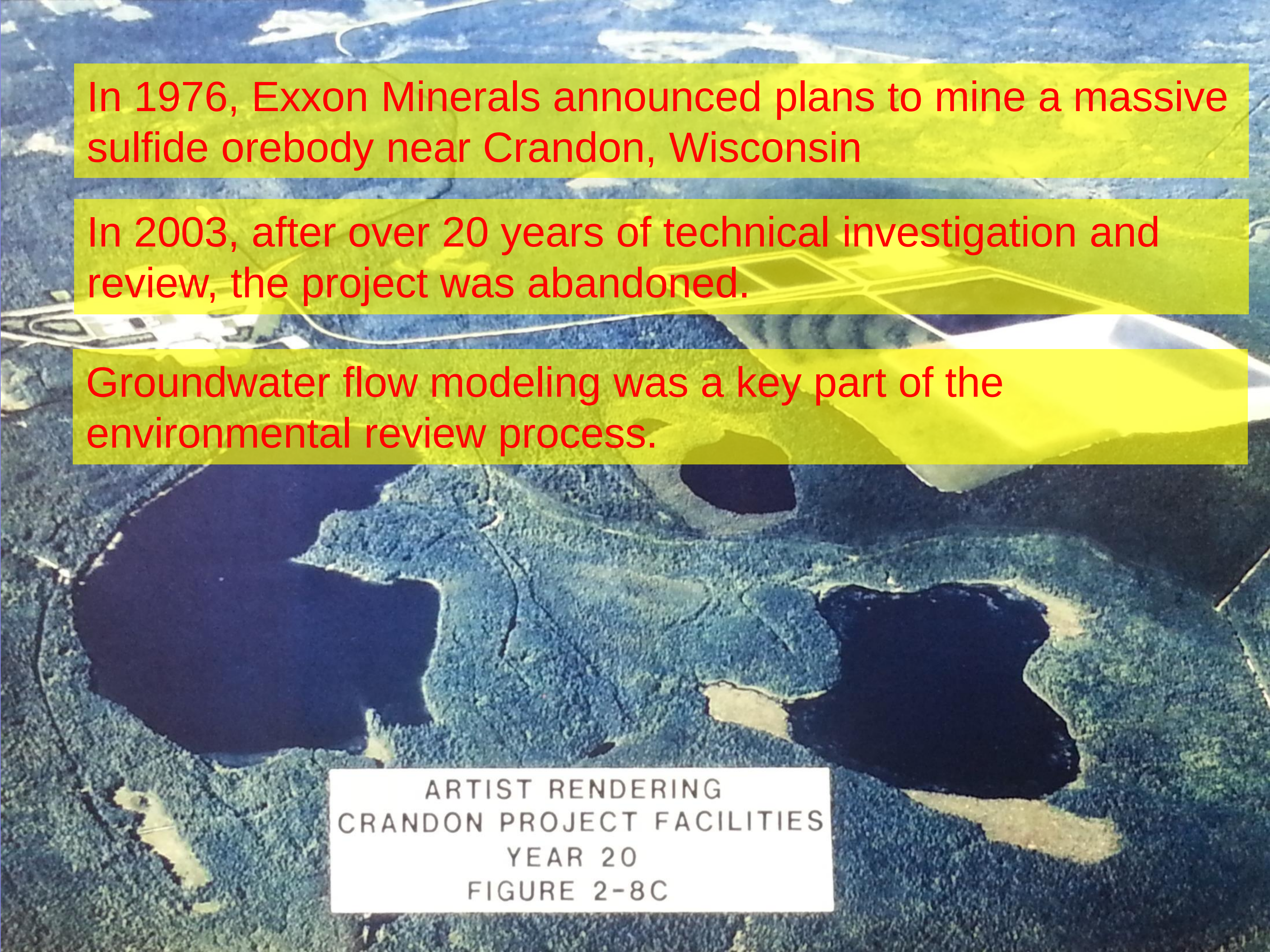
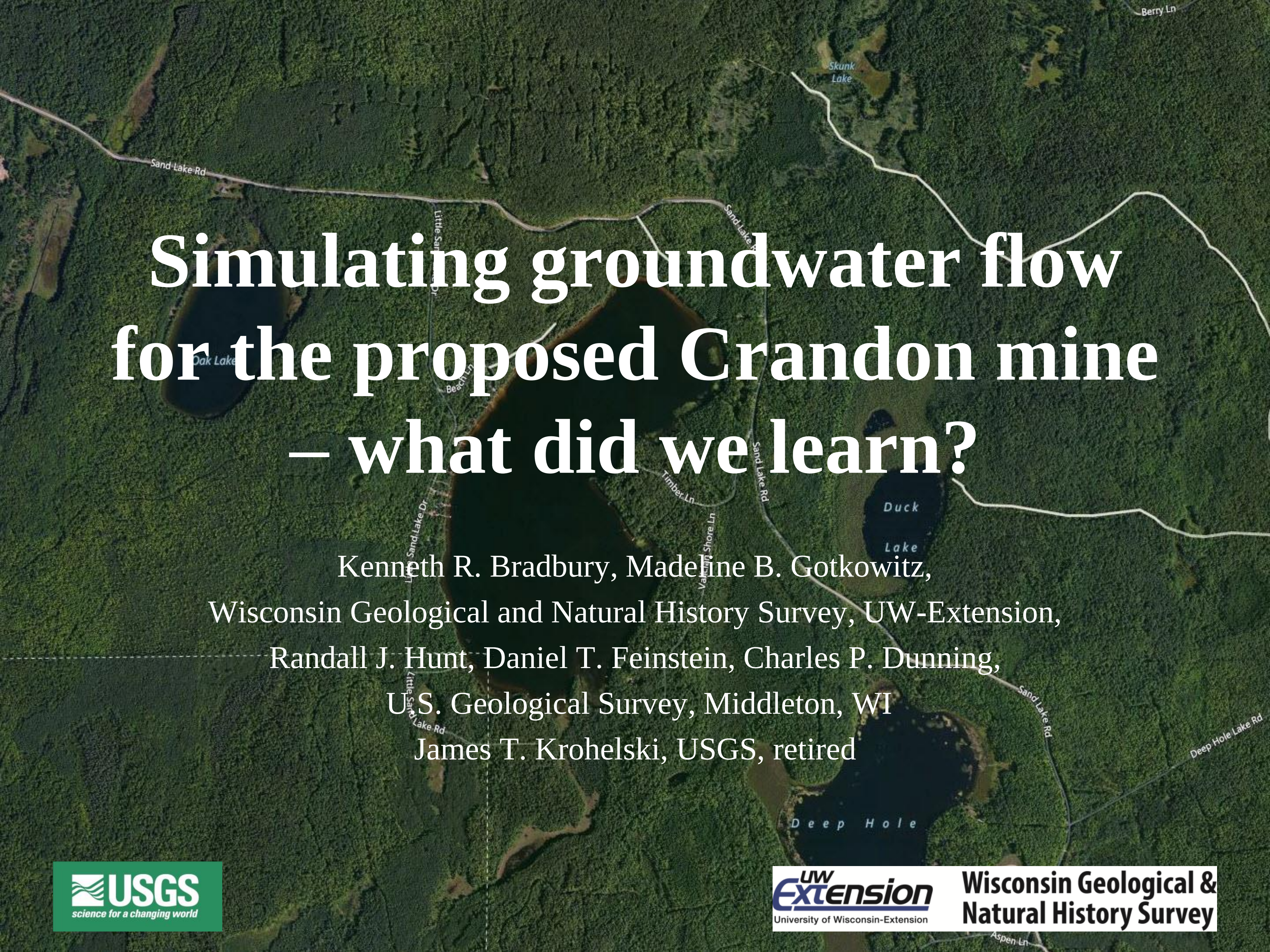
In 1976, Exxon Minerals announced plans to mine a massive sulfide orebody near Crandon, Wisconsin

In 2003, after over 20 years of technical investigation and review, the project was abandoned.

Groundwater flow modeling was a key part of the environmental review process.





Simulating groundwater flow for the proposed Crandon mine – what did we learn?

Kenneth R. Bradbury, Madeline B. Gotkowitz,
Wisconsin Geological and Natural History Survey, UW-Extension,
Randall J. Hunt, Daniel T. Feinstein, Charles P. Dunning,
U.S. Geological Survey, Middleton, WI
James T. Krohelski, USGS, retired

USGS science for a changing world

UW Extension University of Wisconsin-Extension

Wisconsin Geological & Natural History Survey

Why this talk?

