An integrated approach to assessing public supply well vulnerability in fractured siliciclastic aquifer systems

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URBAN WELL VULNERABILITY

- Siliciclastic aquifer systems
  - Preferential flow pathways
  - Deep, confined aquifers
- Wastewater contamination
  - Leaking sewers
  - Virus and chemistry
- Role of well pumping

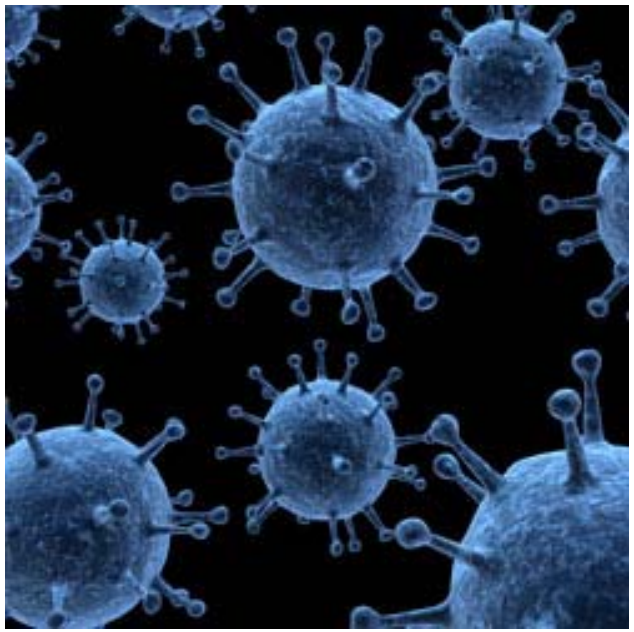
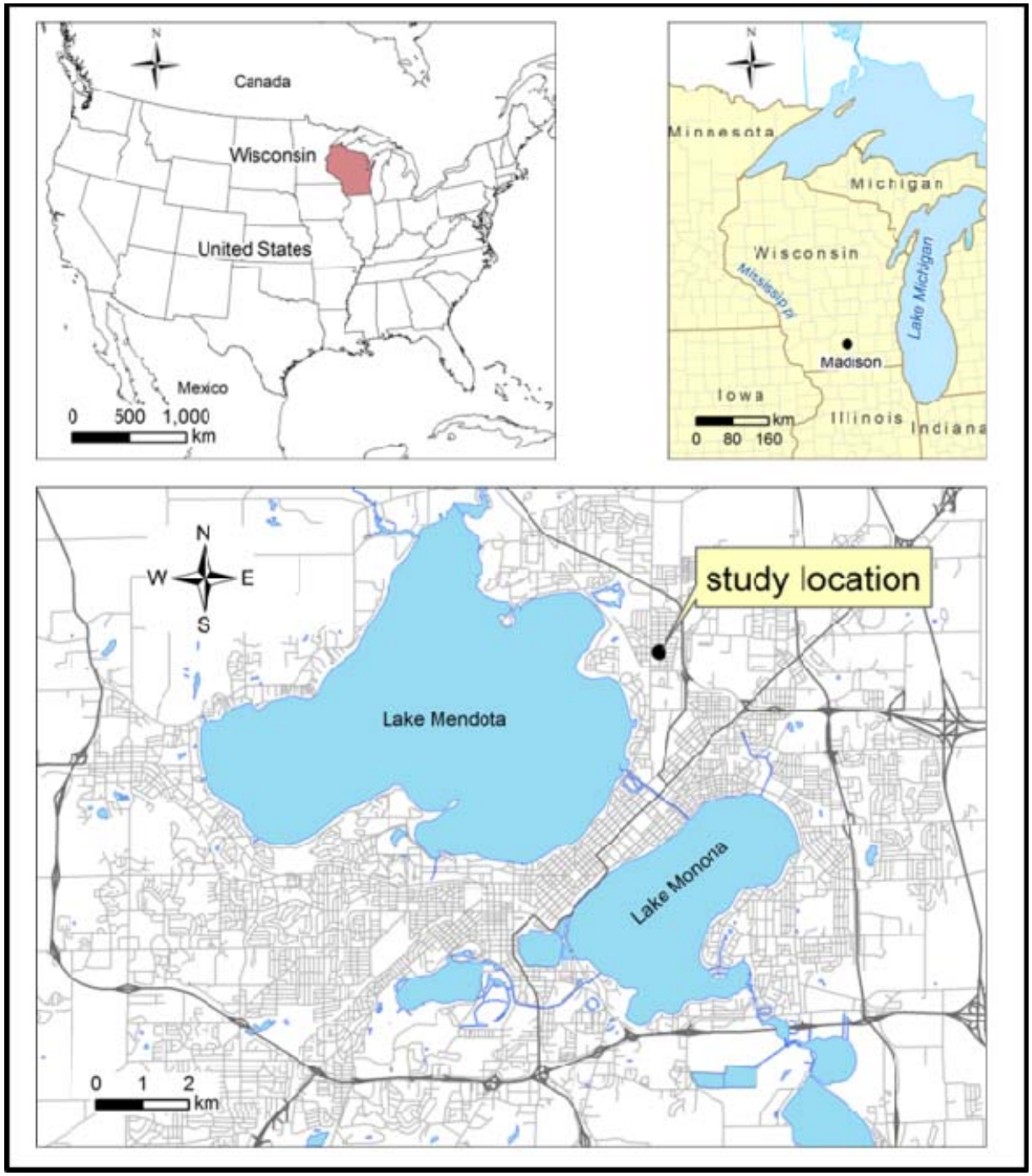


