman-Witherspoon Value
kz6	vertical K of iron-formation @ MW-3D	0.0058 ft/day	0.00590 ft/day (based on 1/B)
kz7	vertical K of iron-formation @ MW-2D	12.4 ft/day	16.7 ft/day (based on 1/B)
kz8	vertical K of iron-formation @ MW-1S	2.1 ft/day	1.60 ft/day (based on 1/B)
sy1	specific yield of sand-and-gravel aquifer	0.08 ft/day	0.01 – 0.04
s2	storativity of bedrock units	0.0049	0.0001 - 0.0079
kx6	horizontal K of iron-formation @ MW-3D	24.4 ft/day	24 ft/day
kx7	horizontal K of iron-formation @ MW-2D	18.3 ft/day	16 ft/day
kx8	horizontal K of iron-formation @ MW-1S	24.8 ft/day	25 ft/day
kx5	horizontal K of sand-and-gravel aquifer in vicinity of Bulk Sample Collection Project	293.6 ft/day	267 to 333 ft/day

Predicted Maximum Drawdown During the Bulk Sample Collection

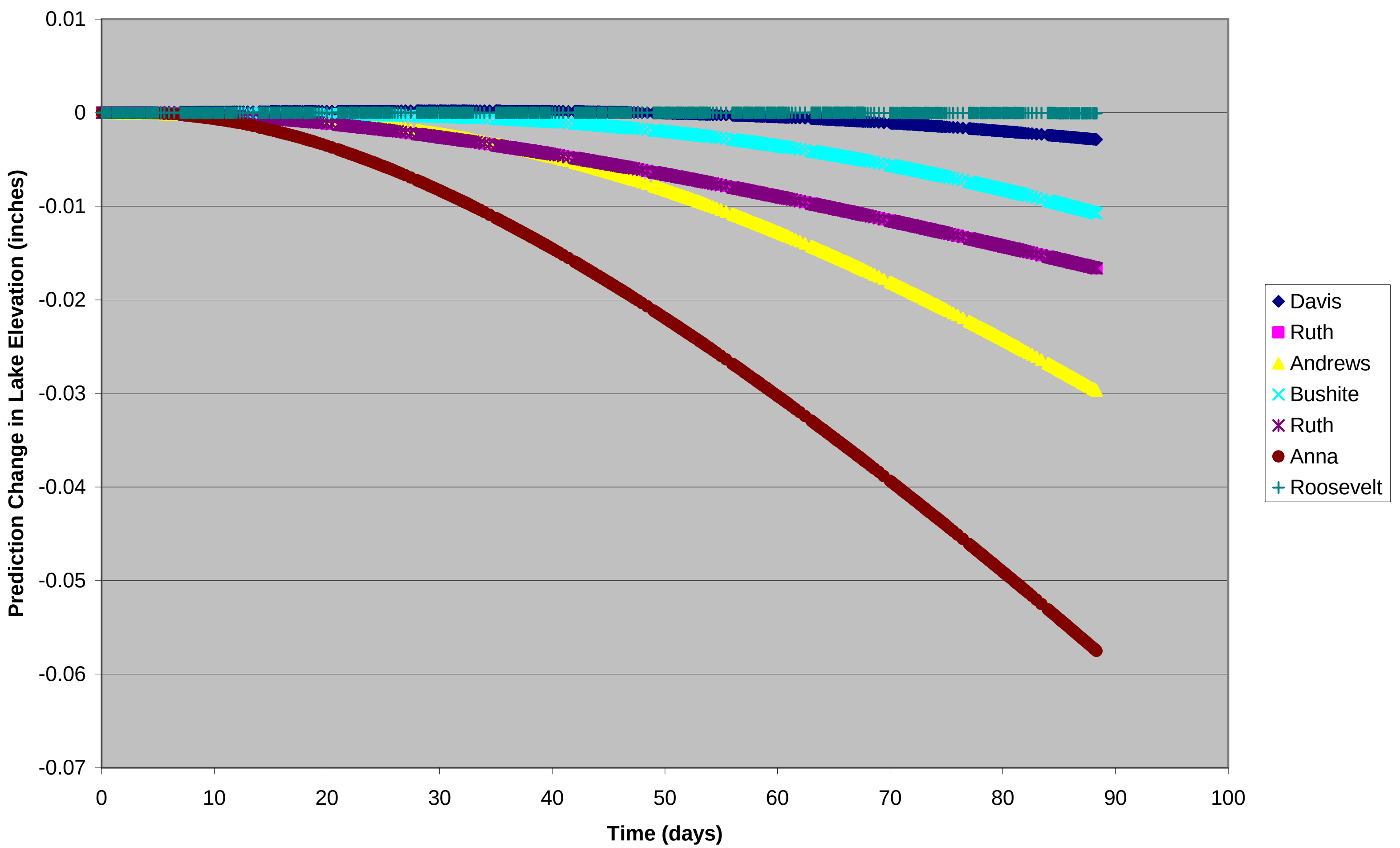


Sand-and-Gravel Aquifer

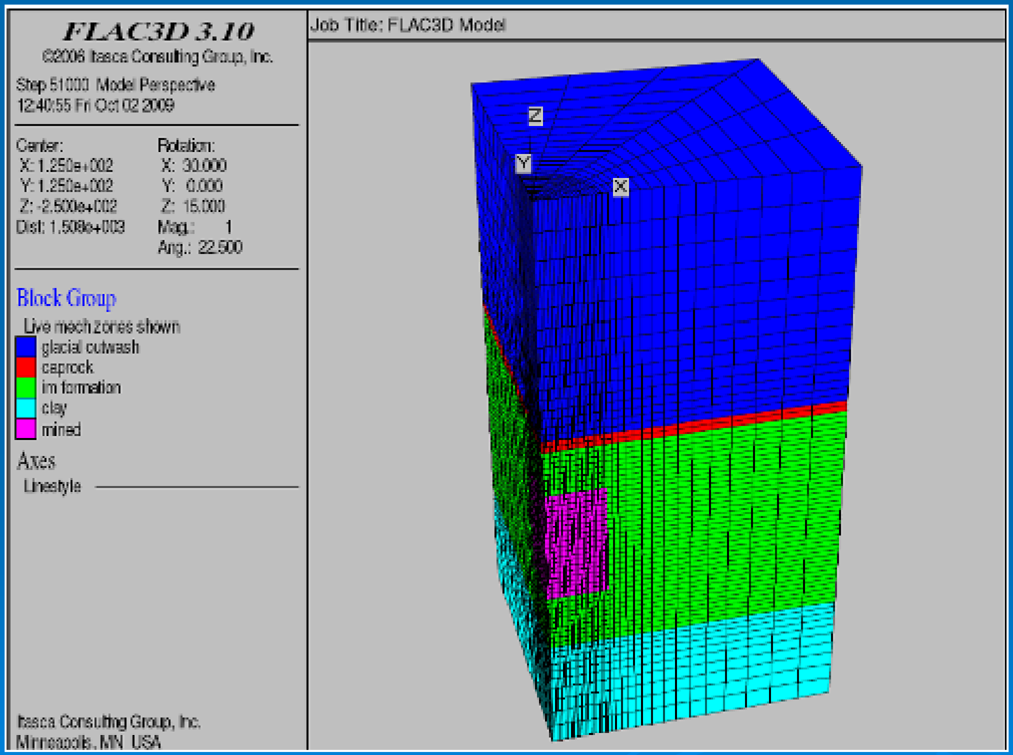


Iron-Formation

Model's Prediction of Changes in Lake Stage Elevation due to Pumping

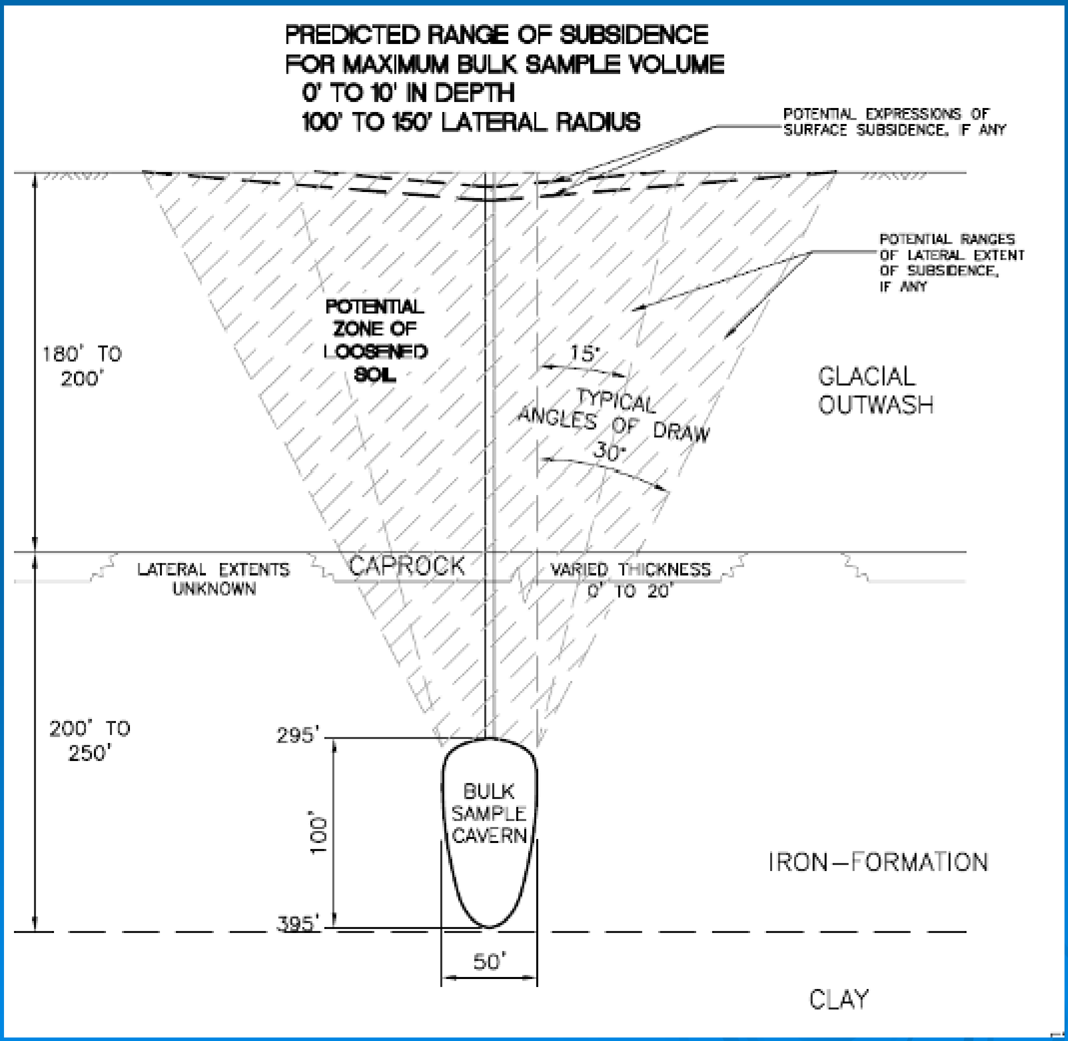


Subsidence



- Modeled using program FLAC
- Model used geotechnical parameters from core tests

Subsidence will be monitored during bulk sample collection



- Maximum subsidence predicted to be <10 feet
- Subsidence radius estimated to be <150 ft
- Extensiometers will be installed to monitor subsidence

What's Next

- Bulk sampling is planned to begin in August
- Continuous monitoring will occur during the sample collection for hydrologic and geotechnical conditions – useful for an EIS
- Full-scale mining will depend on what is learned during the bulk sample collection project – an EIS will be required for this
- Full-scale mining will likely be 1 to 4 simultaneous boreholes in operation at any one time

Acknowledgments

- Ray Wuolo– BARR Engineering
- James Agre - Crow Wing Power

QUESTIONS ?????

please visit our web site:

mndnr.gov/waters

Thank you