Effects of a carbonate-rock aquifer on a groundwater system

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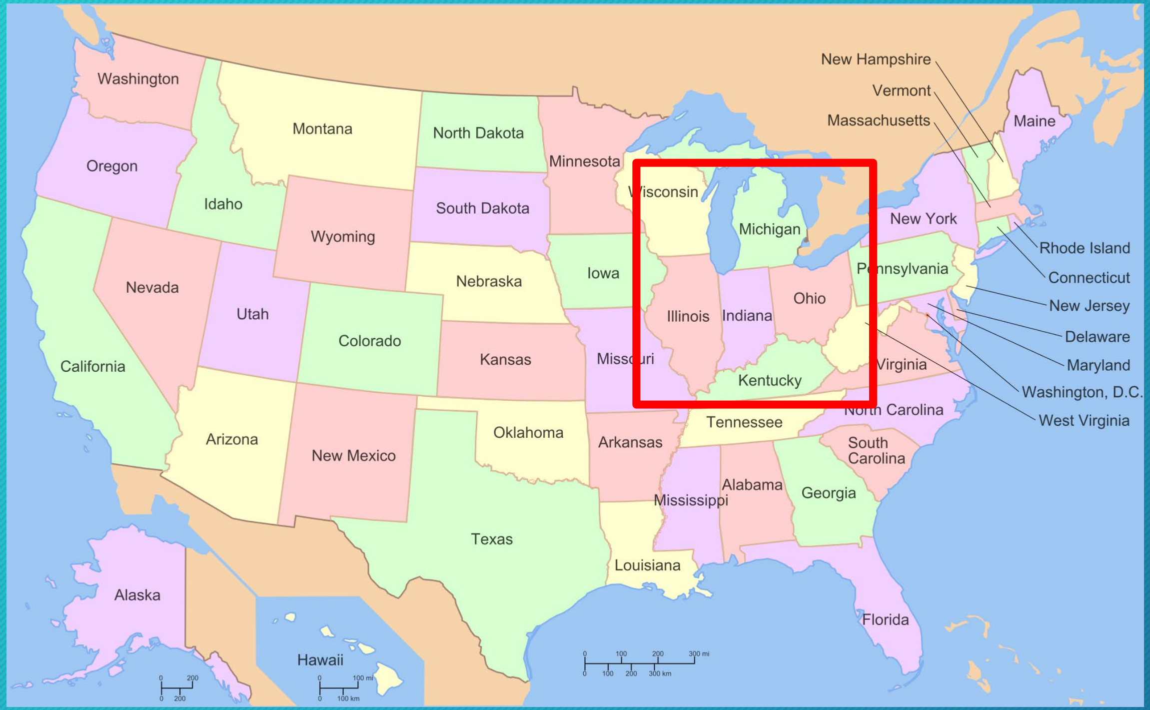
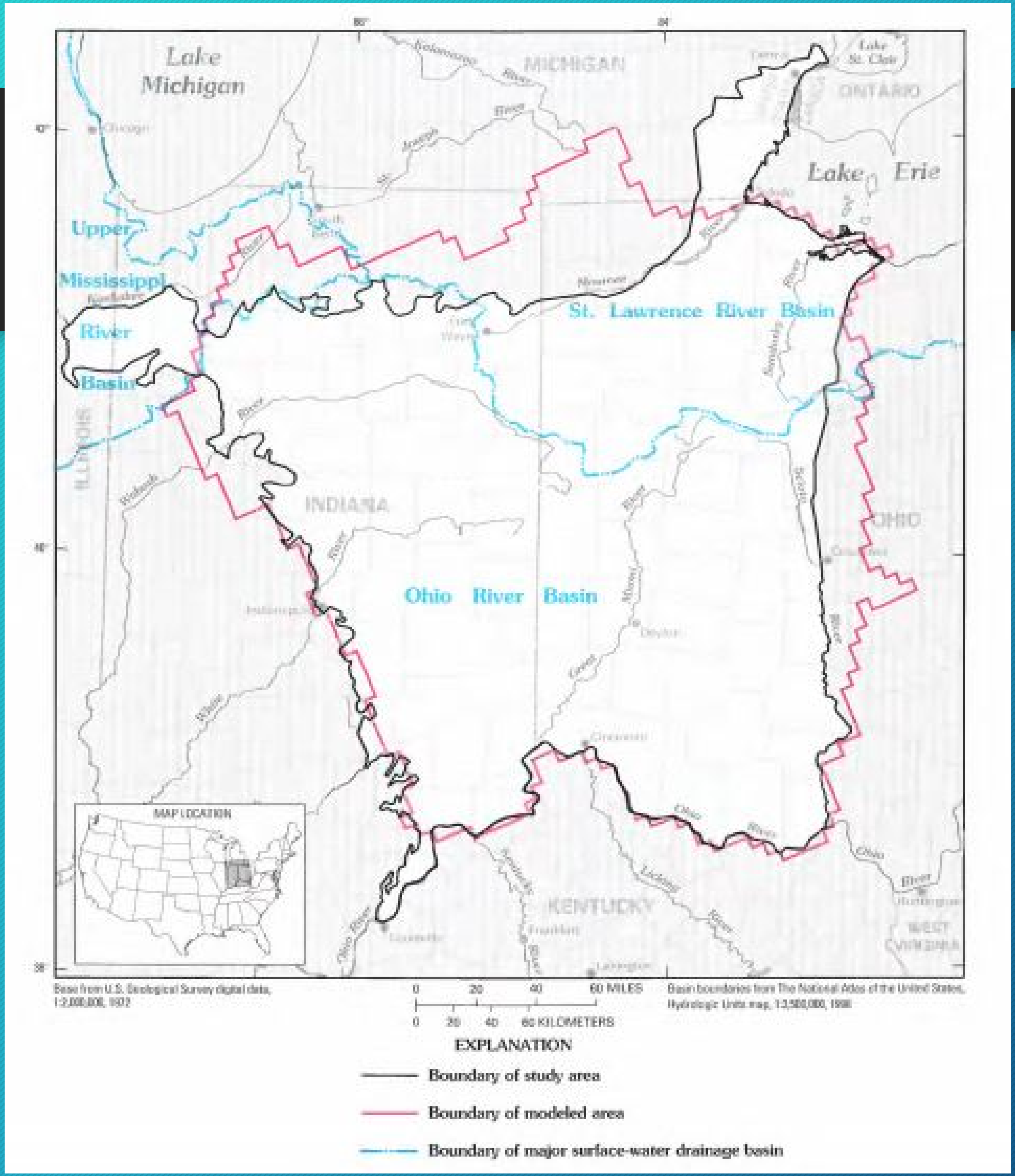
NDSU Geochemistry 2018

