CE4352: Groundwater Modeling
Final Project Presentation

Effect of Dewatering Wells at MSP Airport

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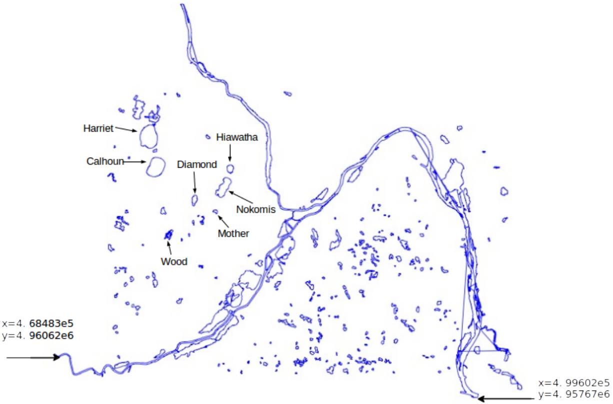
May 15^{th}, 2015



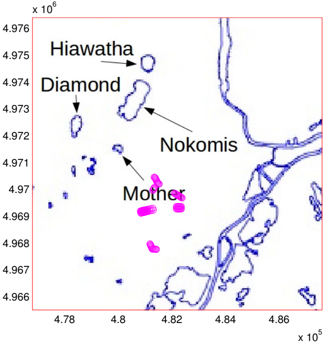
Region of Concern

Task:
Determine the draw-down effects of 88 dewatering wells, shown in magenta on surface levels of:

- Lake Nokomis
- Diamond Lake
- Mother Lake
- Lake Hiawatha

Considering scenarios of:

- no precipitation
- precipitation of 6 $\frac{\text{in}}{\text{year}}$
- precipitation of 12 $\frac{\text{in}}{\text{year}}$



Development Area

Steps required to determine draw down-effects of lake elevations resulting from wells:

- determine discharges to/from aquifer of all concerned pre-development elements (lakes, rivers, that of uniform flow)
- use these predevelopment discharges to derive a function of water table elevation as a function of location
- use this pre-development elevation function to calibrate model according to known aquifer properties and conditions
- introduce wells into model, and solve for post development discharge of elements while preserving pre-development lake discharges
- use solved discharges for all elements to develop a function expressing post development water table elevation as a function of location
- determine difference between pre and post development lake elevations for client

Auxiliary steps:

- determine effect of decreasing/increasing line sink quantity (river elements) on results
- determine effect of adjusting hydraulic conductivity on lake level drops
- determine effect of adjusting hydraulic conductivity on lake level drops
- determine effect of adding/removing additional lakes on lake primary level drops
- determine effect of adjusting aquifers' uniform flow rate on lake level drops

Knowns	Method of Determination
Hydraulic conductivity of local soil	client provided
Elevation of aquifer base	client provided
Aquifer thickness	client provided
Pre-dev lake levels	researched from DNR website
Lake geometries	interpreted from client-provided maps
Pre-dev river levels	assumed to be at aquifer base (bluffs)
River geometries	interpreted from client-provided maps
Well locations	client provided
Well heads	client provided
Pre-dev water table level near wells	client provided
Uniform flow	assumed to be zero (tested later)

Unknowns	Method of Determination
Pre/post dev lake discharges	solved with pre-dev knowns
Pre-dev river discharges	solved with pre-dev knowns
Post-dev lake levels	solved with lake discharges and post-dev knowns
Post-dev river discharges	solved with lake discharges and post-dev knowns
Post-dev well discharges	solved with lake discharges and post-dev knowns
Post-dev lake levels	solved with lake discharges and post-dev knowns
Pre vs. post dev lake levels	difference between post and pre-dev lake levels

Equation for predevelopment complex potential as a function of location (z):

$$\Omega_{total,pre}(z) = Q_{UF} C_{UF}(z) + \sum_{n=1}^{nLK} Q_{lk\,n} C_{lk\,n}(z) + \sum_{n=1}^{nLS} Q_{ls\,n} C_{ls\,n}(z) + \Phi_{inf}(z) + C$$

where:
X_{UF} refers to uniform flow terms;
X_{lk} refers to lake terms;
X_{ls} refers to river terms (line sinks);
X_{inf} refers to infiltration terms