Image: http://www.epa.gov/microbes/research/waterbourneviruses.html

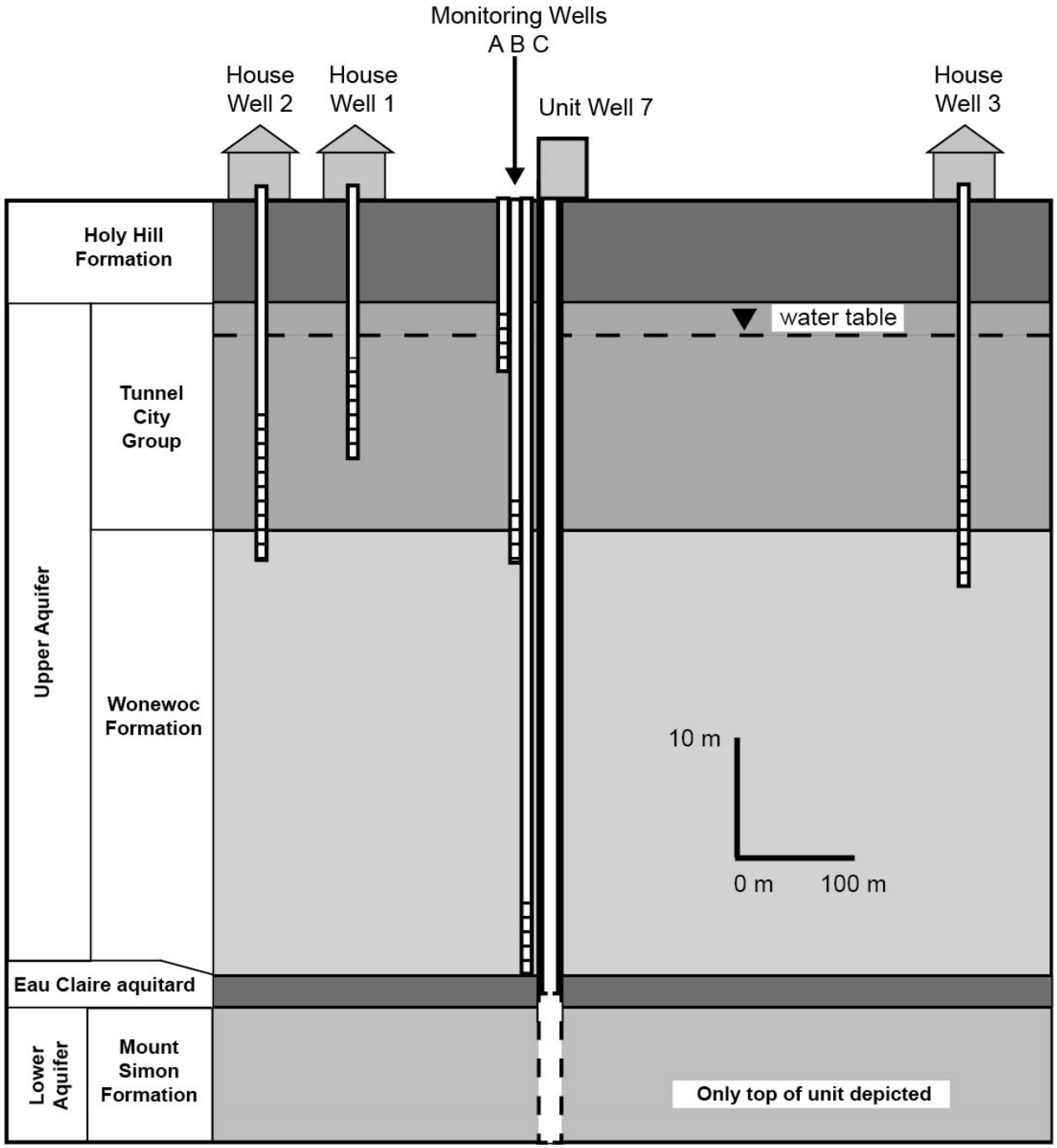
Field Site:
Madison
Unit Well 7

- Constructed in 1939
- Viruses detected in earlier studies
- Cased through aquitard
- Leaky sewers



Madison Unit Well 7

- Multi-aquifer system
- MWs and house wells
- Methods
  - Water levels
  - Logging
  - Chemistry
  - Viruses

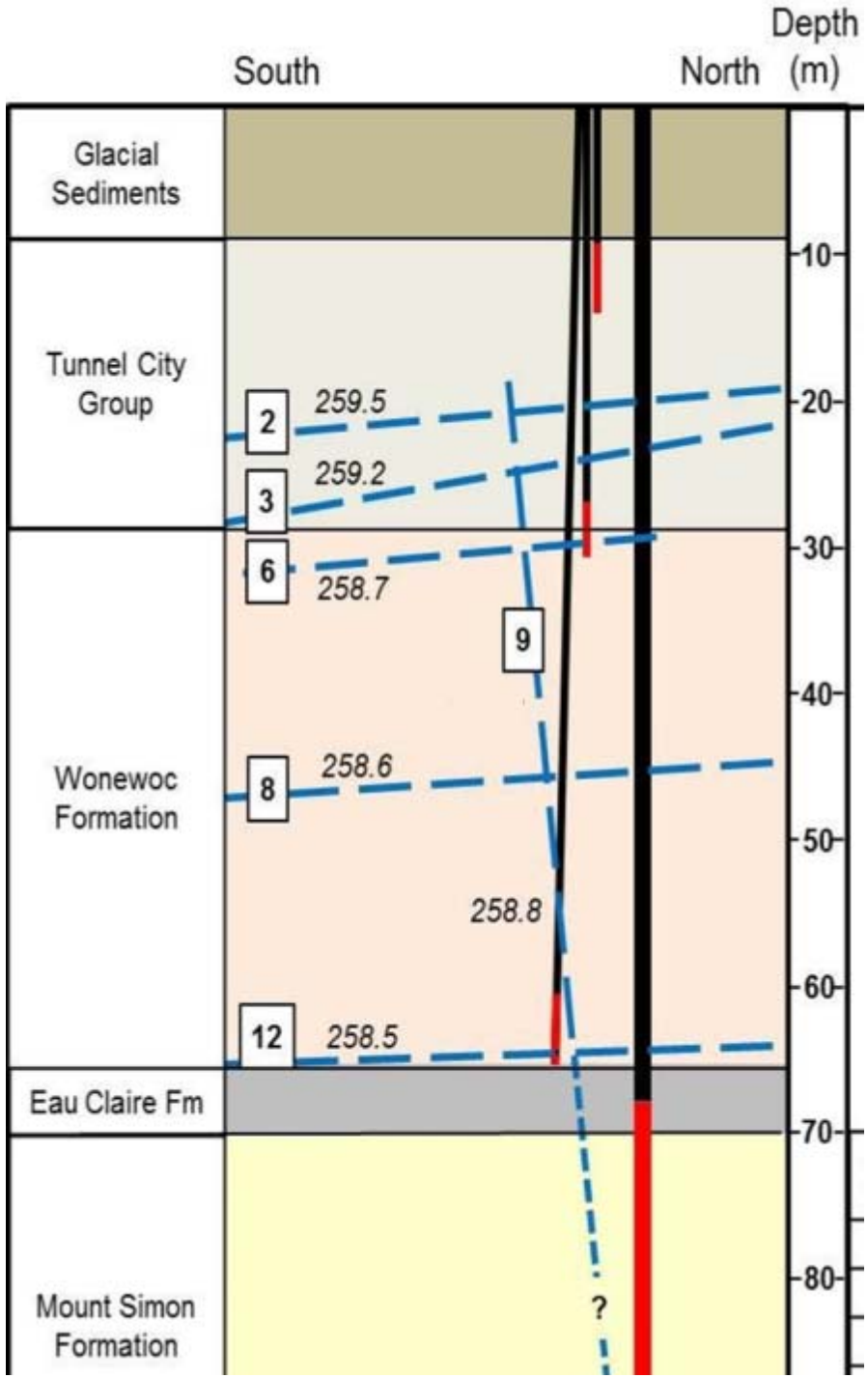


FRACTURE CHARACTERIZATION

- Upper Aquifer
- Borehole Geophysics
- Straddle Packer
  - Slug tests
  - Water chemistry
- Vertical Flow Assessment
- Pumping Test

