

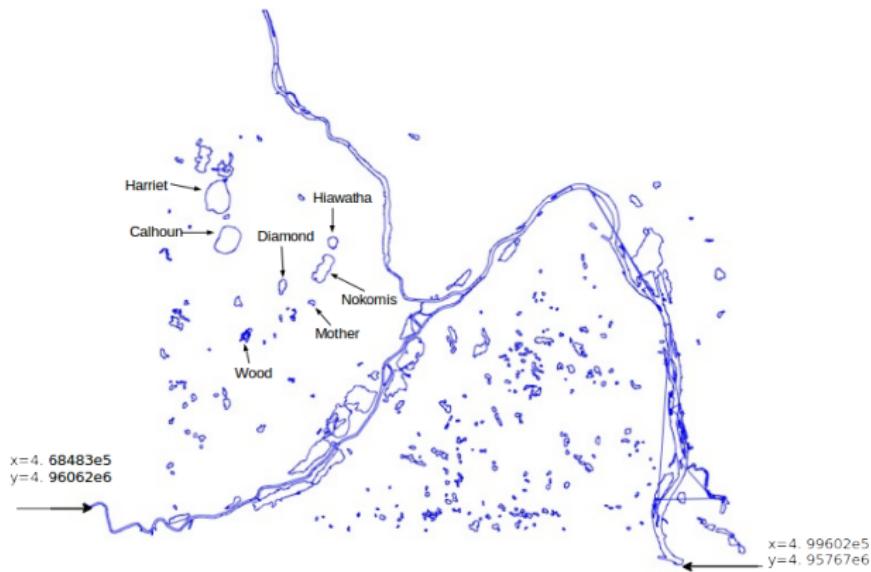
CE4352: Groundwater Modeling

Final Project Presentation

Effect of Dewatering Wells at MSP Airport

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May 15th, 2015



Region of Concern

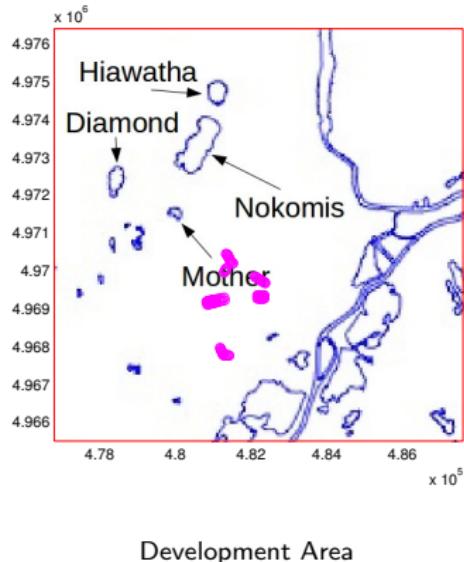
Task:

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:

$$K_{pre} = \begin{pmatrix} \Phi(lkb_1) - Q_{UF} C_{UF}(z_{lk1}) - \Phi_{inf}(z_{lk1}) \\ \vdots \\ \Phi(lkb_f) - Q_{UF} C_{UF}(z_{lk_f}) - \Phi_{inf}(z_{lk_f}) \\ \Phi(lsc_1) - Q_{UF} C_{UF}(z_{ls1}) - \Phi_{inf}(z_{ls1}) \\ \vdots \\ \Phi(lsc_f) - Q_{UF} C_{UF}(z_{lsf}) - \Phi_{inf}(z_{lsf}) \\ \Phi(rf) - Q_{UF} C_{UF}(z_{rf}) - \Phi_{inf}(z_{rf}) \end{pmatrix}$$

Predevelopment matrix of coefficients of unknown values:

$$A_{pre} = \begin{pmatrix} C_{lk1}(z_{lk1}) \cdots C_{lkf}(z_{lk1}) & C_{ls1}(z_{lk1}) \cdots C_{lsf}(z_{lk1}) & 1 \\ \vdots & \vdots & 1 \\ C_{lk1}(z_{lkf}) \cdots C_{lkf}(z_{lkf}) & C_{ls1}(z_{lkf}) \cdots C_{lsf}(z_{lkf}) & 1 \\ C_{lk1}(z_{ls1}) \cdots C_{lkf}(z_{ls1}) & C_{ls1}(z_{ls1}) \cdots C_{lsf}(z_{ls1}) & 1 \\ \vdots & \vdots & 1 \\ C_{lk1}(z_{lsf}) \cdots C_{lkf}(z_{lsf}) & C_{ls1}(z_{lsf}) \cdots C_{lsf}(z_{lsf}) & 1 \end{pmatrix}$$