Lake levels can be solved with:

$$\phi = \sqrt{\frac{2\Re(\Omega)}{k}} + b$$

Predevelopment column vector of known values and their locations:

$$K_{pre} = \begin{pmatrix} \Phi(lkb_1) - Q_{UF}C_{UF}(z_{lk\,1}) - \Phi_{inf}(z_{lk\,1}) \\ \vdots \\ \Phi(lkb_f) - Q_{UF}C_{UF}(z_{lk\,f}) - \Phi_{inf}(z_{lk\,f}) \\ \Phi(lsc_1) - Q_{UF}C_{UF}(z_{ls\,1}) - \Phi_{inf}(z_{ls\,1}) \\ \vdots \\ \Phi(lsc_f) - Q_{UF}C_{UF}(z_{ls\,f}) - \Phi_{inf}(z_{ls\,f}) \\ \Phi(rf) - Q_{UF}C_{UF}(z_{rf}) - \Phi_{inf}(z_{rf}) \end{pmatrix}$$

Predevelopment matrix of coefficients of unknown values:

$$A_{pre} = \begin{pmatrix} C_{lk\,1}(z_{lk\,1}) \cdots C_{lk\,f}(z_{lk\,1}) & C_{ls\,1}(z_{lk\,1}) \cdots C_{ls\,f}(z_{lk\,1}) & 1 \\ \vdots & \vdots & 1 \\ C_{lk\,1}(z_{lk\,f}) \cdots C_{lk\,f}(z_{lk\,f}) & C_{ls\,1}(z_{lk\,f}) \cdots C_{ls\,f}(z_{lk\,f}) & 1 \\ C_{lk\,1}(z_{ls\,1}) \cdots C_{lk\,f}(z_{ls\,1}) & C_{ls\,1}(z_{ls\,1}) \cdots C_{ls\,f}(z_{lk\,1}) & 1 \\ \vdots & \vdots & 1 \\ C_{lk\,1}(z_{ls\,f}) \cdots C_{lk\,f}(z_{ls\,f}) & C_{ls\,1}(z_{ls\,f}) \cdots C_{ls\,f}(z_{ls\,f}) & 1 \end{pmatrix}$$

Solving for unknown discharges and constant using predevelopment matrices:

$$Q_{pre} = \begin{pmatrix} Q_{lk\,1} \\ \vdots \\ Q_{lk\,f} \\ Q_{ls\,1} \\ \vdots \\ Q_{ls\,f} \\ C \end{pmatrix} = A_{pre} \backslash K_{pre}$$

These values are checked to produce all known heads (on lake boundaries and line-sink centers) when used in the Ω_{total} function.

$$\frac{|\phi_{lkb\,given} - \phi_{lkb\,calculated}|}{\phi_{lkb\,given}} \leq 0.001$$

$$\frac{|\phi_{ref\;given} - \phi_{ref\;calculated}|}{\phi_{ref\;given}} \leq 0.001$$

$$|\phi_{lsc\,given} - \phi_{lsc\,calculated}| \leq 0.001$$

Once verified, all lake discharges and constant C are used to solve for post development discharges.

Postdevelopment column vector of known values and their locations, with known well heads added:

$$K_{post} = \begin{pmatrix} \Phi_{lsc\,1} - Q_{lk\,1} C_{lk\,1}(z_{lsc\,1}) \cdots Q_{lk\,f} C_{lk\,f}(z_{lsc\,1}) - Q_{UF} C_{UF}(z_{lsc\,1}) - \Phi_{inf}(z_{lsc\,1}) \\ \vdots \\ \Phi_{lsc\,f} - Q_{lk\,1} C_{lk\,1}(z_{lsc\,f}) \cdots Q_{lk\,f} C_{lk\,f}(z_{lsc\,1}) - Q_{UF} C_{UF}(z_{lsc\,f}) - \Phi_{inf}(z_{lsc\,f}) \\ \Phi_{w\,1} - Q_{lk\,1} C_{lk\,1}(z_{w\,1}) \cdots Q_{lk\,f} C_{lk\,f}(z_{w\,1}) - Q_{UF} C_{UF}(z_{w\,1}) - \Phi_{inf}(z_{w\,1}) \\ \vdots \\ \Phi_{w\,f} - Q_{lk\,1} C_{lk\,1}(z_{w\,f}) \cdots Q_{lk\,f} C_{lk\,f}(z_{w\,f}) - Q_{UF} C_{UF}(z_{w\,f}) - \Phi_{inf}(z_{w\,f}) \\ \Phi_{ref} - Q_{lk\,1} C_{lk\,1}(z_{ref}) \cdots Q_{lk\,f} C_{lk\,f}(z_{ref}) - Q_{UF} C_{UF}(z_{ref}) - \Phi_{inf}(z_{ref}) \end{pmatrix}$$

Postdevelopment matrix of coefficients of unknown values, with known well coefficients added:

$$A_{post} = \begin{pmatrix} C_{ls\,1}(z_{lsc\,1}) \cdots C_{ls\,f}(z_{lsc\,1}) & C_{w\,1}(z_{lsc\,1}) \cdots C_{w\,f}(z_{lsc\,f}) & \\ \vdots & \vdots & 1 \\ C_{ls\,1}(z_{lsc\,f}) \cdots C_{ls\,f}(z_{lsc\,f}) & C_{w\,1}(z_{lsc\,f}) \cdots C_{w\,f}(z_{lsc\,f}) & \\ C_{ls\,1}(z_{w\,1}) \cdots C_{ls\,f}(z_{w\,1}) & C_{w\,1}(z_{w\,1}) \cdots C_{w\,f}(z_{w\,1}) & \\ \vdots & \vdots & 1 \\ C_{ls\,1}(z_{w\,f}) \cdots C_{ls\,f}(z_{w\,f}) & C_{w\,1}(z_{w\,f}) \cdots C_{w\,f}(z_{w\,f}) & \end{pmatrix}$$

Solving for unknown postdevelopment discharges using postdevelopment matrices:

$$Q_{post} = \begin{pmatrix} Q_{ls\,1} \\ \vdots \\ Q_{ls\,f} \\ Q_{w\,1} \\ \vdots \\ Q_{w\,f} \end{pmatrix} = A_{post} \backslash K_{post}$$

These values are checked to produce all known post development heads (at wells and line sink centers) when used in the Ω_{total} function.

$$|\phi_{lsc\,given} - \phi_{lsc\,calculated}| \leq 0.001$$

$$\frac{|\phi_{wb\,given} - \phi_{wb\,calculated}|}{\phi_{wb\,given}} \leq 0.001$$

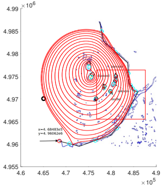
$$\frac{|\phi_{ref\,given} - \phi_{ref\,calculated}|}{\phi_{ref\,given}} \leq 0.001$$

They are then used to determine the post-development lake level heads.

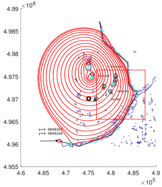
Unverified Preliminary results:

	$\gamma = 0\,\frac{\text{in}}{\text{year}}$	$\gamma = 6\,\frac{\text{in}}{\text{year}}$	$\gamma = 12\,\frac{\text{in}}{\text{year}}$
Nokomis	0.1719	0.3765	0.5849
Diamond	0.2156	0.4714	0.7324
Moter	0.3643	0.7977	1.2495
Hiawatha	0.1394	0.3056	0.4746

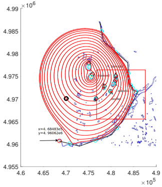
Verification of reference point location: Choosing z_{ref}



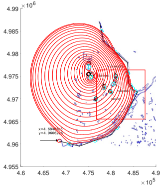
$z_{ref} = 4.65e5 + i4.97e6,\ \Phi_{ref} = 5000 \frac{m^3}{day}$