- Currently renewed interest in mining in Wisconsin and adjacent states
  - Gogebic project
  - Frac sand
  - Massive sulfide deposits
  - Projects in Minnesota and Michigan
- Public/private skepticism of groundwater models
  - Mining
  - High-capacity well approvals
  - Cumulative impacts
  - CAFO studies
- Wisconsin’s capacity to review major environmental projects

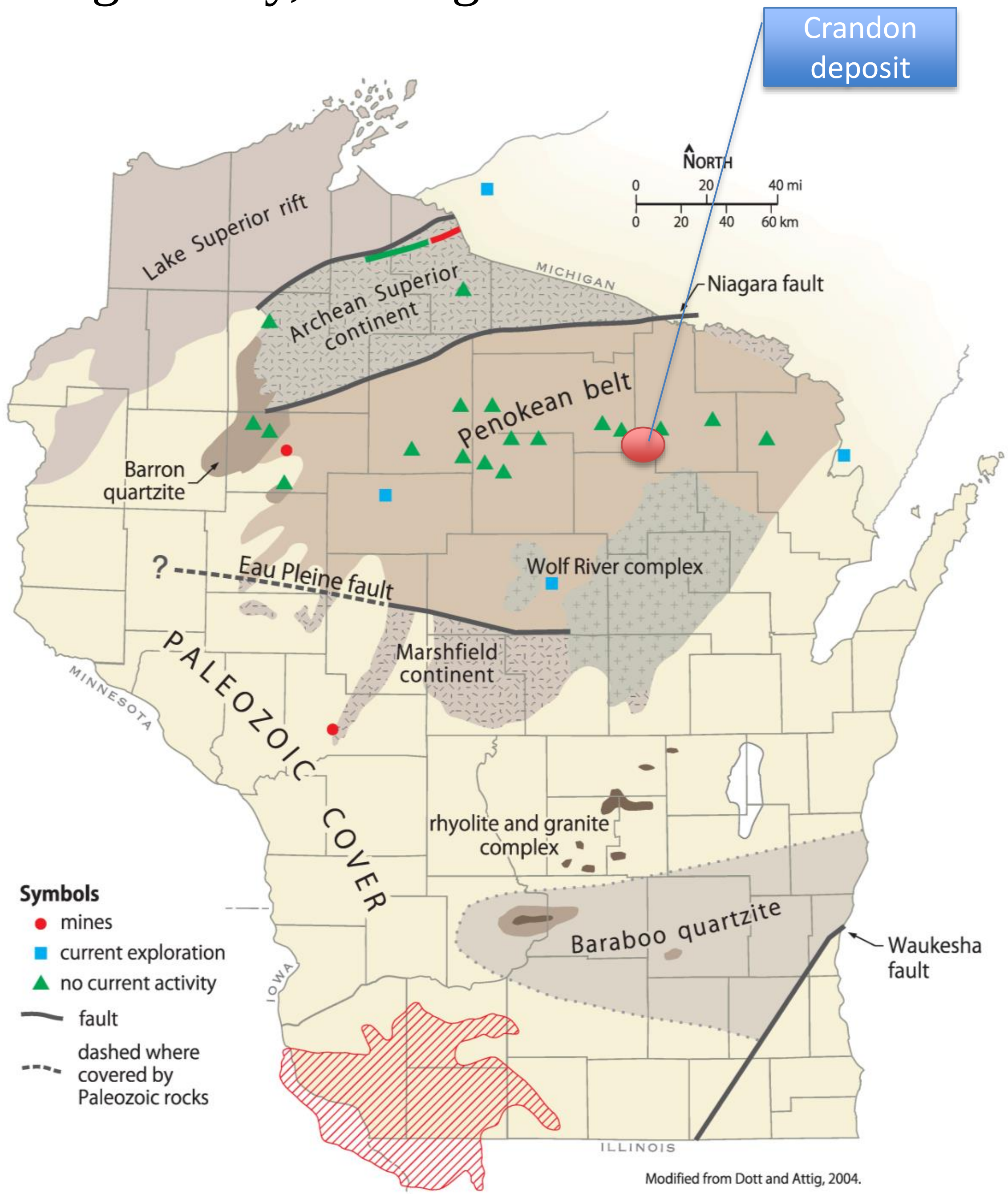
First, some background…

Wisconsin has a long mining history, and significant orebodies

Geologic map of Wisconsin

showing distribution of metallic mineral deposits

- Historic mines
- Current exploration
- Known deposits

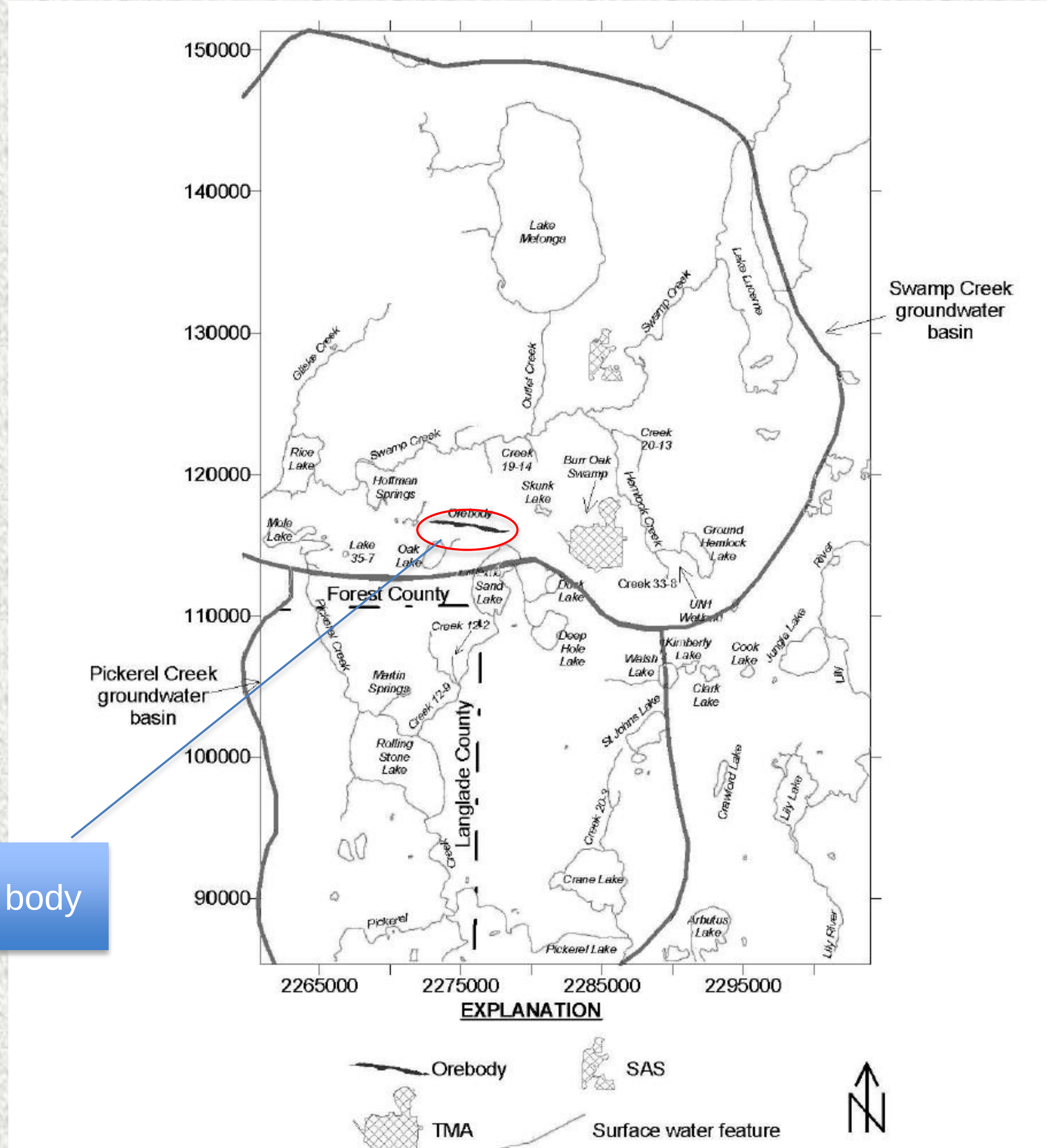


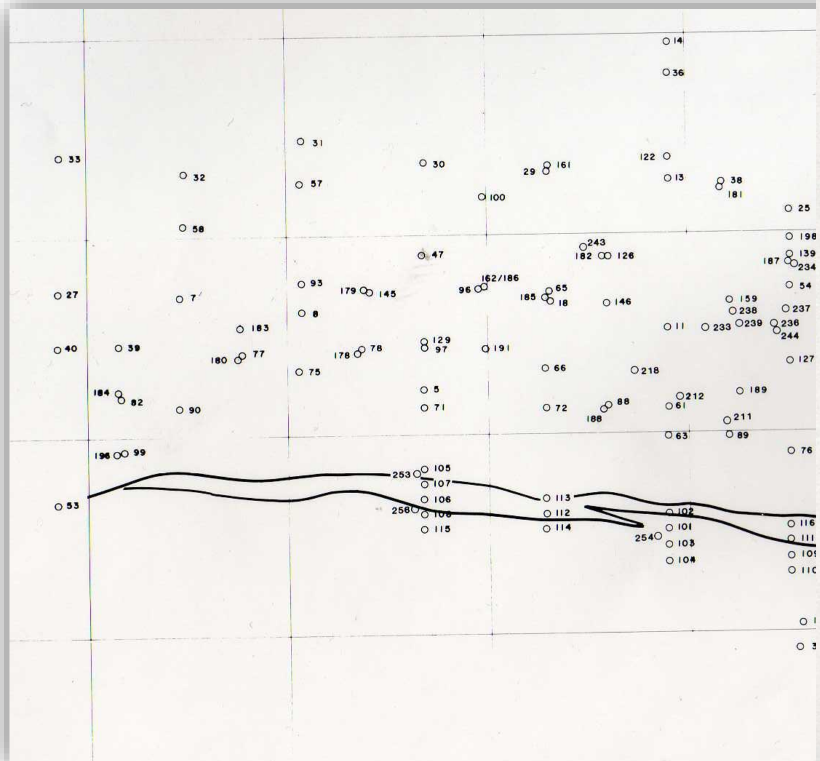
UW Extension Cooperative Extension

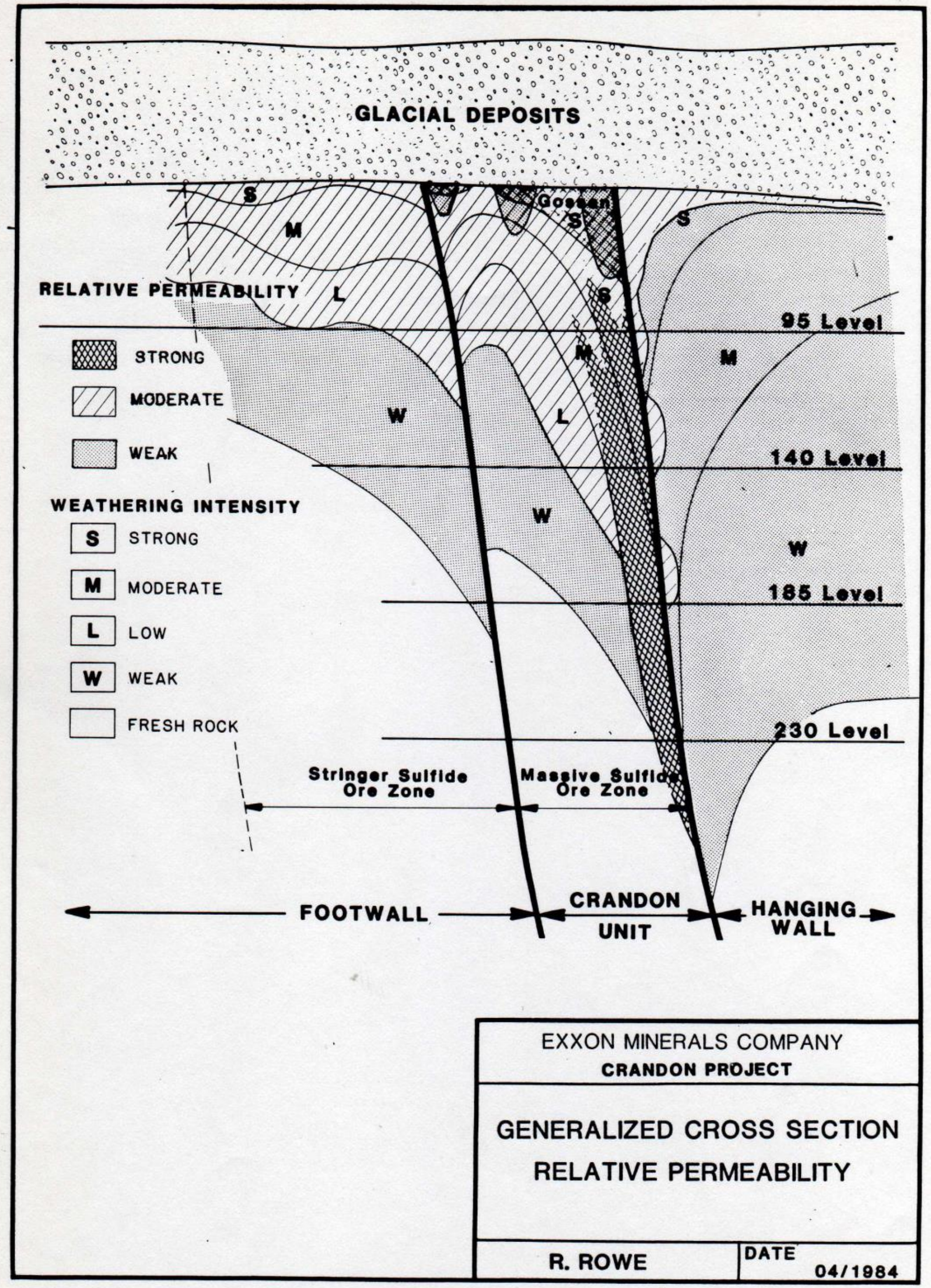
Wisconsin Geological & Natural History Survey