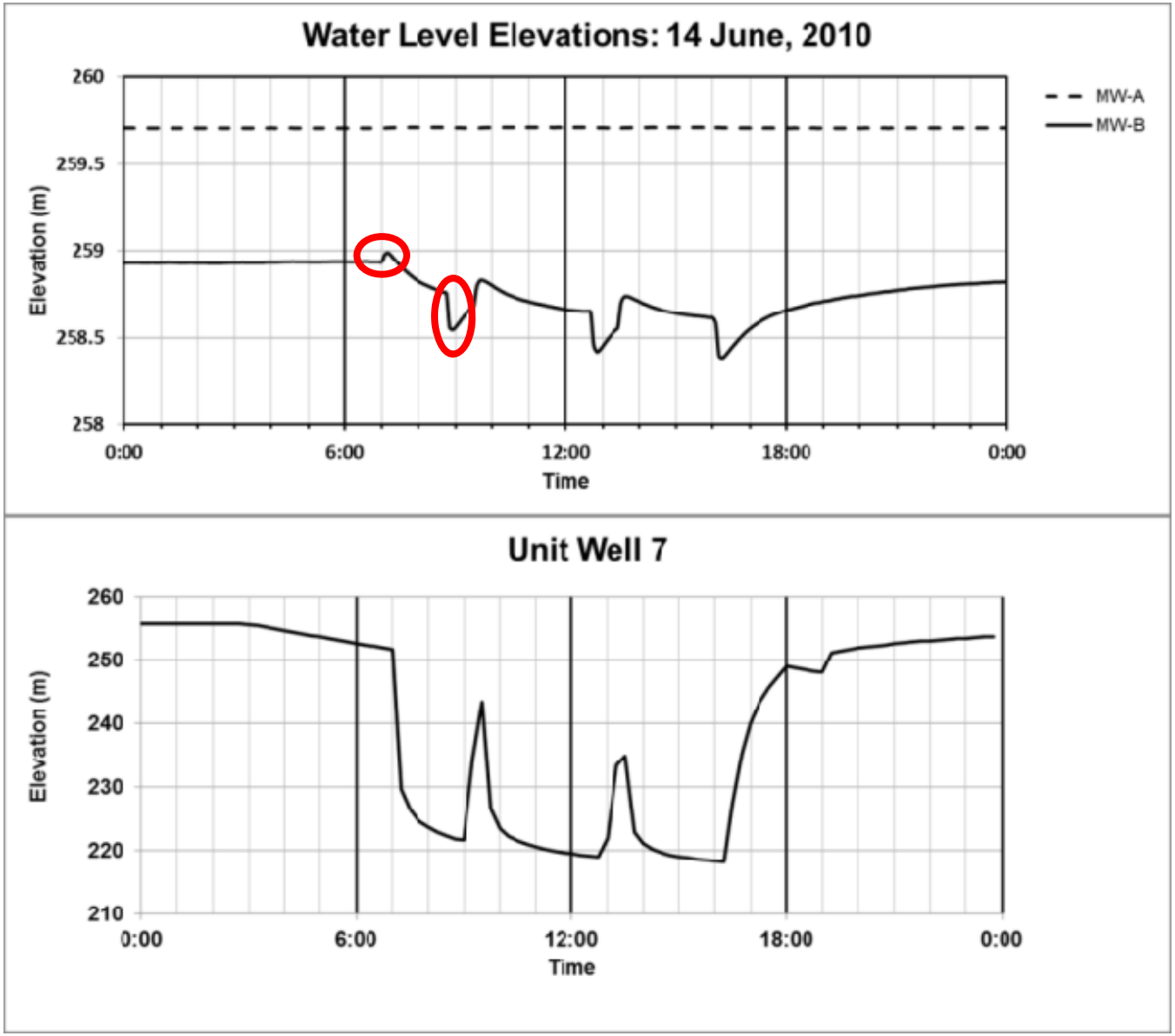
Conceptual Model

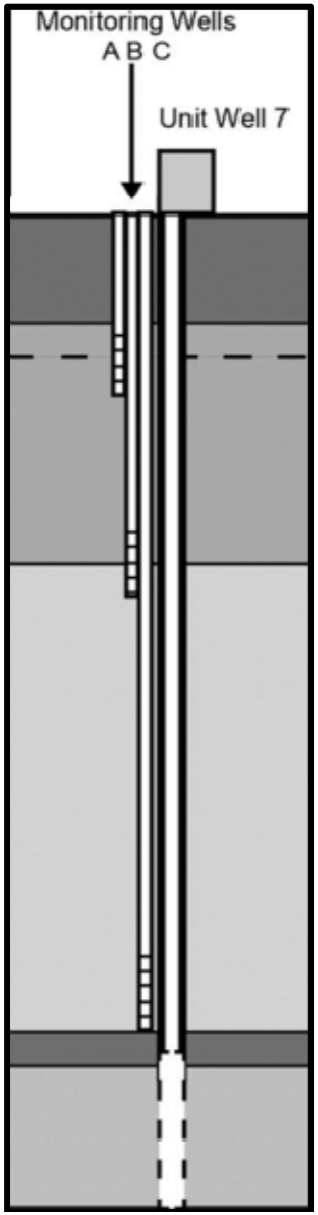
- Fracture dominated
  - 3 separate methods
  - 60-80% of total flow
- Head values
  - Downward flow
  - Fracture connectivity