Location

- Midwestern Basins and Arches aquifer system
- Indiana, Ohio, Michigan, and Illinois




Lake Michigan
MICHIGAN
Lake St. Clair
ONTARIO
Lake Erie
Upper Mississippi River Basin
St. Lawrence River Basin
ILLINOIS
INDIANA
OHIO
Ohio River Basin
KENTUCKY
WEST VIRGINIA
MAP LOCATION
Base from U.S. Geological Survey digital data, 1:2,000,000, 1972
0 20 40 60 MILES
0 20 40 60 KILOMETERS
Basin boundaries from The National Atlas of the United States, Hydrologic Units map, 1:3,500,000, 1986
EXPLANATION
Boundary of study area
Boundary of modeled area
Boundary of major surface-water drainage basin

Background

- Land in this area is primarily temperate deciduous forest with some grasslands and savannah near Lake Michigan
- Less than 20% is being used as cropland
- This area is urbanized and industrialized
- Climate: Humid Continental, moderate climate
- Average Precipitation: Moderate to high, depending on snow fall amounts
- Aquifers used for irrigation and residential use
  - 15% groundwater drawn up in this area is from the carbonate-rock aquifer

Why I Choose This Topic

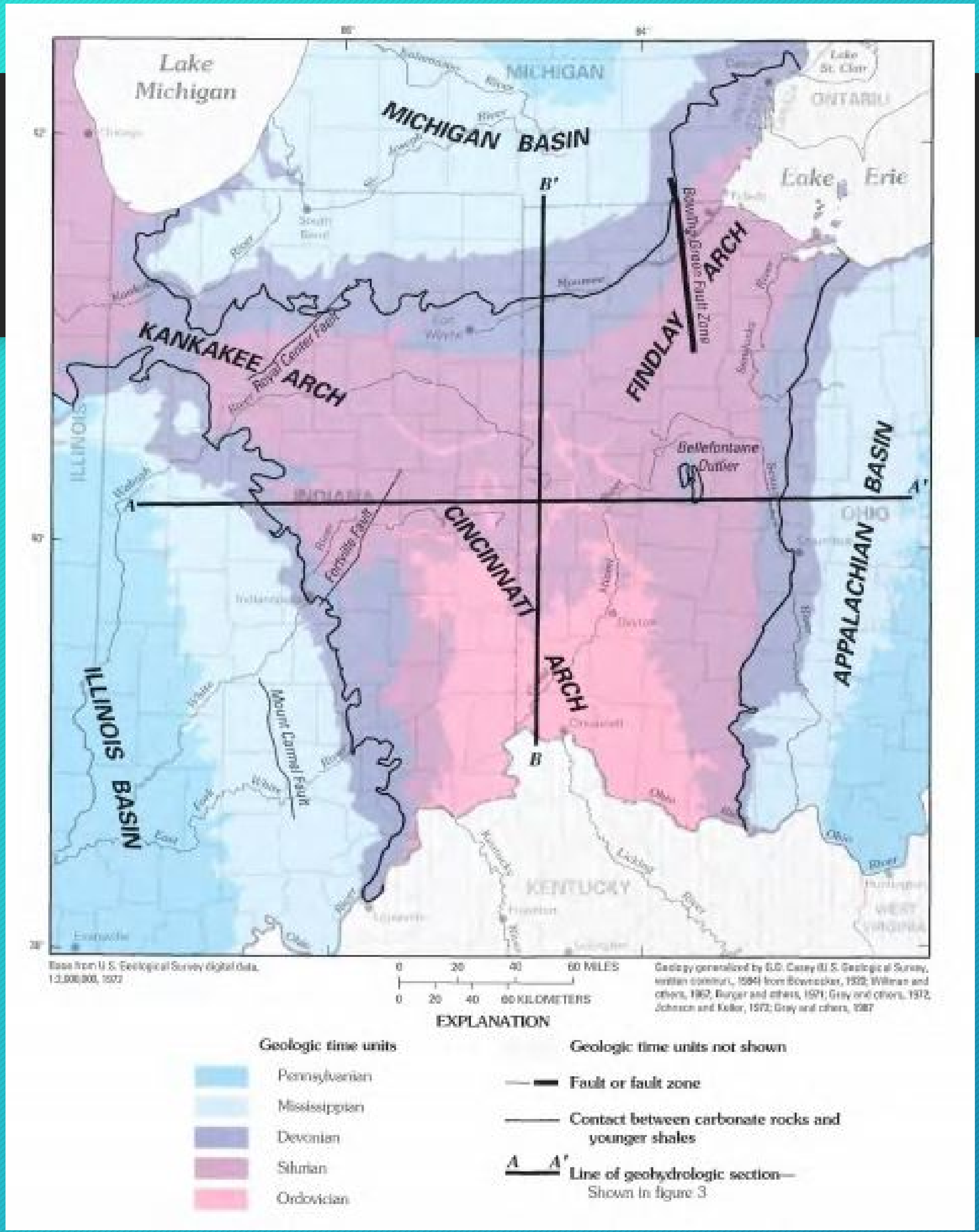
- Interested in carbonates and their relationship to the environment
- Previous work with carbonates
- In an area located nearby

Source of data

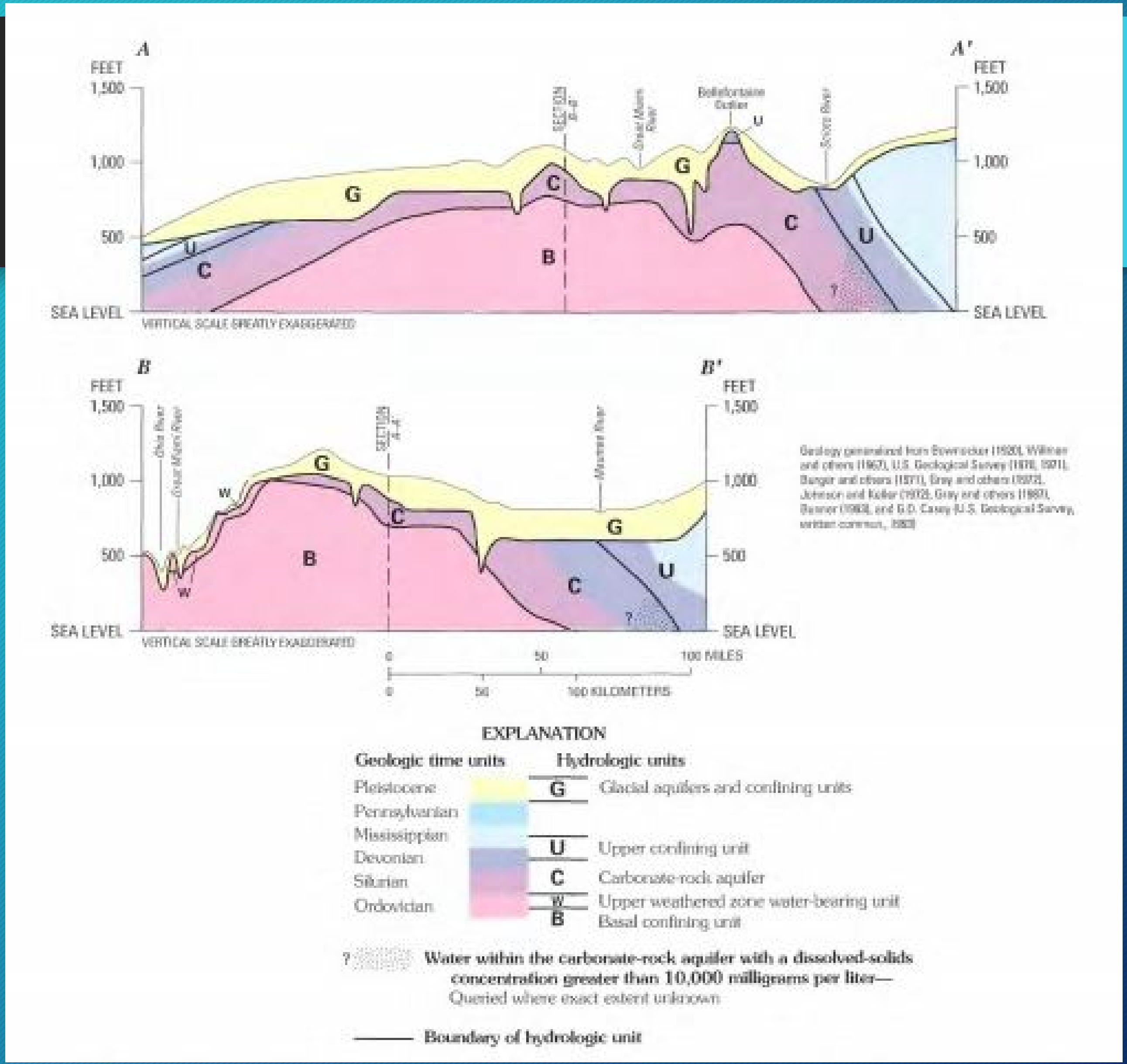
- Samples taken from 1,300 groundwater wells in study location
  - Carbonate-rock aquifers and glacial aquifers
- Detailed analysis done on each sample
- Samples were taken from both domestic and test wells
- Samples were taken at deepest available points in each well