The Crandon massive sulfide deposit is contained in a sequence of pyroclastic and sedimentary rocks beneath 100 to 230 feet of glacial sediments.

These rocks contain significant zinc, lead, and copper, with minor amounts of gold and silver.



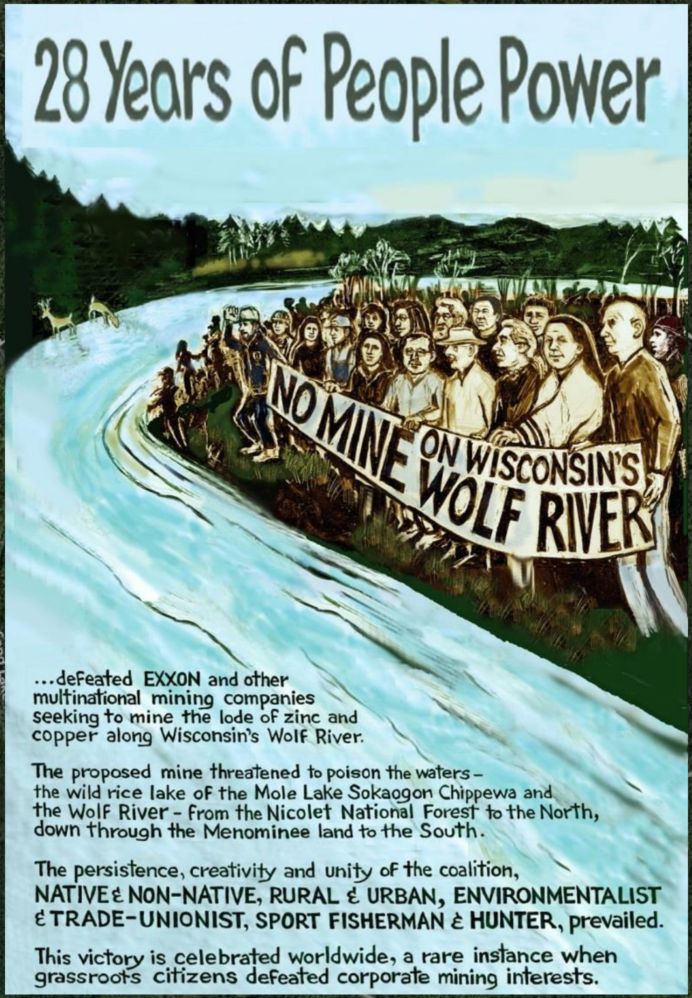




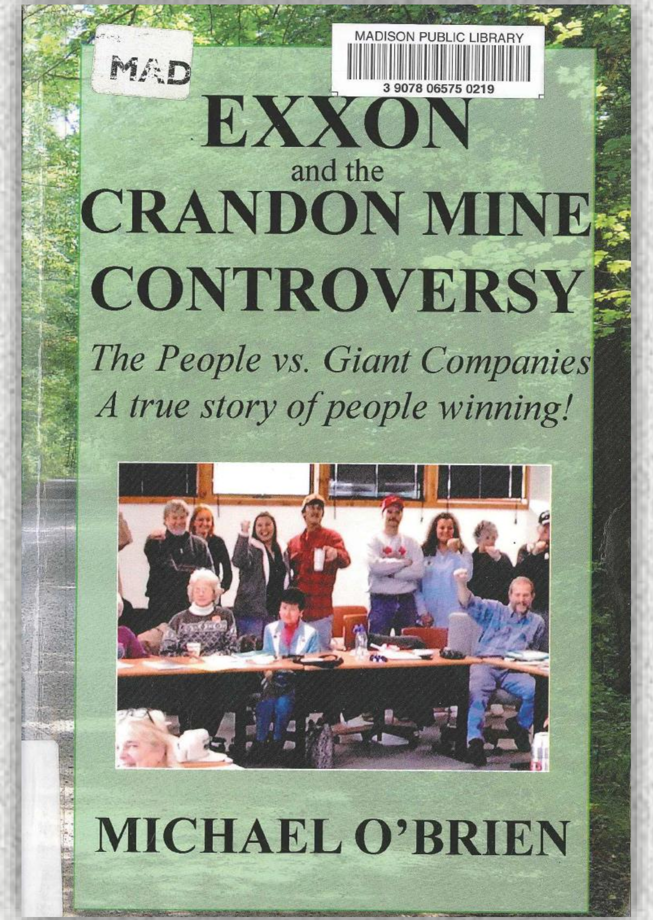
In map view the orebody is lenticular and nearly vertical. Hundreds of angled exploration holes were drilled to assess the reserves.

Mining would occur underground at depths up to nearly 1000 feet. This requires dewatering of the bedrock.


Artist's conception…
headframe, mill
Ore body
tailings disposal



There was significant public opposition to the mine, and mistrust of the state's review process.



Interesting book about the controversy (Badger Books, LLC)

"A major concern…was the groundwater flow model used by Crandon Mining Company.