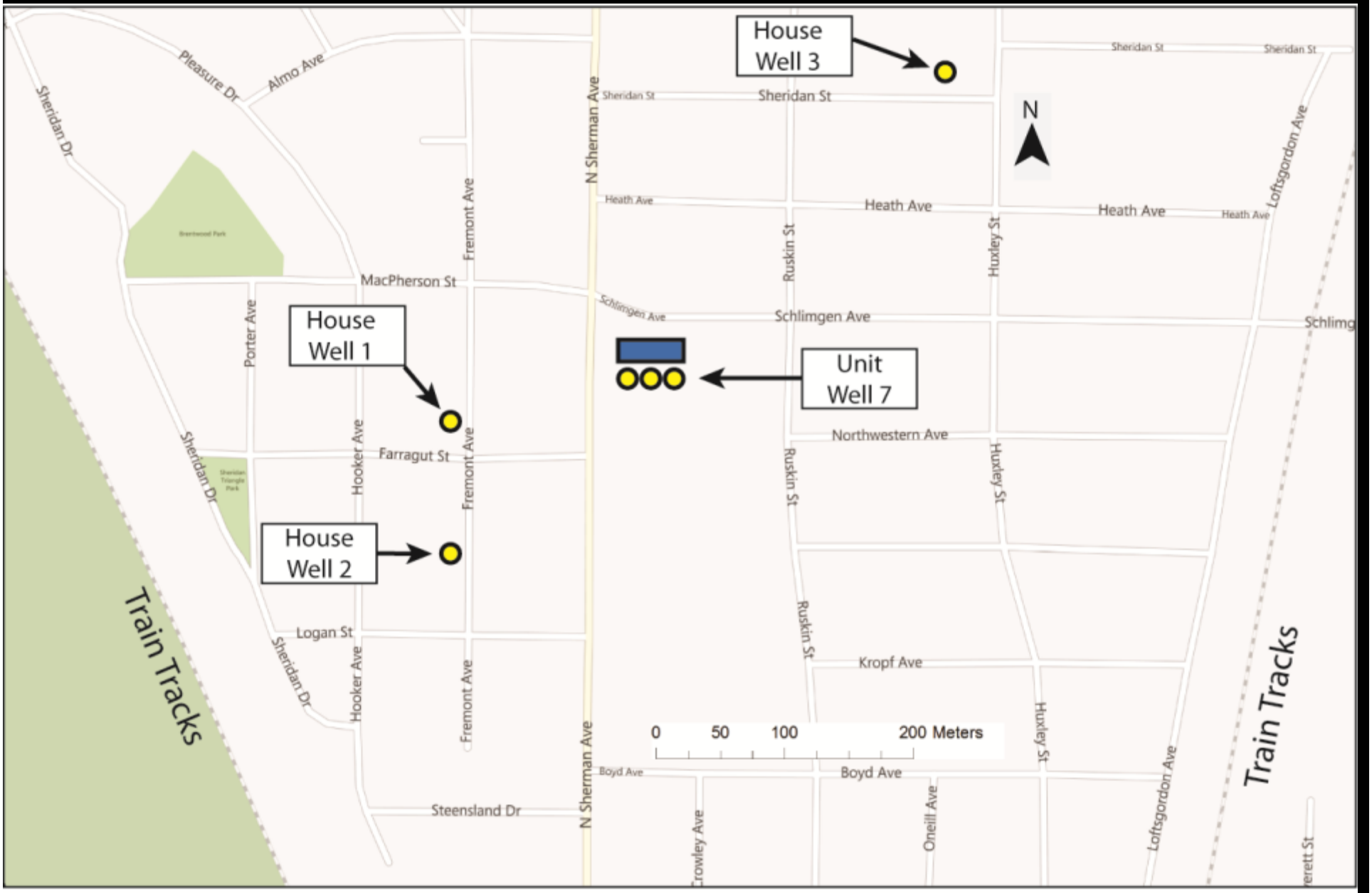


Gellasch, et al., *Hydrogeology Journal*, 2013

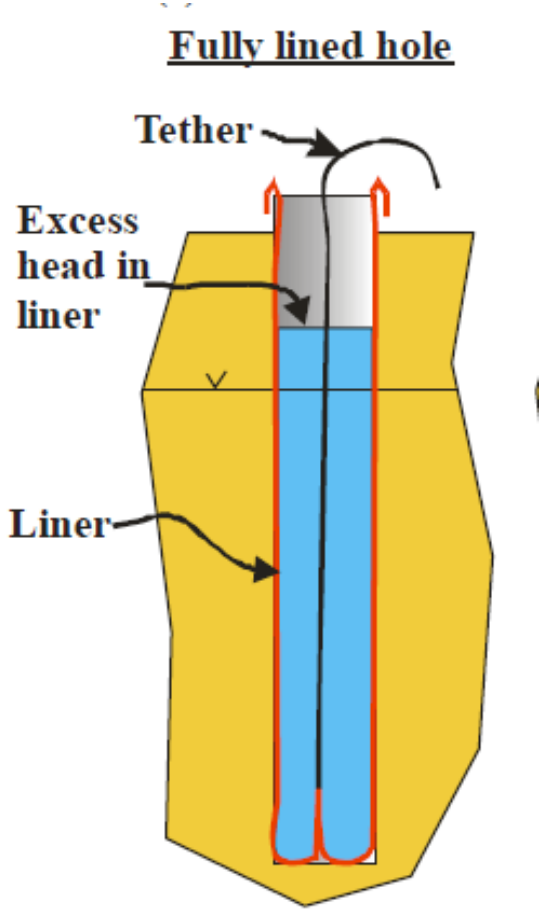
WELL PUMPING RESPONSE

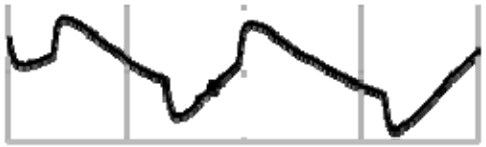
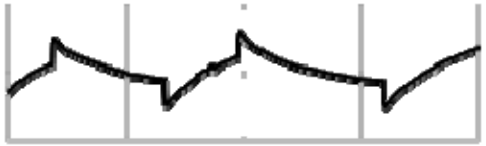
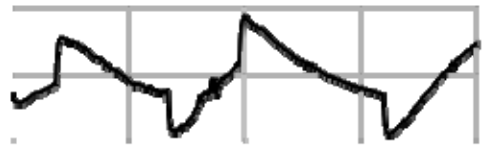
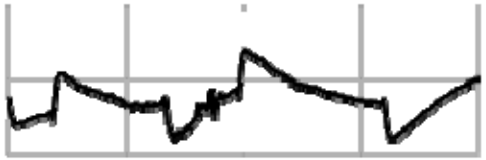





House Well 3
House Well 1
House Well 2
Unit Well 7
N
Sheridan St
Heath Ave
Schlimgen Ave
Northwestern Ave
Kropf Ave
Boyd Ave
Steensland Dr
Logan St
Farragut St
MacPherson St
Pleasure Dr
Almo Ave
Sheridan Dr
Porter Ave
Hooker Ave
Fremont Ave
N Sherman Ave
Ruskin St
Huxley St
Loftsgordon Ave
Crowley Ave
Oneill Ave
Train Tracks
0 50 100 200 Meters