Surrounding Geology

- The Midwestern Basins and Arches aquifer system lies between the Appalachian, the Illinois, and the Michigan Basins.
- Bedrock units range in age from Ordovician to Lower Mississippian
- Ordovician units are predominately shales with interbedded limestone
- Carbonate bedrock in Silurian and Devonian in age
- Mississippian ages shale overlies carbonate rock outside of study area but has been eroded away within this system
- The ground surface is covered with Quaternary aged glacial deposits



Lake Michigan
MICHIGAN
MICHIGAN BASIN
Lake St. Clair
ONTARIO
Lake Erie
Bowling Green Fault Zone
FINDLAY ARCH
KANKAKEE ARCH
Royal Center Fault
Fort Wayne
Maumee
Bellefontaine Outlier
APPALACHIAN BASIN
OHIO
INDIANA
ILLINOIS
CINCINNATI ARCH
Fortville Fault
Indianapolis
Dayton
Cincinnati
Mount Carmel Fault
ILLINOIS BASIN
KENTUCKY
WEST VIRGINIA
Ohio River
White
Wabash
A
A′
B
B′
0 20 40 60 MILES
0 20 40 60 KILOMETERS
EXPLANATION
Geologic time units
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Geologic time units not shown
Fault or fault zone
Contact between carbonate rocks and younger shales
A — A′ Line of geohydrologic section— Shown in figure 3



A
A′
FEET
1,500
1,000
500
SEA LEVEL
VERTICAL SCALE GREATLY EXAGGERATED
Bellefontaine Outlier
G
C
U
B
B
B′
G
W
C
U
B
0 50 100 MILES
0 50 100 KILOMETERS
EXPLANATION
Geologic time units
Hydrologic units
Pleistocene
G Glacial aquifers and confining units
Pennsylvanian
Mississippian
U Upper confining unit
Devonian
C Carbonate-rock aquifer
Silurian
W Upper weathered zone water-bearing unit
Ordovician
B Basal confining unit
? Water within the carbonate-rock aquifer with a dissolved-solids concentration greater than 10,000 milligrams per liter— Queried where exact extent unknown
Boundary of hydrologic unit

Previous work

- Describe physical and hydraulic boundaries of this aquifer system
- Identify relationships between surface and groundwater
- Develop a model to compute a regional ground water budget
- Identify groundwater chemistry in relations to flow

Inverse Modeling of effect of pCO2

- Use PHREEQC to model variations in dolomite concentrations by modifying pCO2
- Used 2 deep carbonate-rock wells
  - One well with bedrock near the surface
  - One well with bedrock far below the surface
- Using inverse modeling
  - Test with pCO2 at average atmosphere level: -3.5
  - Test with average pCO2 in aquifers: -4.8