$z_{ref} = 4.75e5 + i4.97e6,\ \Phi_{ref} = 5000 \frac{m^3}{day}$



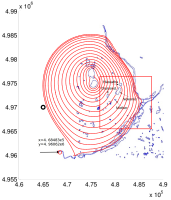
$z_{ref} = 4.7e5 + i4.97e6,\ \Phi_{ref} = 5000 \frac{m^3}{day}$



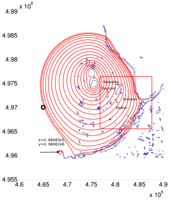
$z_{ref} = 4.75e5 + i4.9755e5,\ \Phi = 5000_{ref} \frac{m^3}{day}$

$\rightarrow z_{ref}$ is chosen to be $4.65e5 + i4.97e6$

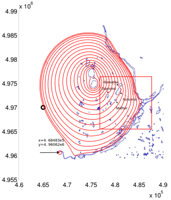
Verification of reference point head: Choosing z_{ref}



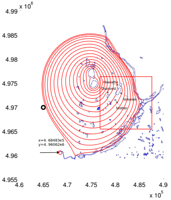
$z_{ref} = 4.65e5 + i4.97e6,\ \Phi_{ref} = 15000\,\frac{m^3}{day}$



$z_{ref} = 4.65e5 + i4.97e6,\ \Phi_{ref} = 3000\,\frac{m^3}{day}$



$z_{ref} = 4.65e5 + i4.97e6,\ \Phi_{ref} = 2000\,\frac{m^3}{day}$

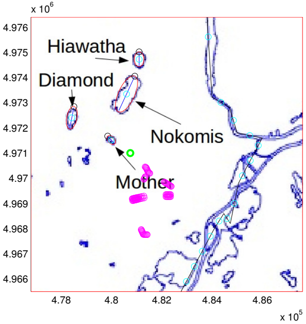


$z_{ref} = 4.65e5 + i4.97e6,\ \Phi_{ref} = 10000_{ref}\,\frac{m^3}{day}$

$\rightarrow \Phi_{ref}$ is chosen to remain $5000\,\frac{m^3}{day}$

Verification of given head in vicinity of wells before development:

The water table elevation within the vicinity of the wells before development is given to be 815 feet, which is 248.412 meters.
Using $z_{test} = 4.8075e5 + i4.971e6$ shown in green, the Ω_{total} function is used to find a $\phi(z_{test})$ of 247.0540 m.

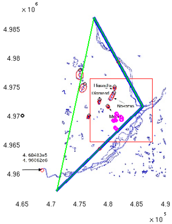


location of well vicinity predevelopment level test

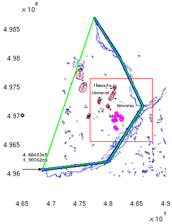
Error Mitigation: Data Collection

	level (ft)	level (m)	date of reading
Nokomis	816.05	248.73204	7/18/2013
Diamond	821.06	250.25909	4/23/2015
Mother	814.96	248.39981	11/14/1996
Hiawatha	811.55	247.36044	11/28/2012
Calhoun	851.08	259.40918	11/28/2012
Harriet	847.19	258.22351	11/30/2005
Wood	819.30	249.72264	10/30/1996