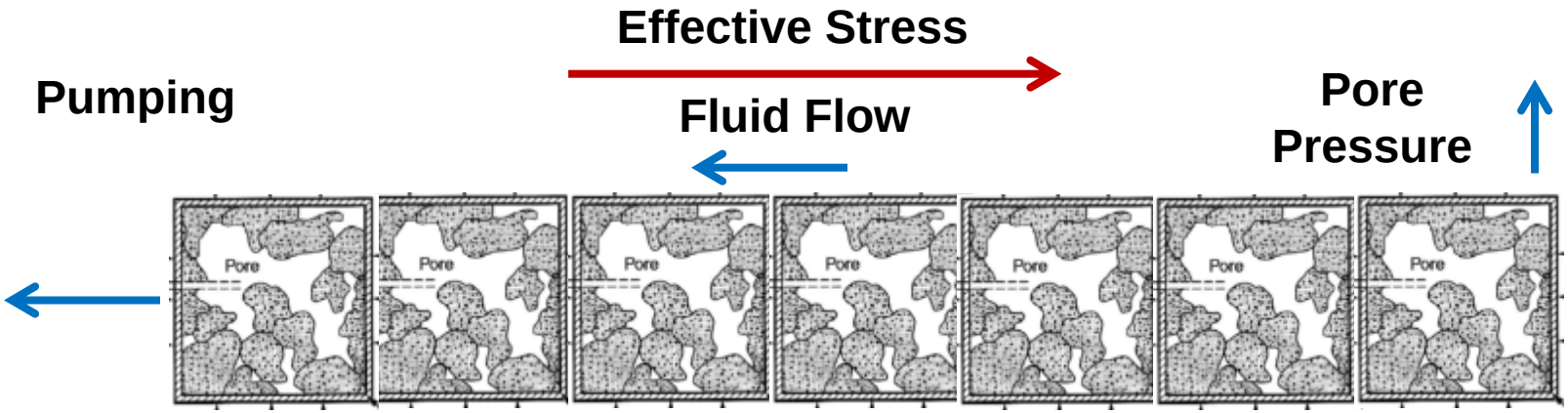
WATER LEVEL MEASUREMENTS



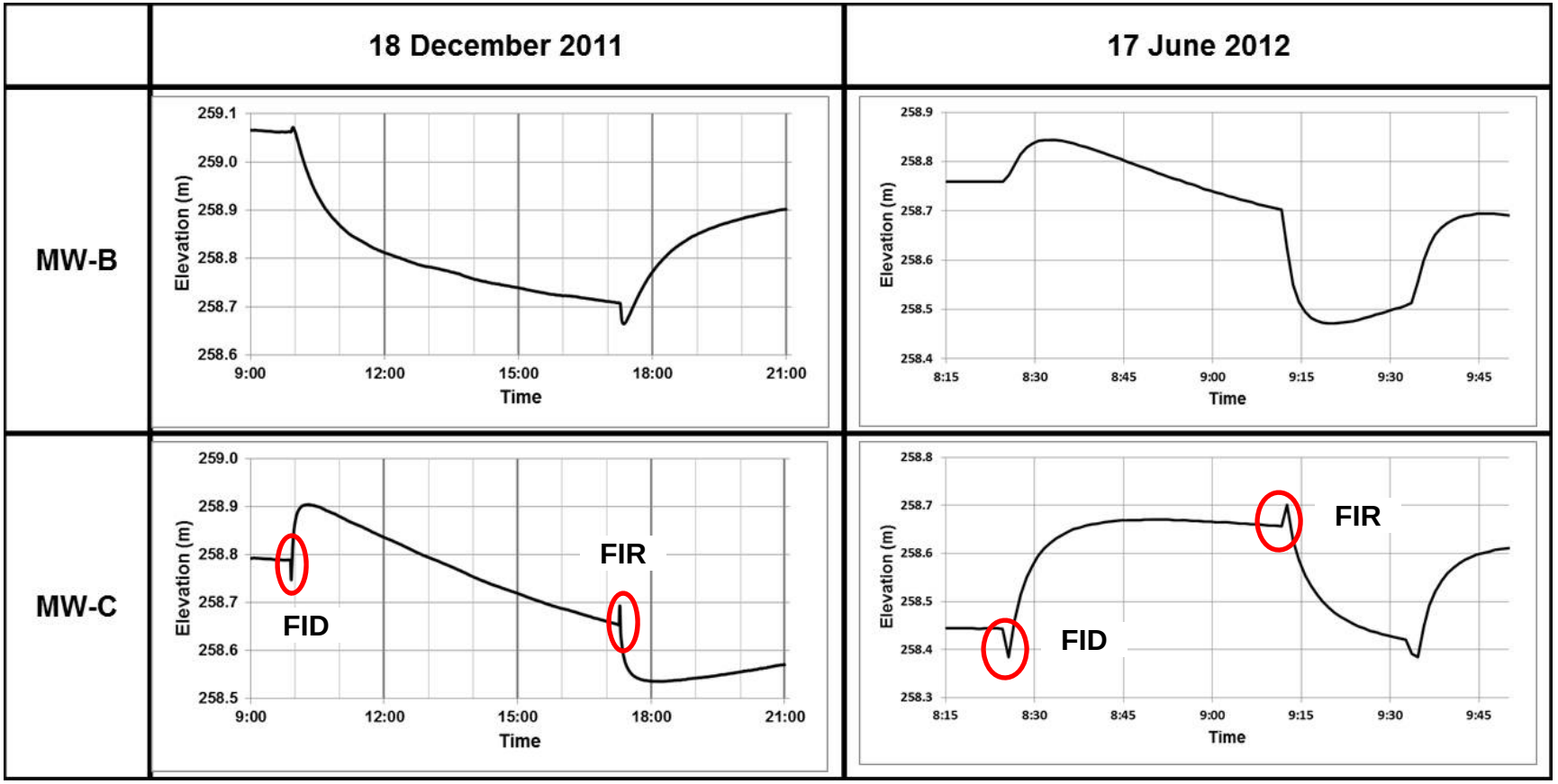
	Lined Borehole August 2011	Grouted Borehole February 2011
MW-A 5 cm range		
MW-B 50 cm range		
MW-C 50 cm range	No Data	
House 1 5 cm range		
House 2 10 cm range		
House 3 10 cm range		

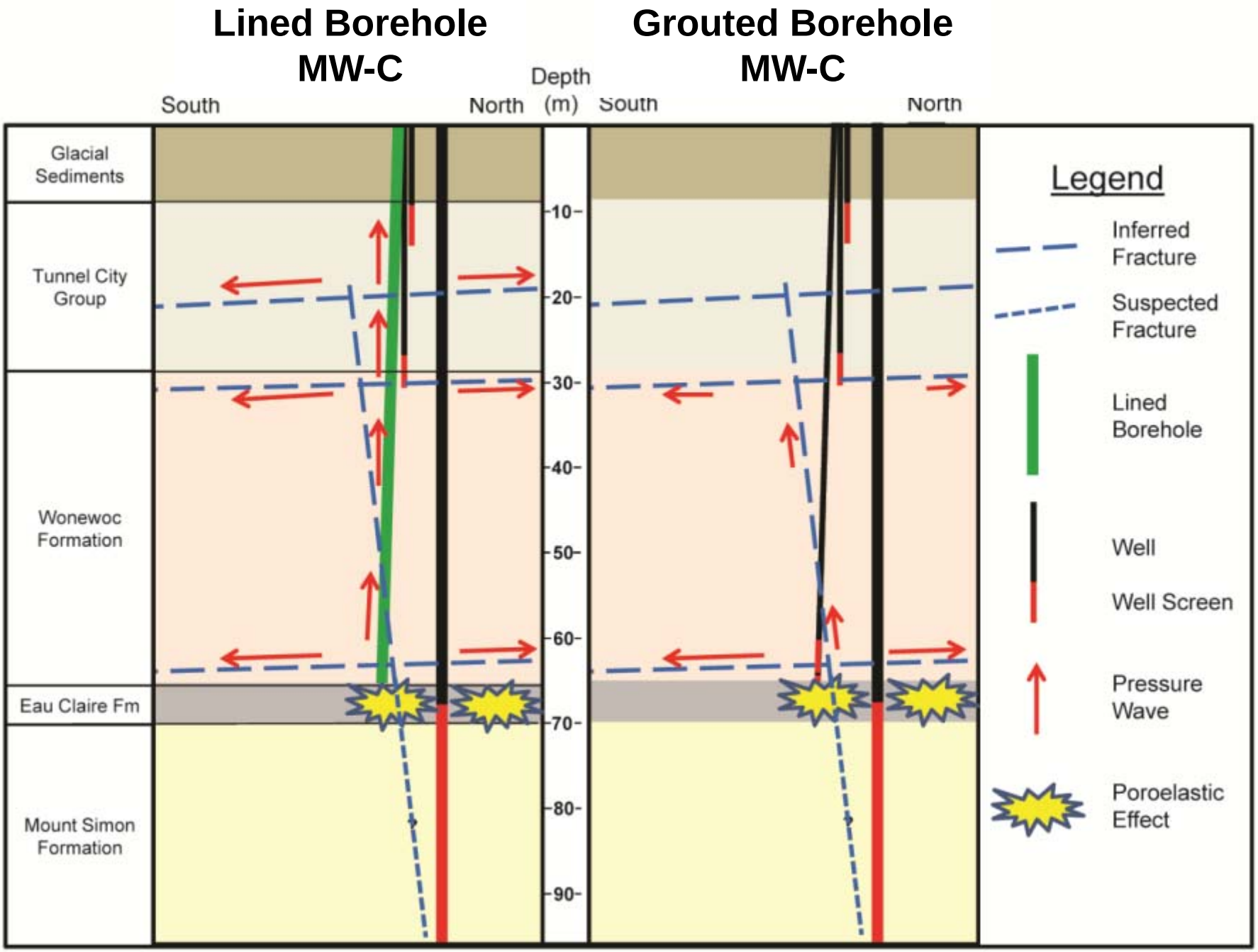
POROELASTICITY

- Solid – Fluid coupling
- Aquitard: mechanical change faster than fluid pressure change
- Pore pressure increases until fluid can migrate