It was an ongoing contentious element in the minds of DNR personnel. The model, a computerized simulation called Modflow, is meant to replicate the mine as closely as possible…

The model was exceptionally complex and attempted to predict water levels and rainfall in Forest County for the following forty years."

(O'Brien, p 82)

Crandon Timeline – nearly 20 years of review over two projects

“Crandon 1” review (10 years)

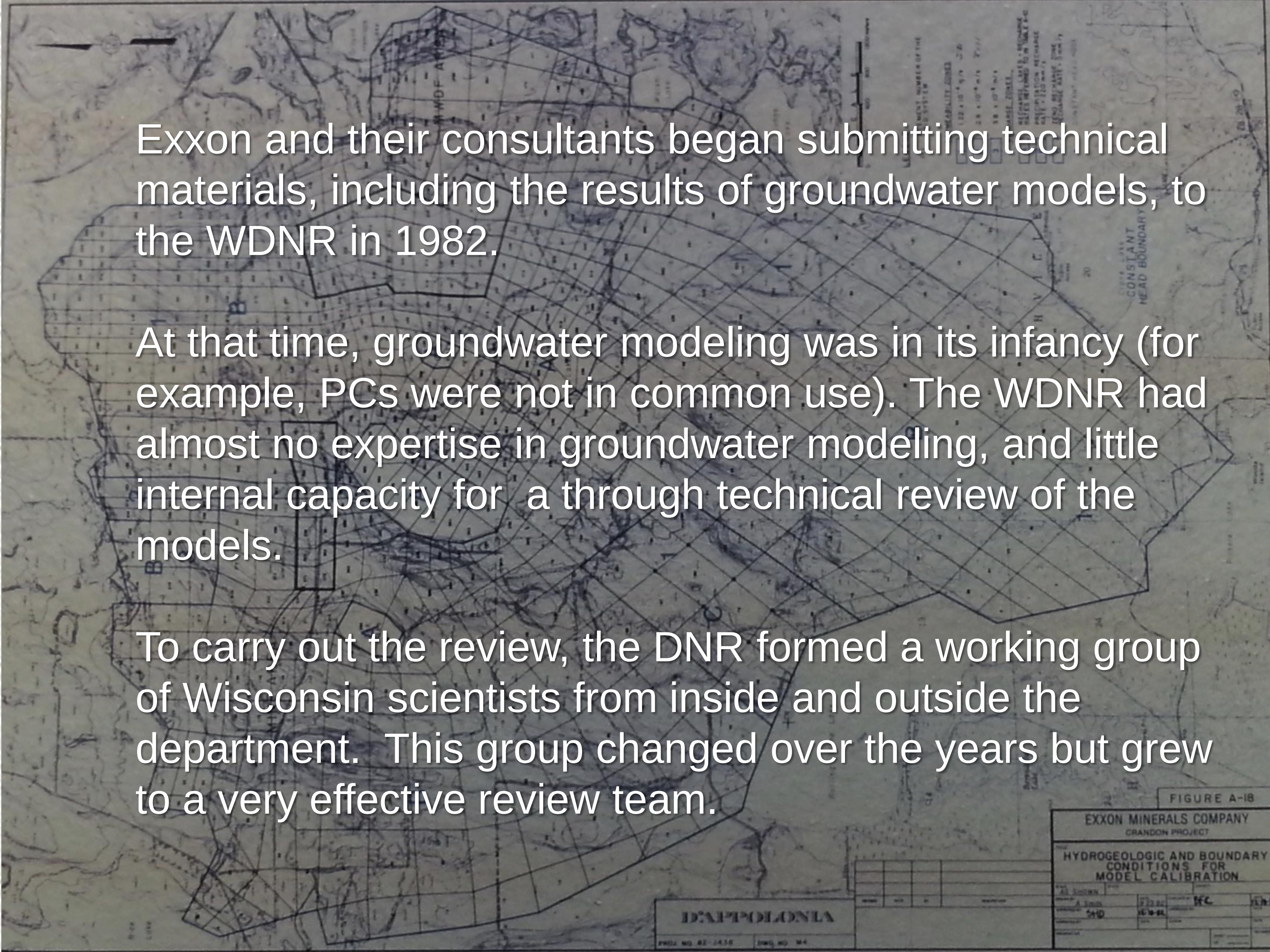
1975	deposit discovered
1976	public announcement by Exxon Minerals Inc; $2.3 billion deposit
1982	Environmental Impact report (EIR) submitted to DNR
1985	Exxon alters mining plan to focus on zinc, delay copper
1986 (Nov)	DNR issues FEIS, testimony prepared for Master Hearing
1986 (Dec)	Exxon shuts down project, cites low mineral prices
1987-1993	No activity

“Crandon 2” review (10 years)

1993	Exxon partners with Rio Algom, forms Crandon Mining Company (CMC), project re-started
1998	Exxon sells mine to Rio Algom, Exxon pulls out, Company name changed to Nicolet Mineral Company (NMC)
2000	BHP Billiton purchases mine from Rio Algom
2002	Billiton effectively mothballs project
2003	Property sold to Northern Wisconsin Resources Group (NWRC), a logging/lumber company
2003 (Oct)	Property sold to two Native American tribes; project terminated

Key groundwater issues

- Mine inflow
  - How much water would be produced by mine dewatering?
  - How much drawdown would occur?
  - How large would the cone of depression be?
- Surface water impacts
  - Would lakes and wetlands be harmed?
  - Would streamflows decrease?
- Tailings disposal
  - Would the tailings landfill leak?
  - If so, would groundwater quality be impaired?
- Long-term impacts
  - What would happen when the underground workings reflood?



Exxon and their consultants began submitting technical materials, including the results of groundwater models, to the WDNR in 1982.

At that time, groundwater modeling was in its infancy (for example, PCs were not in common use). The WDNR had almost no expertise in groundwater modeling, and little internal capacity for a through technical review of the models.

To carry out the review, the DNR formed a working group of Wisconsin scientists from inside and outside the department. This group changed over the years but grew to a very effective review team.

Wisconsin's Crandon groundwater "team" (Technical Working Group)

USGS
Randy Hunt
Jim Krohelski
Daniel Feinstein
Chuck Dunning

WGNHS
Ken Bradbury
Madeline Gotkowitz
Tom Evans
Bill Batten

WDNR
Ken Wade
Chris Carlson
Dave Johnson
Nile Ostenso
Roger Gerhart
Bob Ramharter
Larry Lynch
Archie Wilson
Bill Tans
Ken Markart

UW-Madison
Mary Anderson
Ken Potter
Craig Benson

UW-Milwaukee
Doug Cherkauer
Tim Grundl

Univ of Waterloo
David Blowes

Industry
Galen Kenoyer
Vic Kelson
Henk Haitjema
Dan Morrissey
Donald Bruce

Corps of Engineers
Mark Meyers

GLIFWC
John Coleman

"Regarding… what was learned from the Crandon experience, (one thing is) the validity and essential nature of calling on the pooled expertise of the hydrological community of the state. One person called it a "pool of talent" or "forum" in our strategic plans, …essentially recognizing the significant expertise and talent of state, federal, local, academic scientists. No one agency or academic department could have completed the review as well or as thoroughly as we did when we all were pulling together."

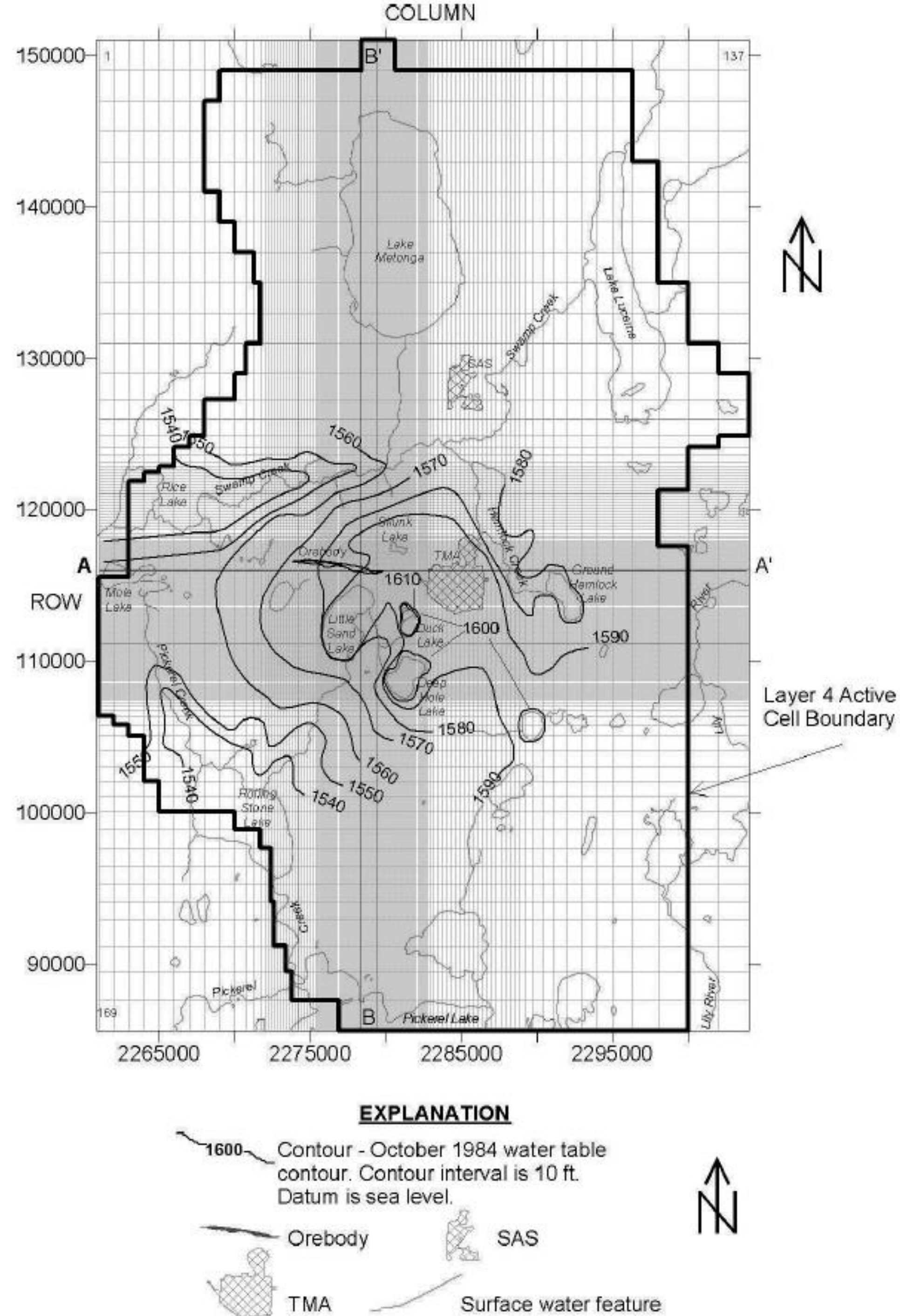
(comments from one team member)