$$CaCO_3 + H_2O + CO_2 <\text{-->} Ca^{2+} + 2HCO_3^-$$

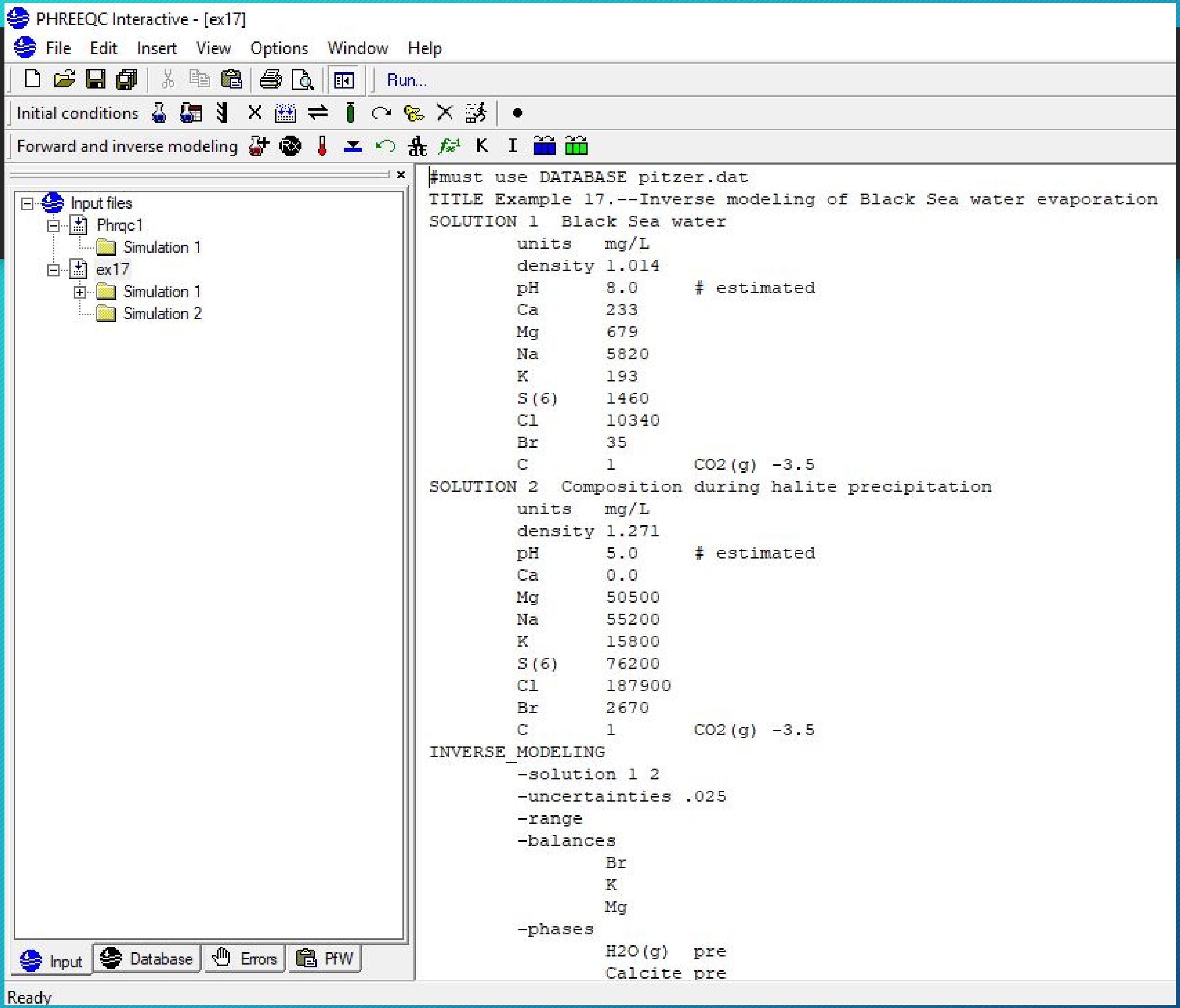
(calcite)

$$CaMg(CO_3)_2 + 2H_2O + 2CO_2 <\text{-->} Ca^{2+} + Mg^{2+} + 4HCO_3^-$$

(dolomite)

- Choose two carbonate rock aquifer wells to test
- Located in North-Eastern section of Midwestern Basins and Arches aquifer system
- Within the Maurmee River Basin
- Well #1: Augustine
- Well #2: City of Weston