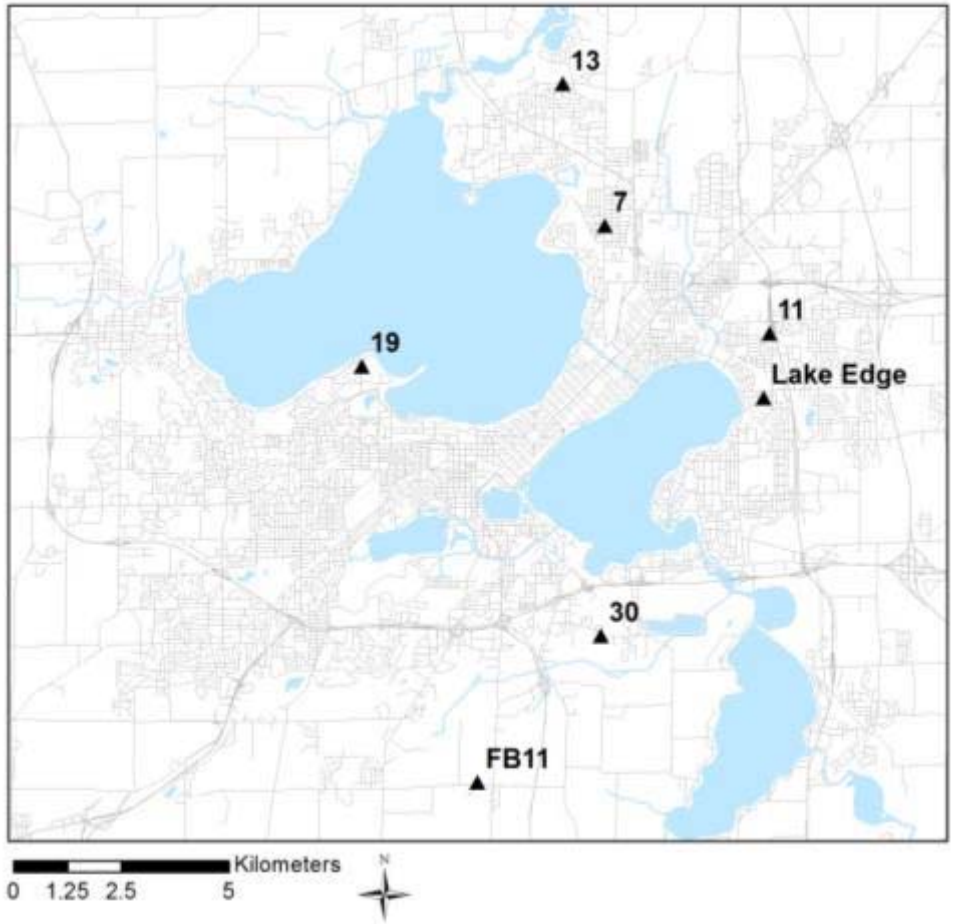
PUMPING RATE AND RWFs




Lined Borehole
MW-C
Grouted Borehole
MW-C
South
North
Depth
(m)
South
North
Glacial Sediments
Tunnel City Group
Wonewoc Formation
Eau Claire Fm
Mount Simon Formation
10
20
30
40
50
60
70
80
90
Legend
Inferred Fracture
Suspected Fracture
Lined Borehole
Well
Well Screen
Pressure Wave
Poroelastic Effect

RWFs AT MULTIPLE SITES

- Seven total sites over 15 km apart
  - Larger virus study
  - Madison
  - Fitchburg
- Similar RWF patterns due to pumping



VIRUS AND CHEMISTRY SAMPLING

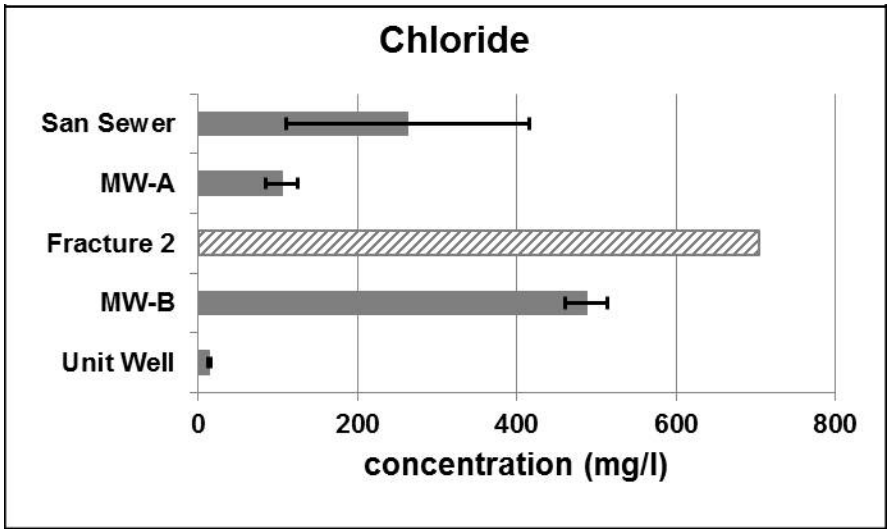
- Multiple rounds
  - Time sequenced sampling
  - Wastewater, MWs, Unit Well 7

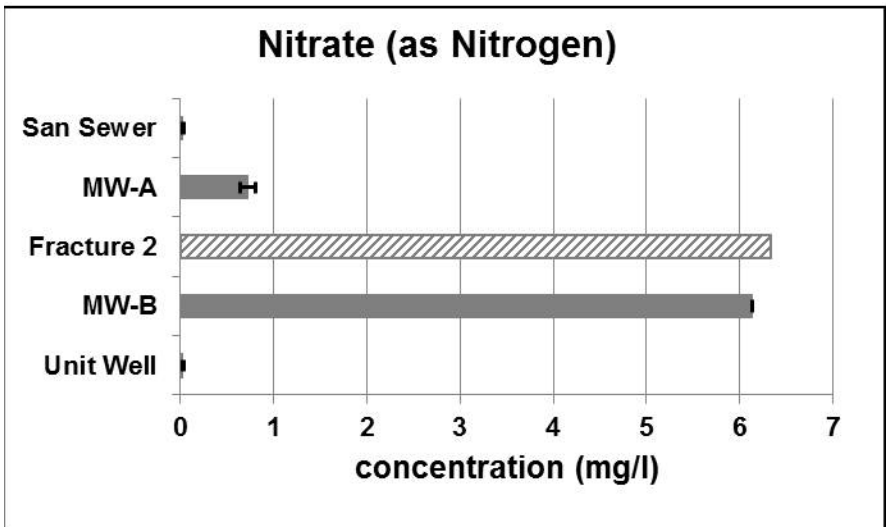
- Viruses
  - Electropositive glass wool filter
  - 800 – 1,000 L per sample
  - Polymerase chain reaction method