(apologies to those I missed!)

The DNR review team constructed its own model using the USGS MODFLOW code.

This model was used to test many different mine scenarios and to identify data shortcomings.

In many cases the company agreed to collect additional data based on model results.



So what did we learn?

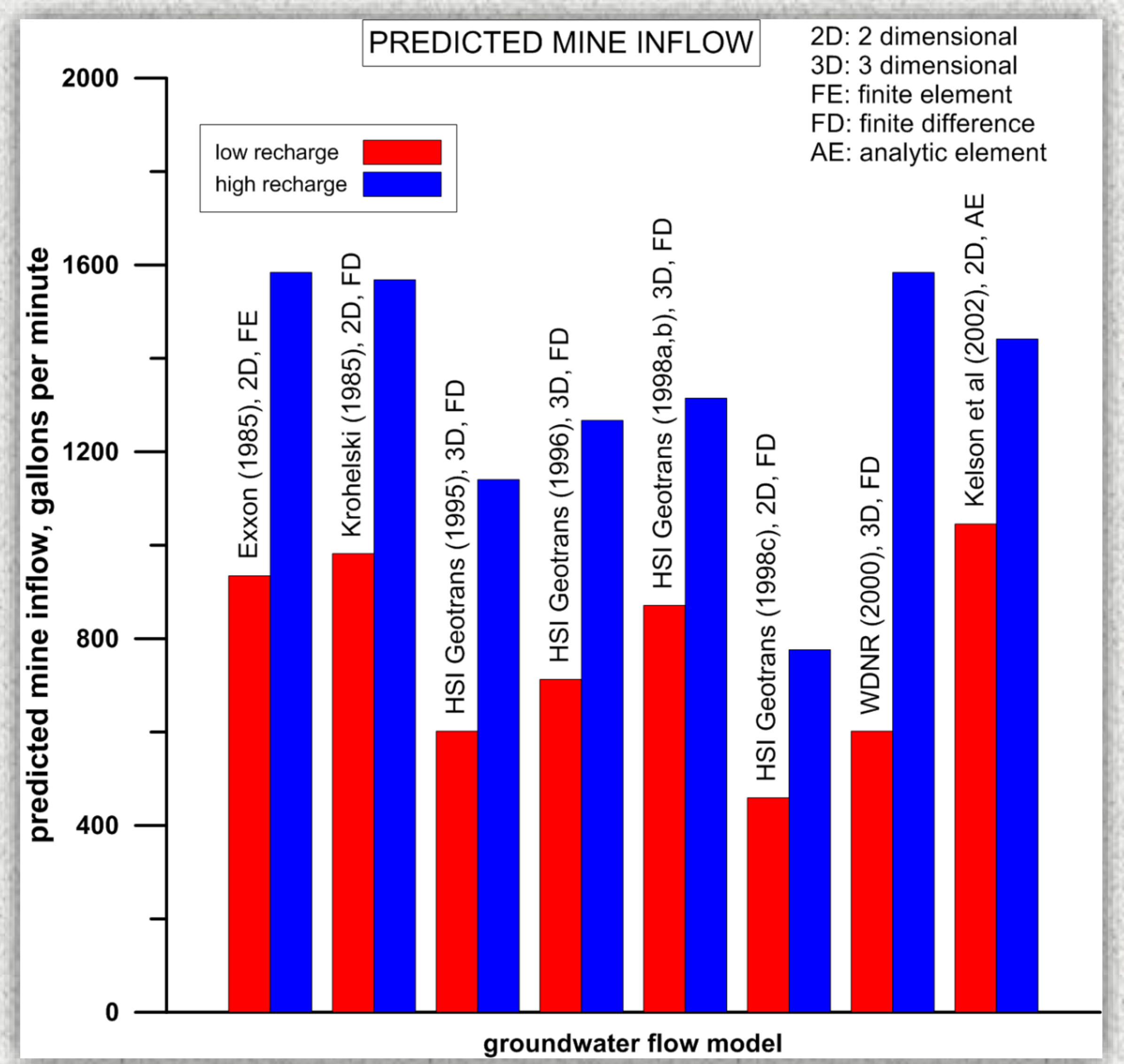
1. Models don't lie. And the most complex model isn't necessarily the best.

Crandon pumping test site.

Kelson, Hunt, and Haitjema (2002) compared the 8 (!) groundwater models built for the Crandon site:

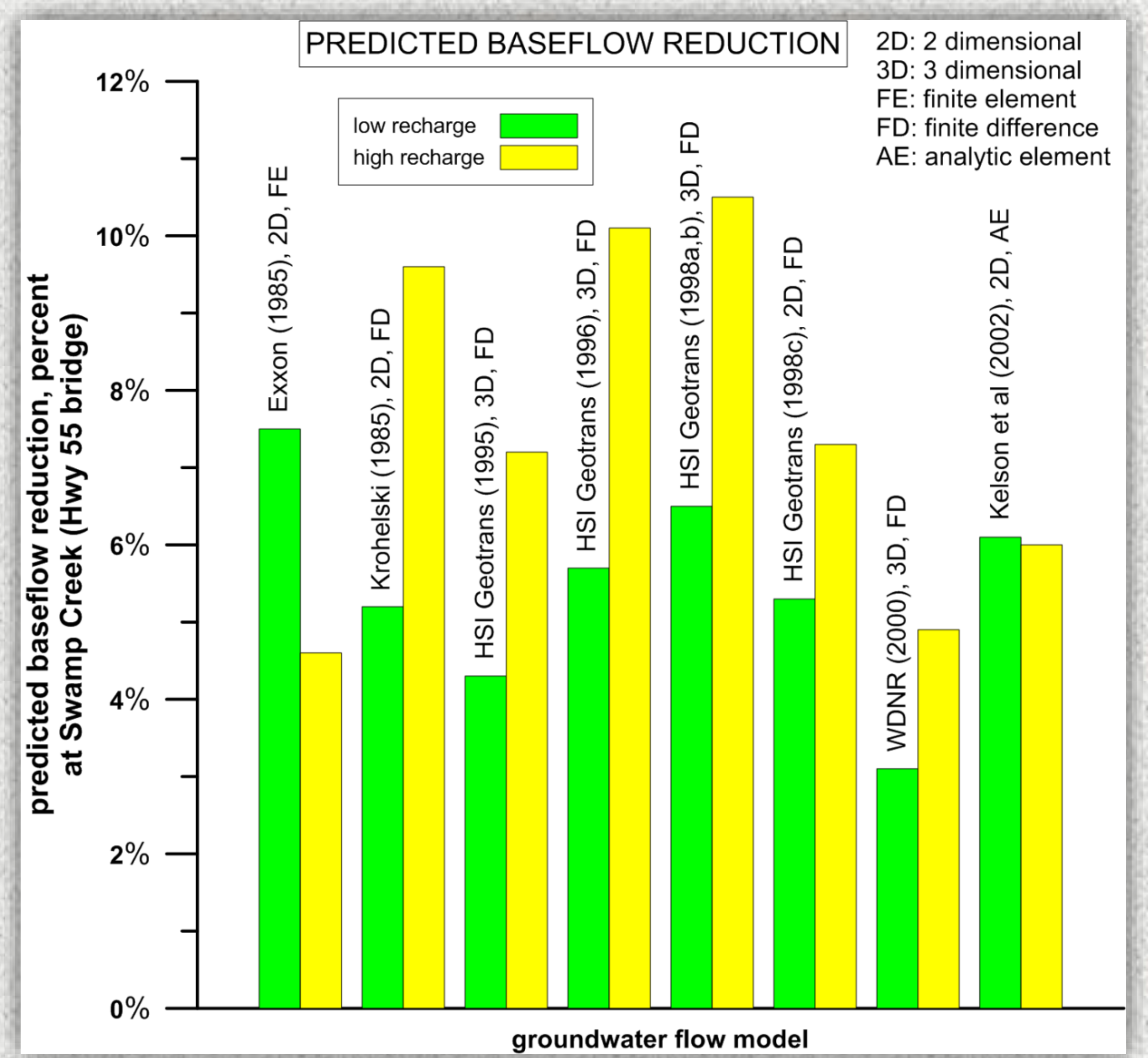
Note that the range of predicted mine inflow, over 8 different models, ranged from about 500 to 1600 gallons per minute.