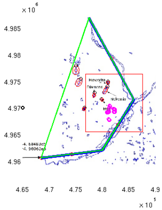
Error Mitigation: Line Sink Quantity



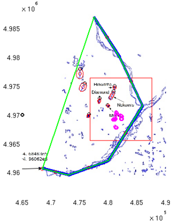
nLS = 2



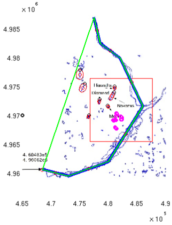
nLS = 4



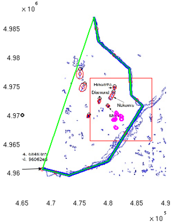
nLS = 3



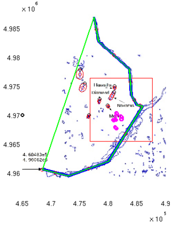
nLS = 5



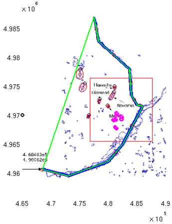
nLS = 6



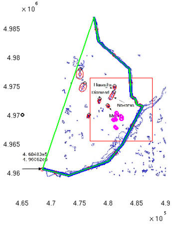
nLS = 7



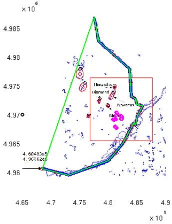
nLS = 8



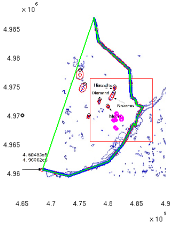
nLS = 9



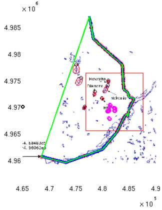
nLS = 10



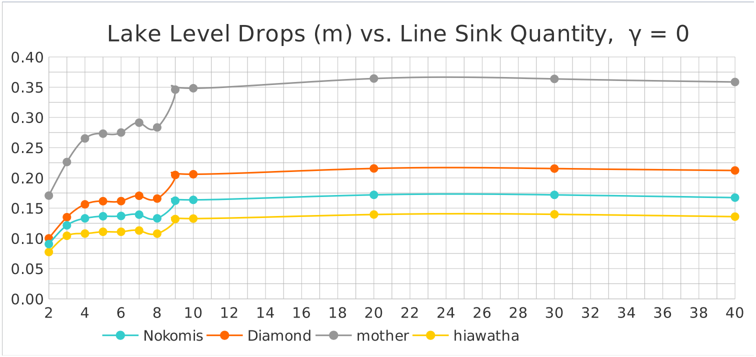
nLS = 20



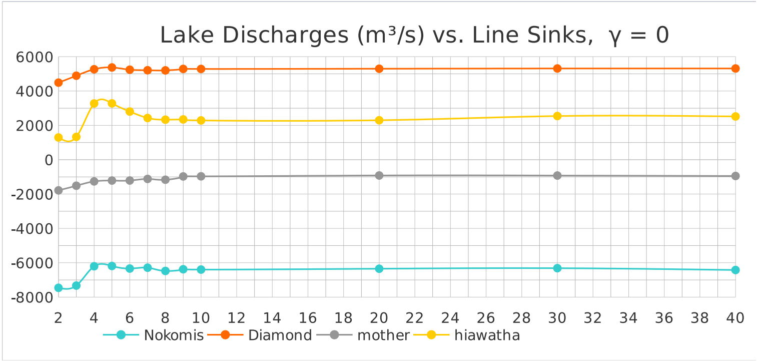
nLS = 30



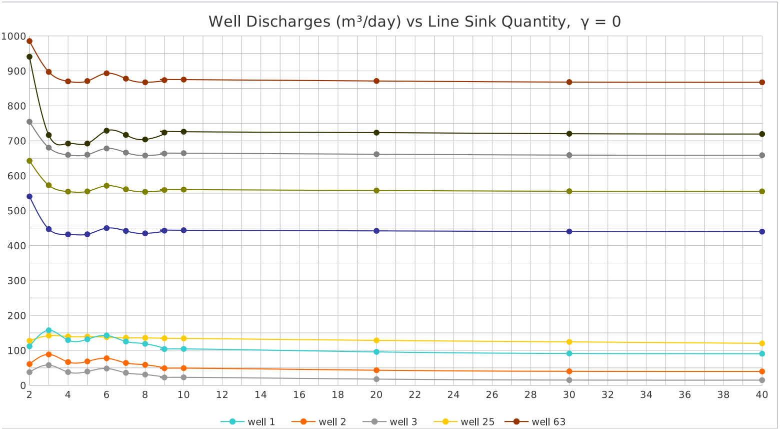
nLS = 40


Lake Level Drops (m) vs. Line Sink Quantity, γ = 0
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Nokomis
Diamond
mother
hiawatha