- Water chemistry
  - Grab samples: sewer, wells and packer
  - Major ions

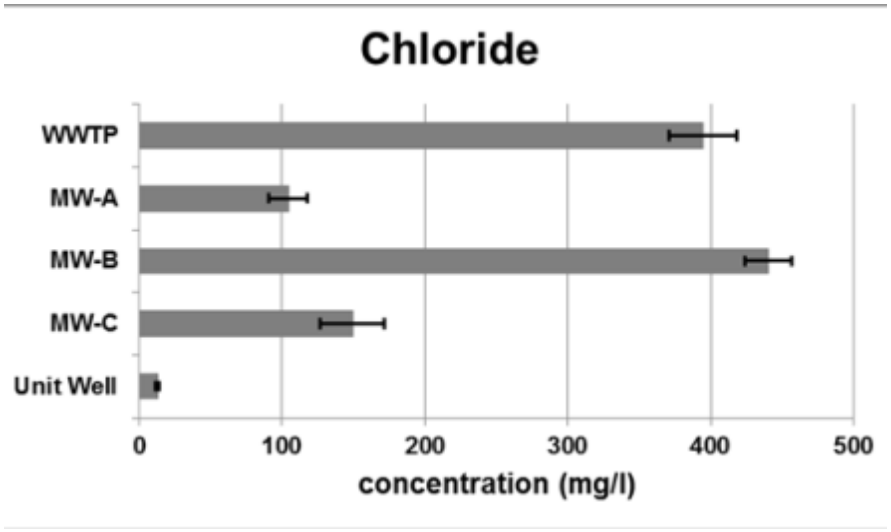
GROUNDWATER CHEMISTRY

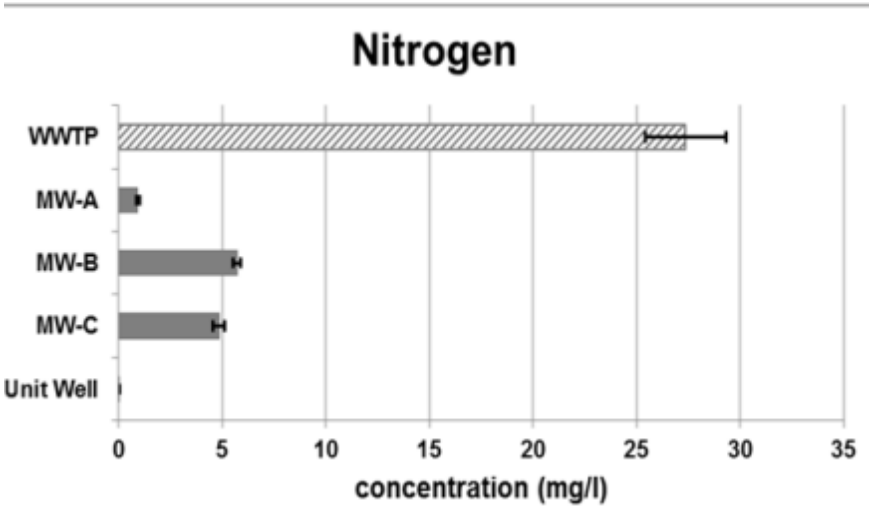
2010



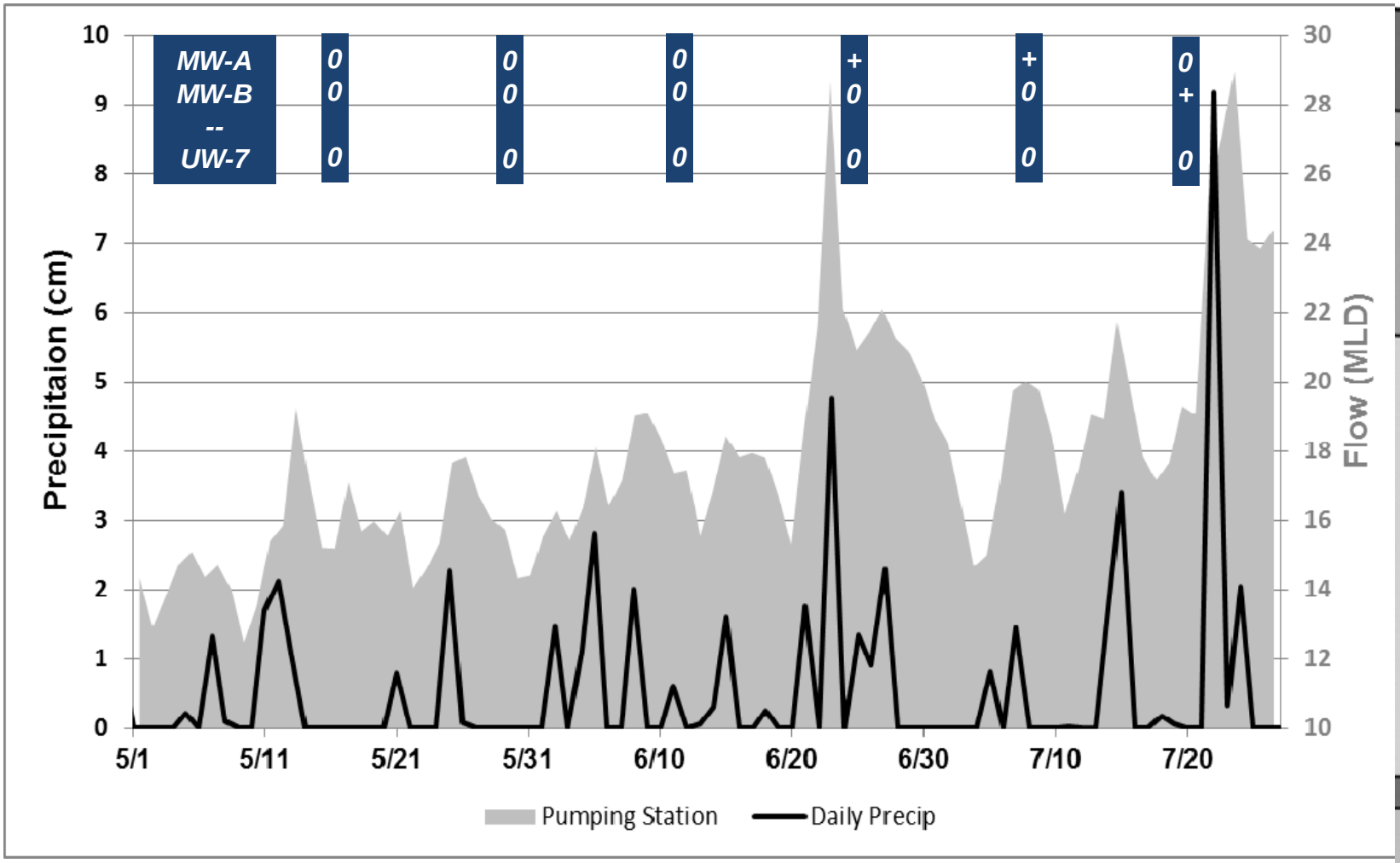


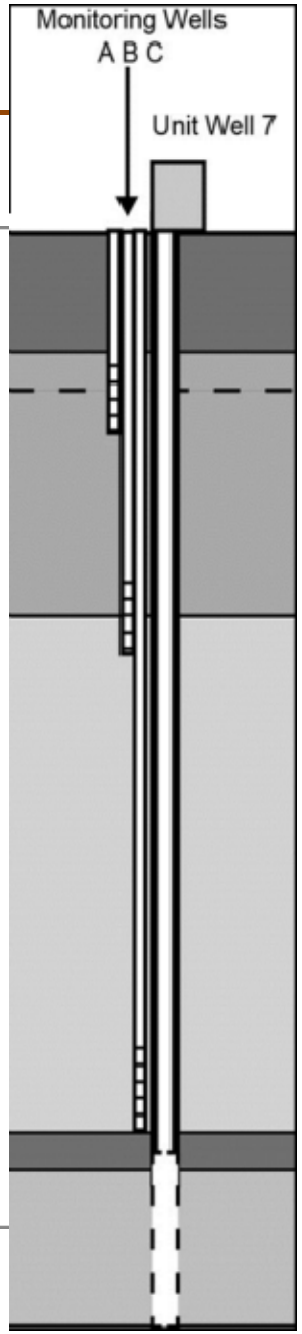
2012





VIRUS SAMPLING

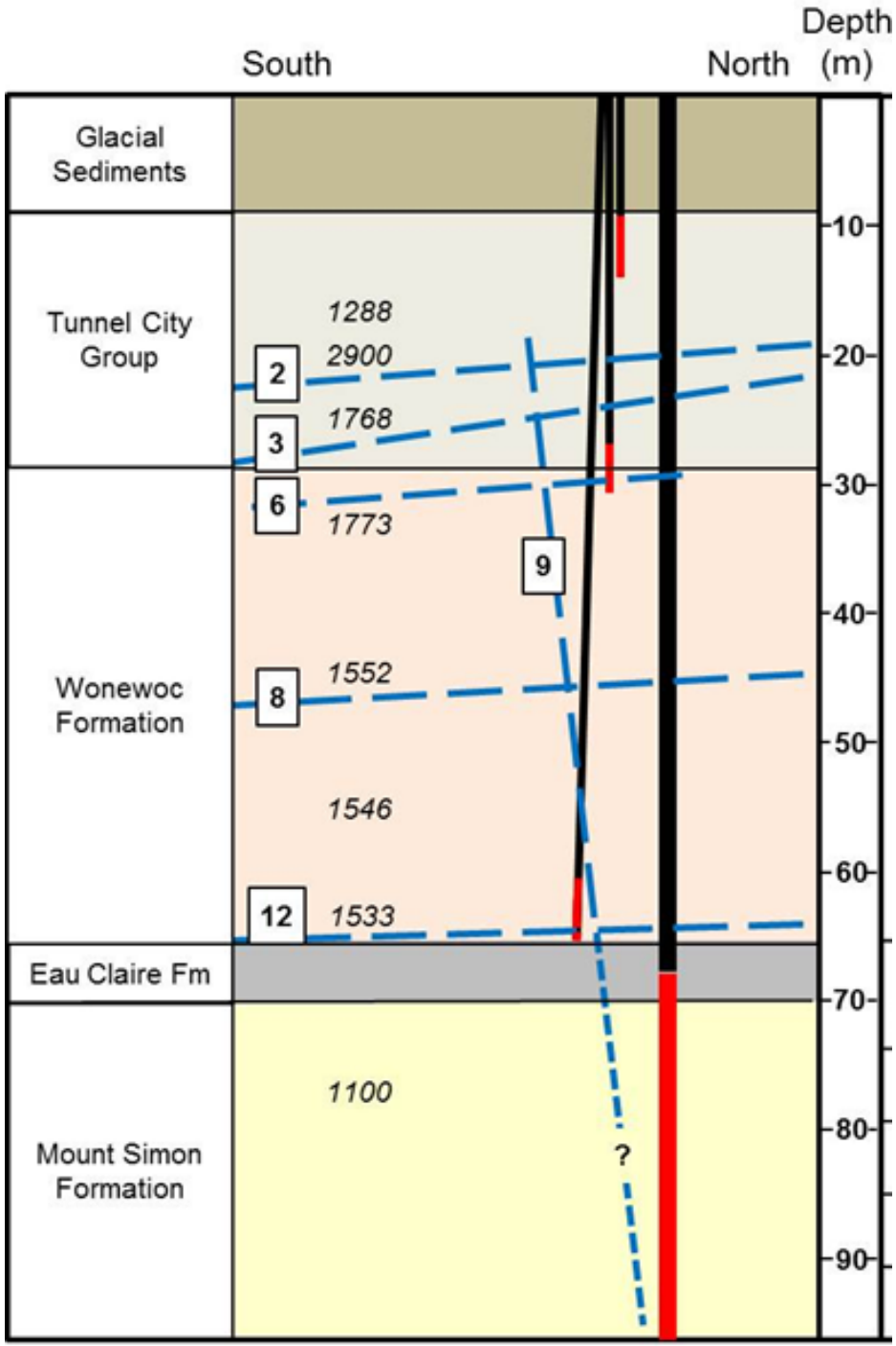




Conceptual Model

- Electrical conductivity
  - General trends
  - MW-B
  - MW-C
- Virus detection

Sample Location	Open Interval (m)	Virus Detects	Virus Groups	Average Conductivity (µS/cm)
MW-A	10.0 – 14.6	5/17 (29%)	4	1080
MW-B	27.5 – 30.5	3/17 (18%)	2	2296
MW-C	62.5 – 65.5	3/10 (30%)	2	1240
UW-7	70 – 202	3/16 (19%)	3	756



CONCLUSIONS

- Fractures in upper aquifer appear to significantly control groundwater flow
- Wastewater indicators present at discrete depths in upper aquifer
- Well pumping may rapidly influence upper aquifer at substantial radial distances
- Multiple approaches useful for determining well vulnerability

ACKNOWLEDGEMENTS

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REFERENCES

Gellasch, C.A., K.R. Bradbury, D.J. Hart, and J.M. Bahr. 2013. Characterization of fracture connectivity in a siliciclastic bedrock aquifer near a public supply well (Wisconsin, USA). *Hydrogeology Journal* v. 21 no. 2, p. 383-399. doi: 10.1007/s10040-012-0914-7

Gellasch, C.A., H.F. Wang, K.R. Bradbury, J.M. Bahr, and L.L. Lande. 2014. Reverse Water-Level Fluctuations Associated with Fracture Connectivity. *Groundwater* v. 52 no. 1, p. 105-117. doi: 10.1111/gwat.12040