For context many municipal wells are in the 1000 GPM range.



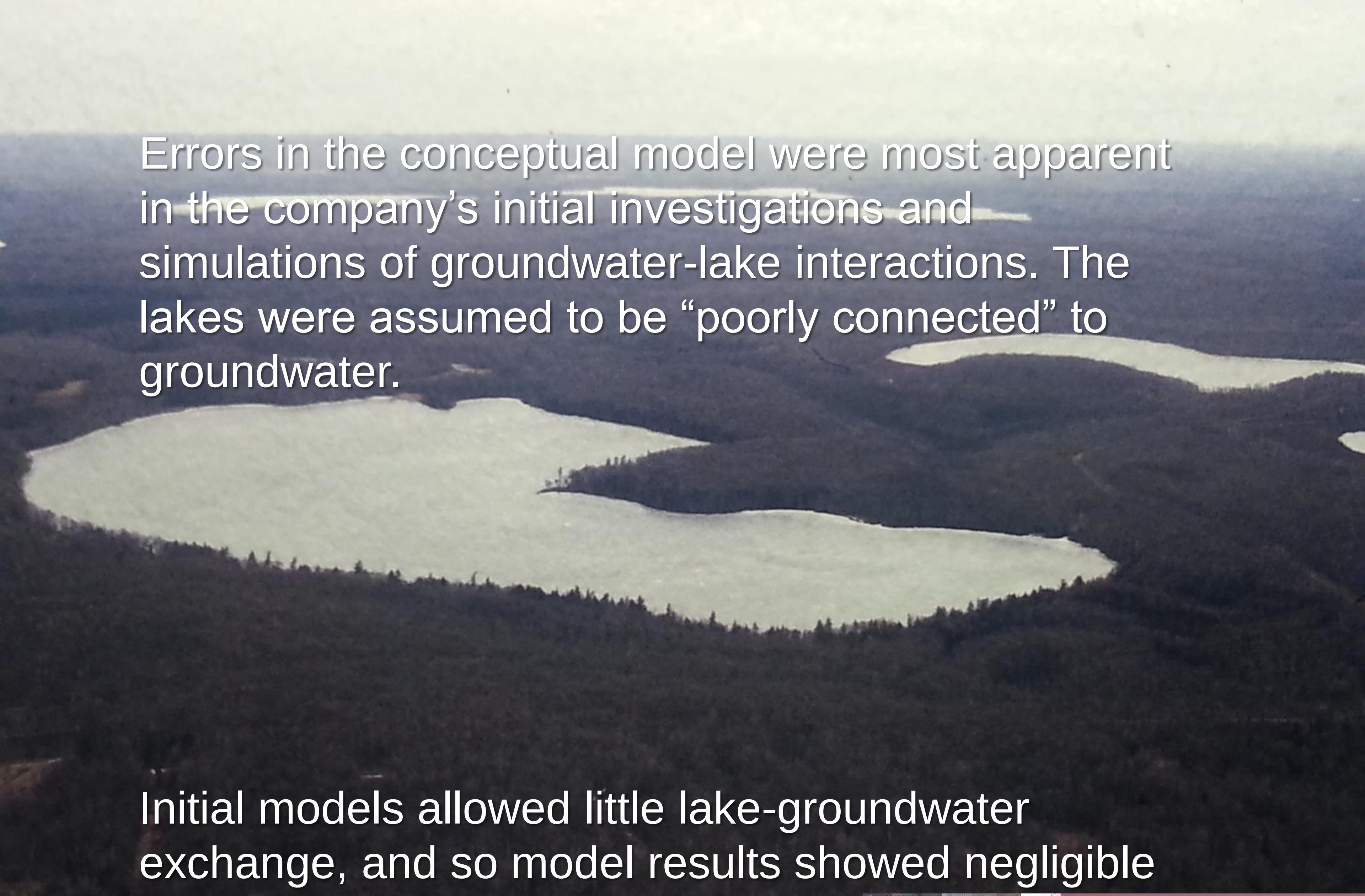
Kelson, Hunt, and Haitjema (2002) compared the 8 (!) groundwater models built for the Crandon site:

Predicted baseflow reduction ranged from about 3 to 11 percent at Swamp Creek.



So what did we learn?

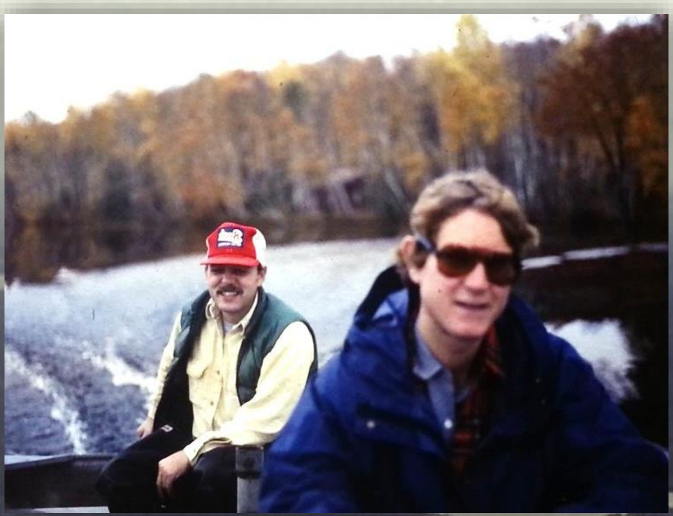
1. Models don’t lie. And the most complex model isn’t necessarily the best.
2. Developing an appropriate conceptual model is crucial.



Errors in the conceptual model were most apparent in the company’s initial investigations and simulations of groundwater-lake interactions. The lakes were assumed to be “poorly connected” to groundwater.

Initial models allowed little lake-groundwater exchange, and so model results showed negligible impacts on lakes.

Minipiezometer showing downward gradients



Searching for springs

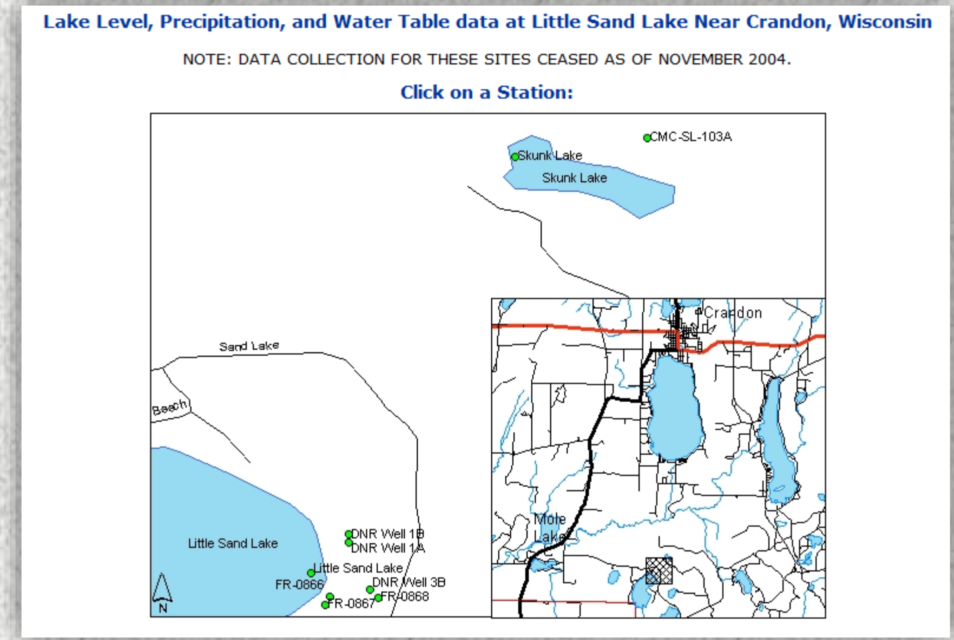
Little Sand Lake – immediately over orebody

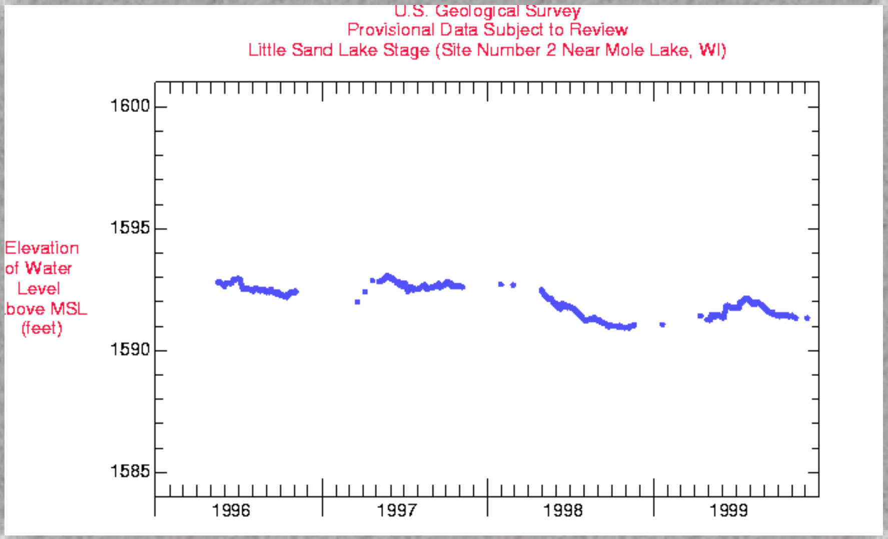
Was it connected to groundwater?