$\gamma = 0$

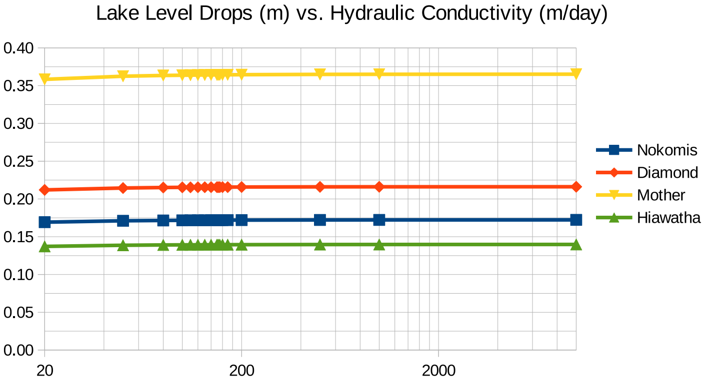

Lake Discharges (m³/s) vs. Line Sinks, γ = 0
6000
4000
2000
0
-2000
-4000
-6000
-8000
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
Nokomis
Diamond
mother
hiawatha

$\gamma = 0$


Well Discharges (m³/day) vs Line Sink Quantity, γ = 0
1000
900
800
700
600
500
400
300
200
100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
well 1
well 2
well 3
well 25
well 63

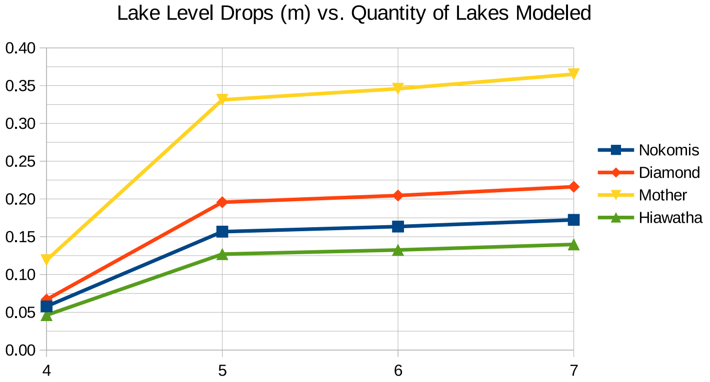
$\gamma = 0$

Error Mitigation: Hydraulic Conductivity



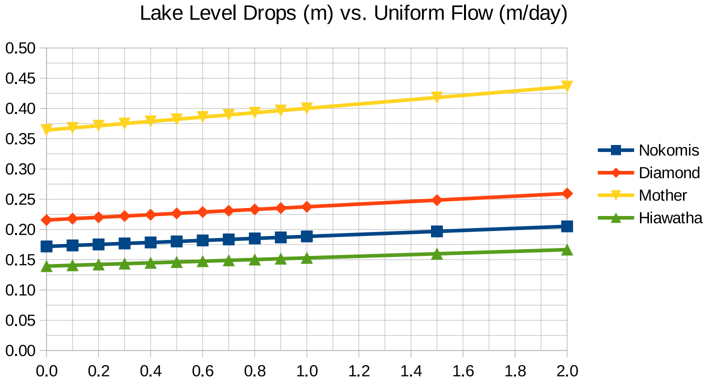
nLS $= 20$, $\gamma = 0$

Error Mitigation: Number of Lakes Modeled



nLS $= 20$, $\gamma = 0$

Error Mitigation: Uniform Flow



nLS $= 20$, $\gamma = 0$

If contracted to continue, or firm proposes to:

Update surface levels for:

- Lake Nokomis
- Diamond Lake
- Mother Lake
- Lake Hiawatha
- Lake Calhoun
- Lake Harriet
- Lake Wood

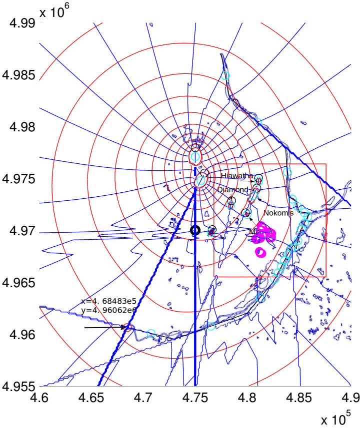
Introduce models for, and most recent lake level readings for:

- Legion Lake
- Cedar Lake
- Lake of the Isles
- Grass Lake
- Richfield Lake
- Taft Lake

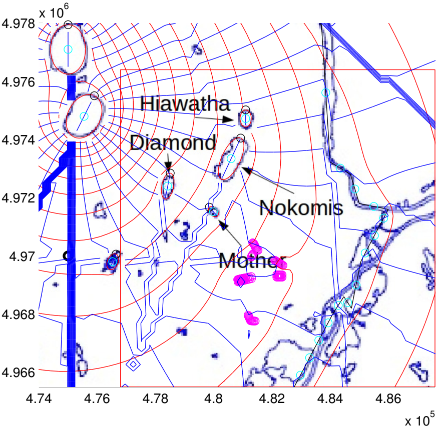
As well as:

- More closely fit line sink models to relevant reaches of Minnesota and Mississippi River
- Determine more accurate uniform flow rate of aquifer
- Remove impermeable zone of airport area from infiltration region
- Remove impermeable streets near dewatering wells from infiltration region

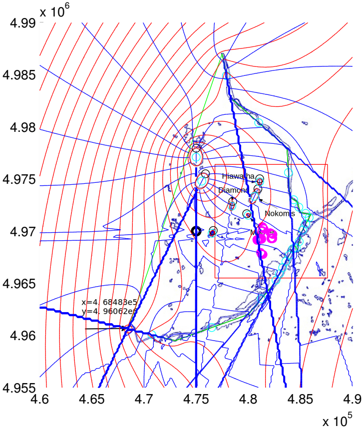
Questions/Comments?



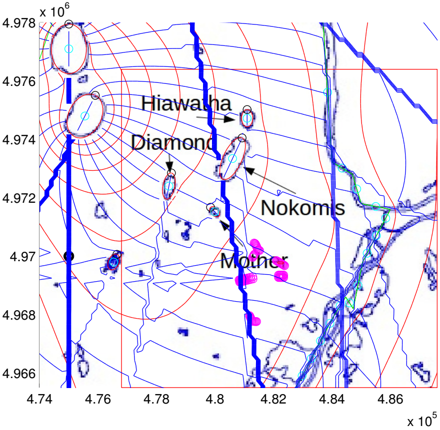
Post-development, no infiltration



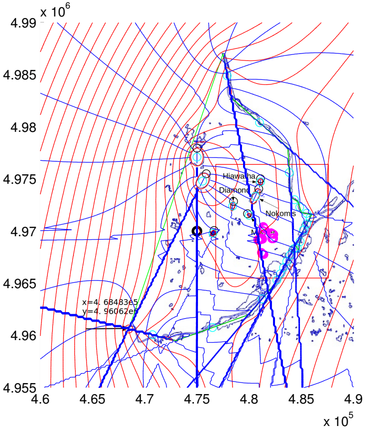
Zoom-in, no infiltration



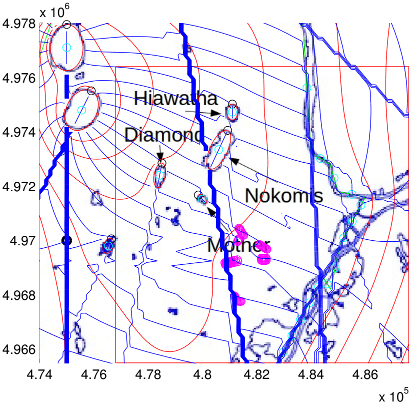
Post-development, $\gamma = 6\,\frac{\text{in}}{\text{year}}$



Zoom-in, $\gamma = 6 \frac{\text{in}}{\text{year}}$



Post-development, $\gamma = 12\,\frac{\text{in}}{\text{year}}$



Zoom-in, $\gamma = 12 \frac{\text{in}}{\text{year}}$