Well name	Map number	Well depth (ft)	Depth to bedrock (ft)	Depth to top of open interval (ft)	Depth to bottom of open interval (ft)	Length of open interval (ft)	Aquifer
Ross	10 G	102	--	N.A.	N.A.	N.A.	G
Birt	10 S	86	76	80	86	6	C-R
Ben Logan H.S.	10 D	340	97	160	340	[a]180	C-R
Searfoss	15 G	60	--	N.A.	N.A.	N.A.	G
Rife	15 S	39	34	34	39	5	C-R
Schoenberger	15 D	240	33	36	240	205	C-R
Beasley	16 G	81	--	61	81	20	G
Hill	16 S	80	52	63	80	17	C-R
Gillig	16 D	310	45	55	310	255	C-R
Lamalie	17 G	75	--	71	75	4	G
S-18	17 D	340	70	180	340	[b]160	C-R
Finnegan	18 D	185	2	26	185	159	C-R
Wilson	11 G	50	--	N.A.	N.A.	N.A.	G
Spencer	11 S	43	16	22	43	21	C-R
Stair	11 D	250	18	21	250	229	C-R
Francis	12 S	62	40	43	62	20	C-R
Augustine	12 D	320	6	9	320	311	C-R
Richard	13 G	81	--	N.A.	N.A.	N.A.	G
Kern	13 S	102	73	75	102	27	C-R
Auckerman	13 D	400	78	109	400	[c]291	C-R
Rice	14 S	35	32	32	35	3	C-R
City of Weston	14 D	500	65	410	500	[d]90	C-R
Hartman	19	144	114	114	144	30	C-R
Lacy	4 G	67	--	64	67	3	G
Hummel	4 S	121	88	90	121	31	C-R
Jones	4 D	201	119	122	201	79	C-R
Harrison	3 S	117	108	108	117	9	C-R
Martin	3 D	200	135	138	200	62	C-R
Lockhart	2 G	140	--	136	140	4	G
Mattingly	2 S	150	140	140	150	10	C-R
Merchant	2 D	310	170	170	310	140	C-R
Gates	1 D	320	88	88	320	[e]232	C-R
Bickford	5 G	45	--	41	45	4	G
Bartlett	5 S	106	74	74	106	32	C-R