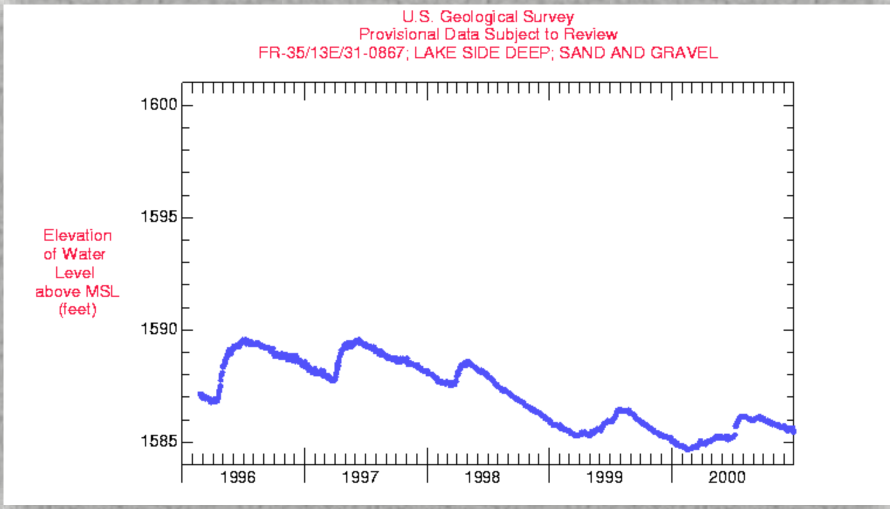
Piezometer installation through ice

So what did we learn?

1. Models don't lie. And the most complex model isn't necessarily the best.
2. Developing an appropriate conceptual model is crucial.
3. Monitoring and historical records, over many years and seasons, are <u>essential</u> for model development and calibration.



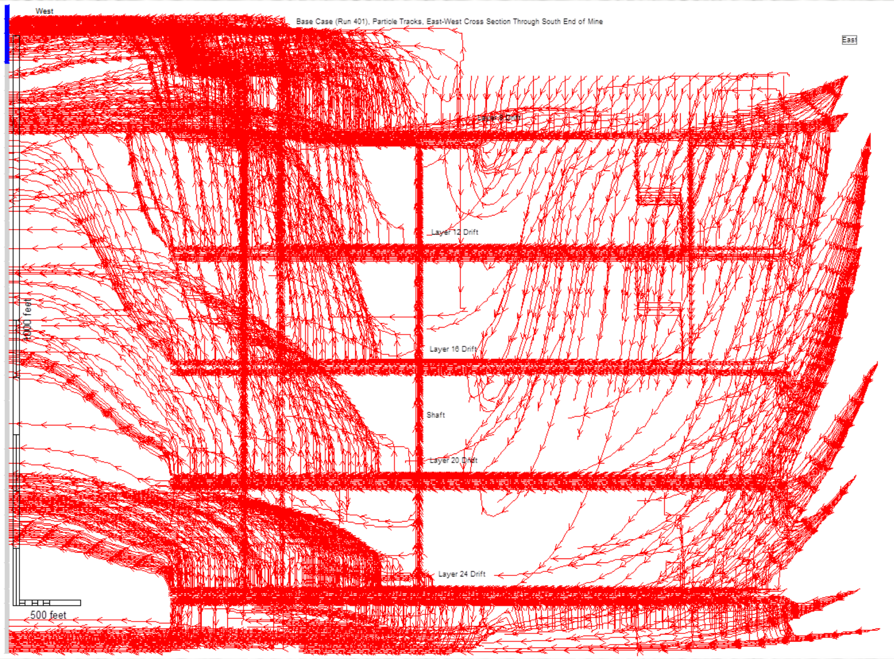




USGS observations near Little Sand Lake

So what did we learn?

1. Models don't lie. And the most complex model isn't necessarily the best.
2. Developing an appropriate conceptual model is crucial.
3. Monitoring and historical records, over many years and seasons, are <u>essential</u> for model development and calibration.
4. Contaminant transport simulations are usually very uncertain, but necessary for regulatory compliance.

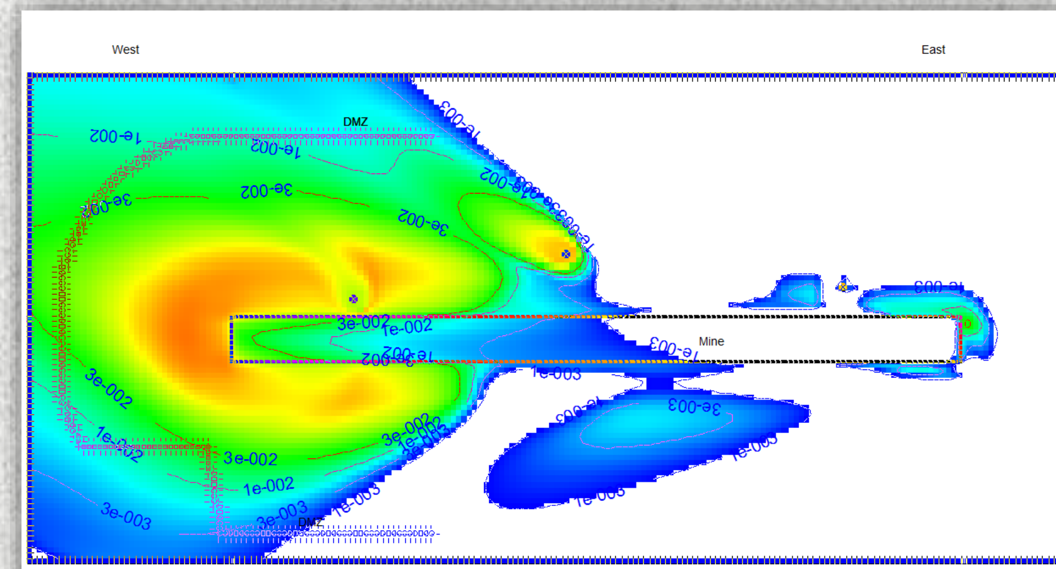


Regulations required a simulation of flow away from the reflooded mine far into the future. Such simulations are necessarily very uncertain.

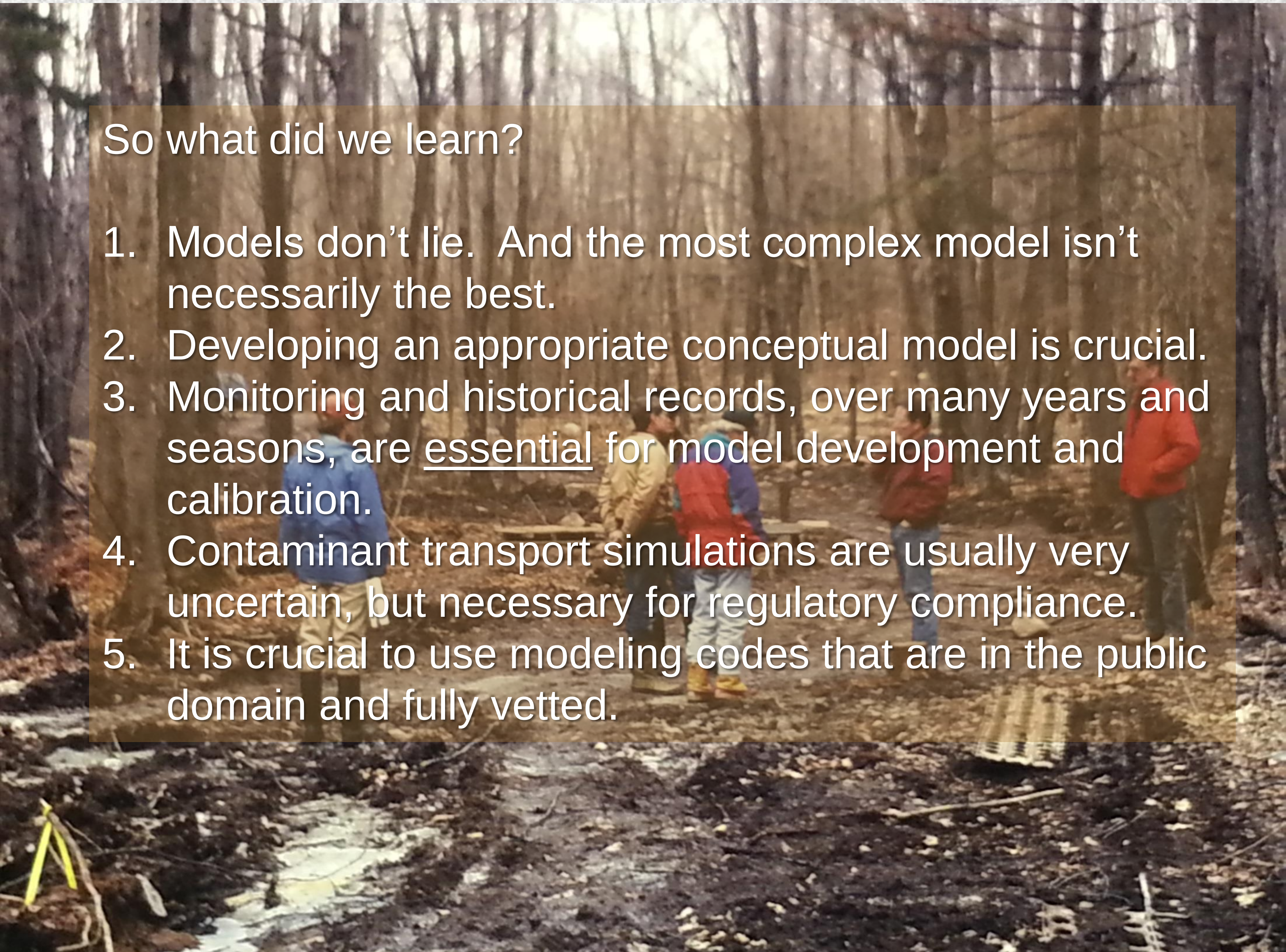
Profile view of flow paths around mine workings