Solving for unknown discharges and constant using predevelopment matrices:

$$Q_{pre} = \begin{pmatrix} Q_{lk1} \\ \vdots \\ Q_{l kf} \\ Q_{ls1} \\ \vdots \\ Q_{lsf} \\ C \end{pmatrix} = A_{pre} \setminus K_{pre}$$

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:

$$K_{post} = \begin{pmatrix} \Phi_{lsc1} - Q_{lk1} C_{lk1}(z_{lsc1}) \cdots Q_{lkf} C_{lkf}(z_{lsc1}) - Q_{UF} C_{UF}(z_{lsc1}) - \Phi_{inf}(z_{lsc1}) \\ \vdots \\ \Phi_{lscf} - Q_{lk1} C_{lk1}(z_{lscf}) \cdots Q_{lkf} C_{lkf}(z_{lscf}) - Q_{UF} C_{UF}(z_{lscf}) - \Phi_{inf}(z_{lscf}) \\ \Phi_{w1} - Q_{lk1} C_{lk1}(z_{w1}) \cdots Q_{lkf} C_{lkf}(z_{w1}) - Q_{UF} C_{UF}(z_{w1}) - \Phi_{inf}(z_{w1}) \\ \vdots \\ \Phi_{wf} - Q_{lk1} C_{lk1}(z_{wf}) \cdots Q_{lkf} C_{lkf}(z_{wf}) - Q_{UF} C_{UF}(z_{wf}) - \Phi_{inf}(z_{wf}) \\ \Phi_{ref} - Q_{lk1} C_{lk1}(z_{ref}) \cdots Q_{lkf} C_{lkf}(z_{ref}) - Q_{UF} C_{UF}(z_{ref}) - \Phi_{inf}(z_{ref}) \end{pmatrix}$$

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

$$A_{post} = \begin{pmatrix} C_{ls1}(z_{lsc1}) \cdots C_{lsf}(z_{lsc1}) & C_{w1}(z_{lsc1}) \cdots C_{wf}(z_{lscf}) & \\ \vdots & \vdots & 1 \\ C_{ls1}(z_{lscf}) \cdots C_{lsf}(z_{lscf}) & C_{w1}(z_{lscf}) \cdots C_{wf}(z_{lscf}) & \\ C_{ls1}(z_{w1}) \cdots C_{lsf}(z_{w1}) & C_{w1}(z_{w1}) \cdots C_{wf}(z_{w1}) & \\ \vdots & \vdots & 1 \\ C_{ls1}(z_{wf}) \cdots C_{lsf}(z_{wf}) & C_{w1}(z_{wf}) \cdots C_{wf}(z_{wf}) & \end{pmatrix}$$

Solving for unknown postdevelopment discharges using postdevelopment matrices:

$$Q_{post} = \begin{pmatrix} Q_{ls1} \\ \vdots \\ Q_{lsf} \\ Q_{w1} \\ \vdots \\ Q_{wf} \end{pmatrix} = A_{post} \backslash K_{post}$$

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

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

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

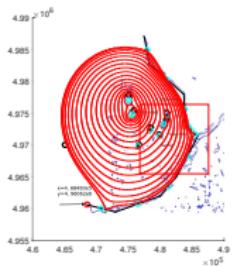
$$\frac{|\phi_{ref\ given} - \phi_{ref\ calculated}|}{\phi_{ref\ given}} \leq 0.001$$