Desoto Substation	5 D	265	88	91	265	174	C-R
Staggs	6 G	116	--	113	116	3	G
Ice	6 S	110	92	92	110	18	C-R
Underwood	6 D	302	161	162	302	140	C-R
Cohee	7 G	99	--	84	89	5	G
Ellis	7 S	102	49	55	102	47	C-R
Harmon	7 D	293	51	53	293	240	C-R
Fox	8 G	89	--	84	89	5	G
Skiles	8 D	202	63	64	202	138	C-R
Justice	9 G	62	--	59	62	3	G
Lee	9 S	113	65	67	113	46	C-R
Starbuck	9 D	182	76	79	182	103	C-R
Geradot	22	260	72	70	260	190	G, C-R
Stenzel	21	260	170	170	260	90	C-R
Rees	20	230	160	160	230	70	C-R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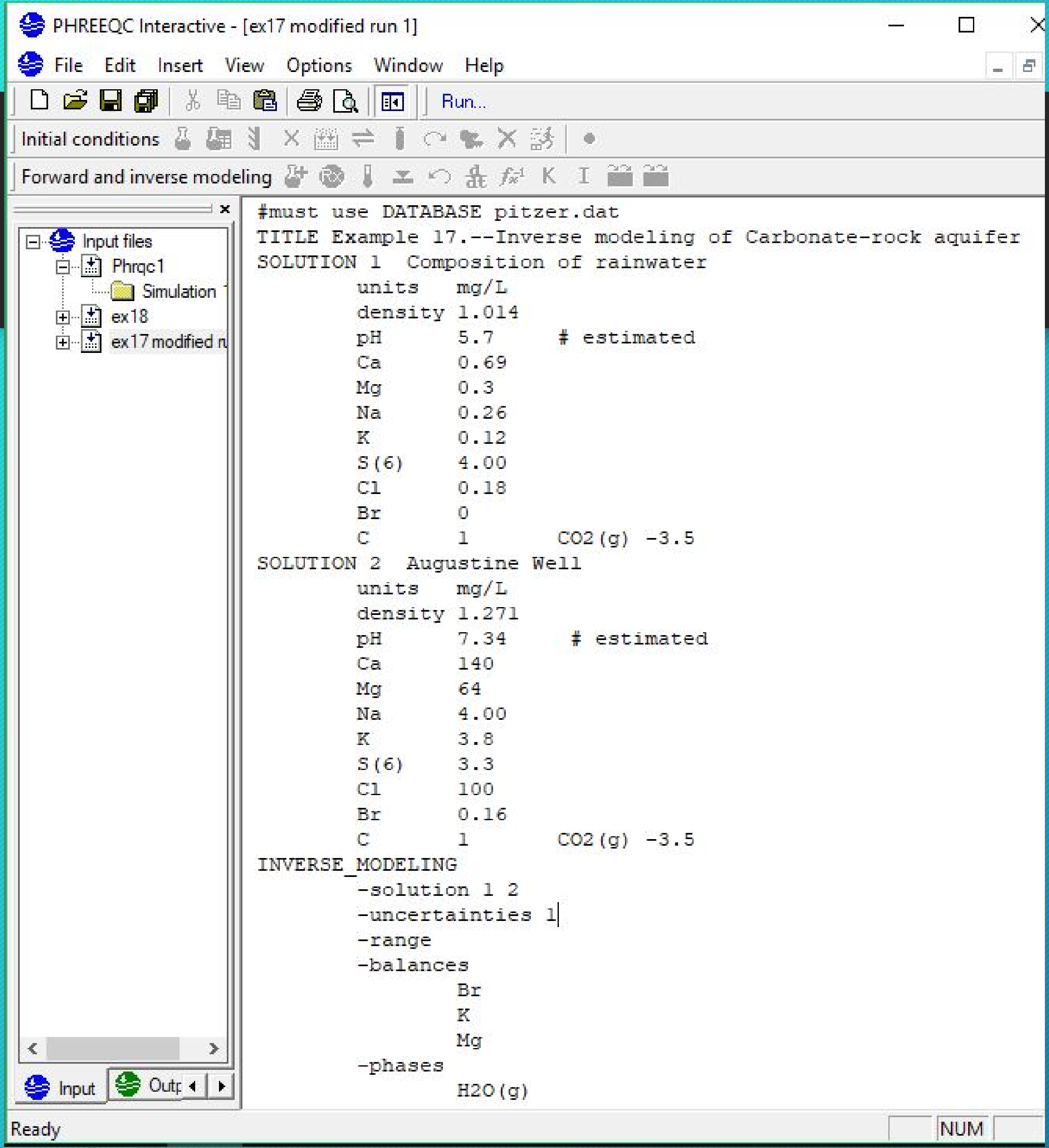
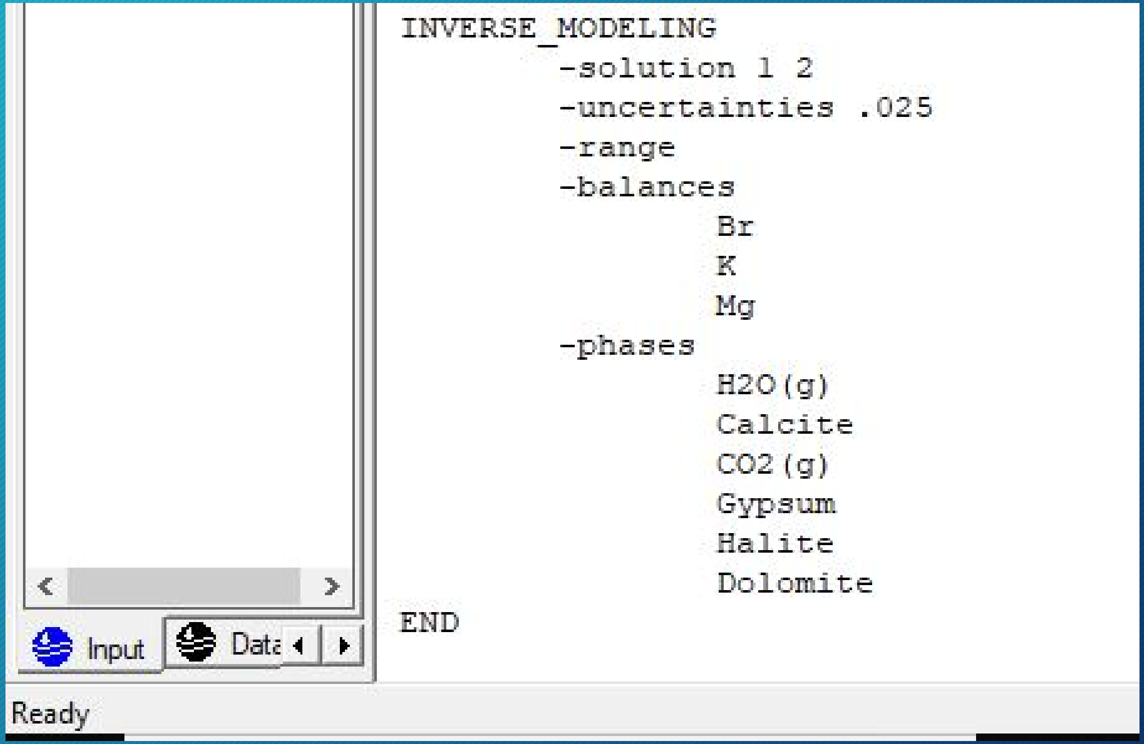
Run...
Initial conditions
Forward and inverse modeling
Input files
Phrqc1
Simulation 1
ex17
Simulation 1
Simulation 2
#must use DATABASE pitzer.dat
TITLE Example 17.--Inverse modeling of Black Sea water evaporation
SOLUTION 1 Black Sea water
units   mg/L
density 1.014
pH   8.0   # estimated
Ca   233
Mg   679
Na   5820
K   193
S(6)   1460
Cl   10340
Br   35
C   1   CO2(g) -3.5
SOLUTION 2 Composition during halite precipitation
units   mg/L
density 1.271
pH   5.0   # estimated
Ca   0.0
Mg   50500
Na   55200
K   15800
S(6)   76200
Cl   187900
Br   2670
C   1   CO2(g) -3.5
INVERSE_MODELING
-solution 1 2
-uncertainties .025
-range
-balances
Br
K
Mg
-phases
H2O(g) pre
Calcite pre
Input
Database
Errors
PfW
Ready