Unknowns…

- exact mine layout
- exact rock properties for flow or transport
- How much grouting?
- How will mine be backfilled?
- Will tunnels collapse over time?
- Will the climate change?



Isoconcentrations in the bedrock around mine at 10,000 years

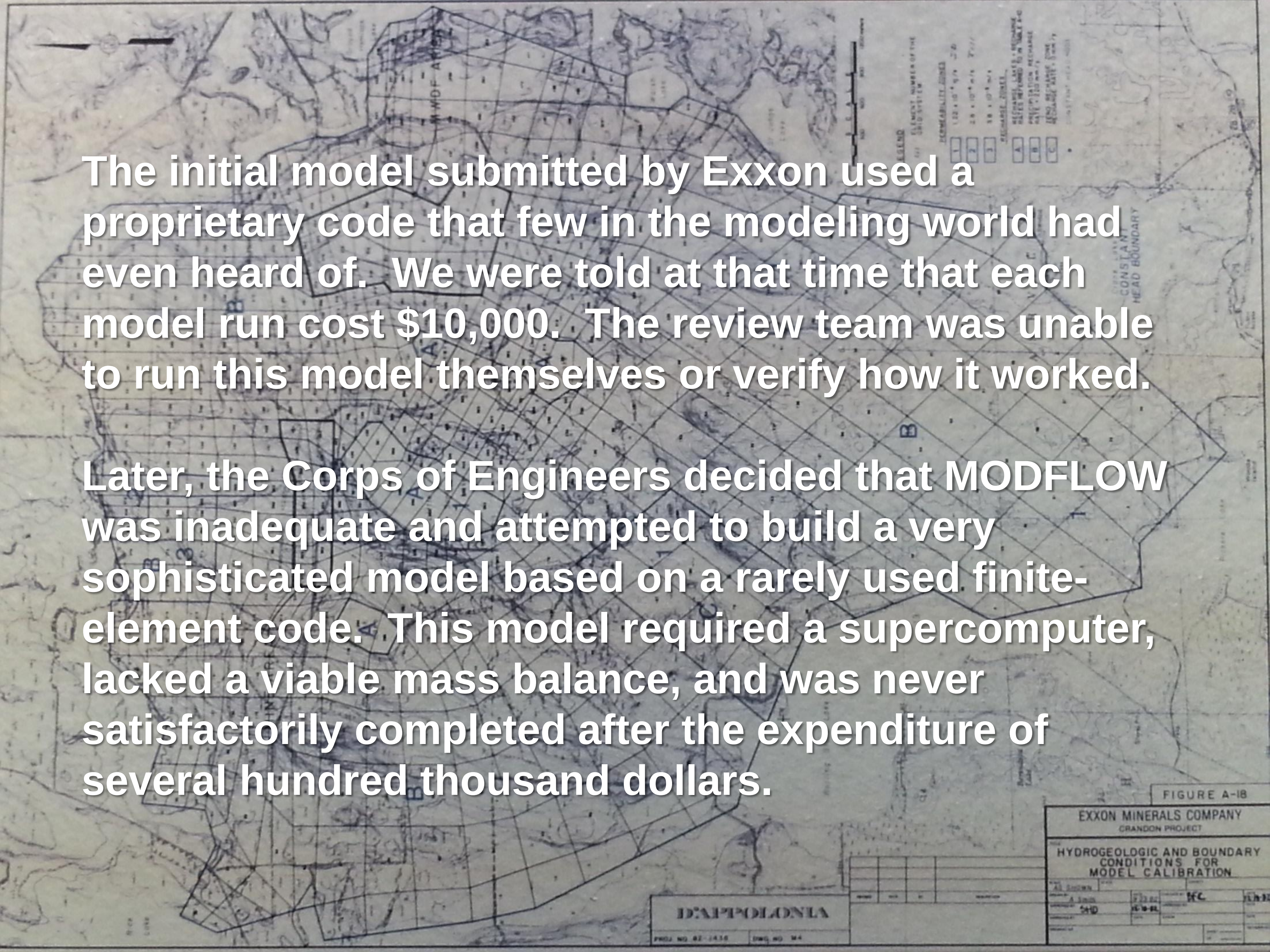


So what did we learn?

1. Models don’t lie. And the most complex model isn’t necessarily the best.
2. Developing an appropriate conceptual model is crucial.
3. Monitoring and historical records, over many years and seasons, are <u>essential</u> for model development and calibration.
4. Contaminant transport simulations are usually very uncertain, but necessary for regulatory compliance.
5. It is crucial to use modeling codes that are in the public domain and fully vetted.

The initial model submitted by Exxon used a proprietary code that few in the modeling world had even heard of. We were told at that time that each model run cost $10,000. The review team was unable to run this model themselves or verify how it worked.

Later, the Corps of Engineers decided that MODFLOW was inadequate and attempted to build a very sophisticated model based on a rarely used finite-element code. This model required a supercomputer, lacked a viable mass balance, and was never satisfactorily completed after the expenditure of several hundred thousand dollars.



The review team's work is summarized in a series of WGNHS open-file reports (available online):

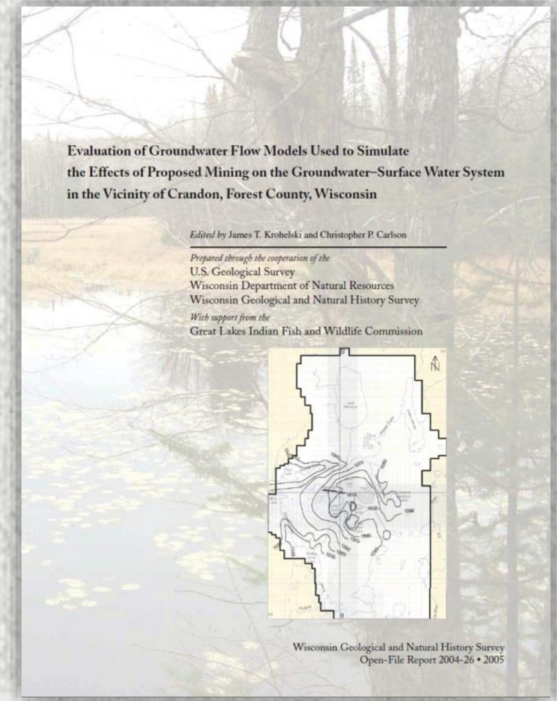
2004-02. Evaluation of the solute transport model developed for the proposed Crandon Mine tailings management area and reclaim pond.

2004-26. Evaluation of groundwater flow models used to simulate the effects of proposed mining on the groundwater–surface water system in the vicinity of Crandon, Forest County, Wisconsin.

2004-27. Source term review for the tailings management area and reclaim pond at the proposed Crandon Mine, Forest County, Wisconsin.

2004-28. Evaluation of the reflooded mine solute transport model developed for the proposed Crandon Mine, Forest County, Wisconsin.

2004-29. Reflooded mine source term technical memoranda for the proposed Crandon Mine, Forest County, Wisconsin.



Finally, why did the reviews take so long?

1. It was a complex project that changed a number of times, and each change required a thorough and painstaking review.

2. There was a perceived lack of urgency and deadlines from DNR.

3. At least initially, the companies sometimes failed to take the review team's concerns seriously.

4. The various companies and consultants were often less than fully responsive to requests for additional data or model simulations.