PHREEQC Interactive - [ex17 modified run 1]
File Edit Insert View Options Window Help
Run...
Initial conditions
Forward and inverse modeling
Input files
Phrqc1
Simulation
ex18
ex17 modified r
Input
Outp
Ready
NUM
#must use DATABASE pitzer.dat
TITLE Example 17.--Inverse modeling of Carbonate-rock aquifer
SOLUTION 1 Composition of rainwater
units mg/L
density 1.014
pH 5.7 # estimated
Ca 0.69
Mg 0.3
Na 0.26
K 0.12
S(6) 4.00
Cl 0.18
Br 0
C 1 CO2(g) -3.5
SOLUTION 2 Augustine Well
units mg/L
density 1.271
pH 7.34 # estimated
Ca 140
Mg 64
Na 4.00
K 3.8
S(6) 3.3
Cl 100
Br 0.16
C 1 CO2(g) -3.5
INVERSE_MODELING
-solution 1 2
-uncertainties 1
-range
-balances
Br
K
Mg
-phases
H2O(g)


INVERSE_MODELING
-solution 1 2
-uncertainties .025
-range
-balances
Br
K
Mg
-phases
H2O(g)
Calcite
CO2(g)
Gypsum
Halite
Dolomite
END
Input
Data
Ready

Results- wells at average pCO2 (-3.5)

- Augustine Well
  - 65 Models found with uncertainty at 1

Phase mole transfers:		Minimum	Maximum	
H2O(g)	5.551e+01	5.551e+01	5.551e+01	H2O
Calcite	-1.152e-04	-2.304e-04	1.223e-04	CaCO3
CO2(g)	7.091e-05	-1.223e-04	2.641e-04	CO2
Gypsum	2.703e-05	0.000e+00	5.407e-05	CaSO4:2H2O
Halite	1.369e-04	0.000e+00	2.739e-04	NaCl
Dolomite	8.816e-05	0.000e+00	1.763e-04	CaMg(CO3)2

- City of Weston Well
  - 65 Models found with uncertainty at 1

Phase mole transfers:		Minimum	Maximum	
H2O(g)	5.551e+01	5.551e+01	5.551e+01	H2O
Calcite	-1.780e-04	-3.560e-04	1.134e-04	CaCO3
CO2(g)	6.598e-05	-1.134e-04	2.454e-04	CO2
Gypsum	6.065e-05	0.000e+00	1.213e-04	CaSO4:2H2O
Dolomite	1.174e-04	0.000e+00	2.347e-04	CaMg(CO3)2

"+" dissolving
"-" precipitating

Results- Wells at average aquifer pCO2 (-4.8)

- Augustine Well
  - 65 Models found with uncertainty at 1

Phase mole transfers:		Minimum	Maximum	
H2O(g)	5.551e+01	5.551e+01	5.551e+01	H2O
Calcite	-5.729e-05	-1.146e-04	6.435e-06	CaCO3
CO2(g)	3.399e-06	-6.435e-06	1.323e-05	CO2
Gypsum	2.703e-05	0.000e+00	5.407e-05	CaSO4:2H2O
Halite	1.369e-04	0.000e+00	2.739e-04	NaCl
Dolomite	3.025e-05	0.000e+00	6.050e-05	CaMg(CO3)2

- City of Weston Well
  - 65 Models found with uncertainty at 1

Phase mole transfers:		Minimum	Maximum	
H2O(g)	5.551e+01	5.551e+01	5.551e+01	H2O
Calcite	-1.243e-04	-2.487e-04	6.066e-06	CaCO3
CO2(g)	3.116e-06	-6.066e-06	1.230e-05	CO2
Gypsum	6.065e-05	0.000e+00	1.213e-04	CaSO4:2H2O
Halite	9.993e-04	0.000e+00	1.999e-03	NaCl
Dolomite	6.368e-05	0.000e+00	1.274e-04	CaMg(CO3)2

"+" dissolving
"-" precipitating

City of Weston Well Results

- At pCO2 = -3.5

Phase mole transfers:		Minimum	Maximum	
H2O(g)	5.551e+01	5.551e+01	5.551e+01	H2O
Calcite	-1.780e-04	-3.560e-04	1.134e-04	CaCO3
CO2(g)	6.598e-05	-1.134e-04	2.454e-04	CO2
Gypsum	6.065e-05	0.000e+00	1.213e-04	CaSO4:2H2O
Dolomite	1.174e-04	0.000e+00	2.347e-04	CaMg(CO3)2

- At pCO2 = -4.8

Phase mole transfers:		Minimum	Maximum	
H2O(g)	5.551e+01	5.551e+01	5.551e+01	H2O
Calcite	-1.243e-04	-2.487e-04	6.066e-06	CaCO3
CO2(g)	3.116e-06	-6.066e-06	1.230e-05	CO2
Gypsum	6.065e-05	0.000e+00	1.213e-04	CaSO4:2H2O
Halite	9.993e-04	0.000e+00	1.999e-03	NaCl
Dolomite	6.368e-05	0.000e+00	1.274e-04	CaMg(CO3)2

Conclusions

- Every test showed precipitation of Calcite
  - Greater at a higher pCO2
  - Greater at City of Weston Well → deeper bedrock
- Every test showed dissolution of Dolomite
  - Greater dissolution at higher pCO2
  - Greater at City of Weston Well

$$CaCO_3 + H_2O + CO_2 \longleftrightarrow Ca^{2+} + 2HCO_3^-$$

(calcite)

$$CaMg(CO_3)_2 + 2H_2O + 2CO_2 \longleftrightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$$

(dolomite)

Questions

References

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