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

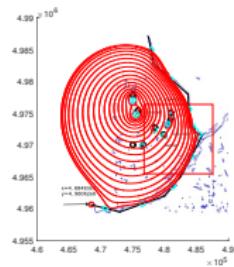
Unverified Preliminary results:

| | $\gamma = 0 \frac{\text{in}}{\text{year}}$ | $\gamma = 6 \frac{\text{in}}{\text{year}}$ | $\gamma = 12 \frac{\text{in}}{\text{year}}$ |
|----------|--|--|---|
| 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 |

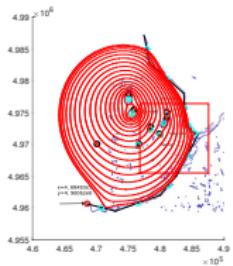
Verification of reference point location: Choosing z_{ref}



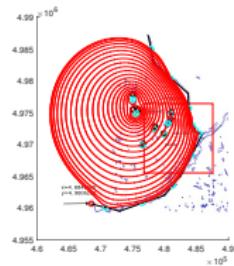
$$z_{ref} = 4.65e5 + i4.97e6, \Phi_{ref} = 5000 \frac{m^3}{day}$$



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



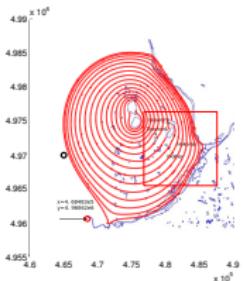
$$z_{ref} = 4.7\text{e}5 + i4.97\text{e}6, \Phi_{ref} = 5000 \frac{m^3}{day}$$



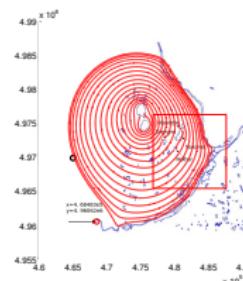
$$z_{ref} = 4.75e5 + i4.9755e5, \Phi = 5000_{ref} \frac{m^3}{day}$$

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

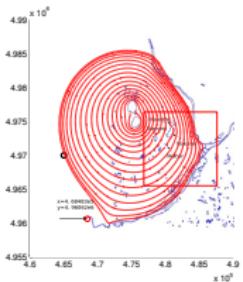
Verification of reference point head: Choosing z_{ref}



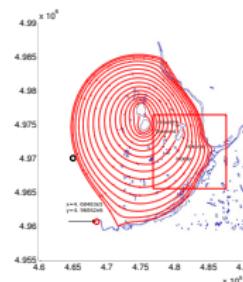
$$z_{ref} = 4.65e5 + i4.97e6, \Phi_{ref} = 15000 \frac{m^3}{day}$$



$$z_{ref} = 4.65\text{e}5 + \text{i}4.97\text{e}6, \Phi_{ref} = 3000 \frac{m^3}{day}$$



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



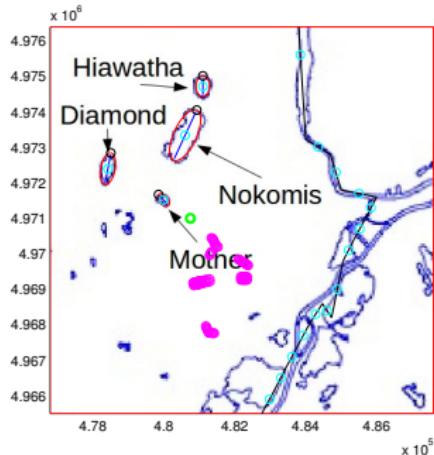
$$z_{ref} = 4.65e5 + i4.97e6, \Phi_{ref} = 10000_{ref} \frac{m^3}{day}$$

$\rightarrow \Phi_{ref}$ 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.

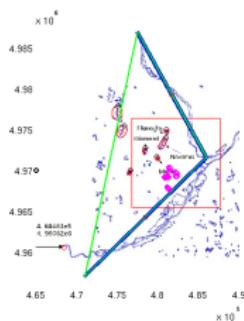


location of well vicinity predevelopment level test

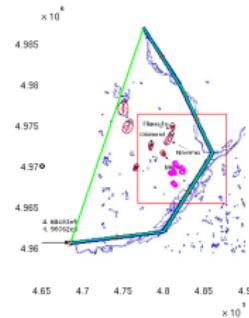
Error Mitigation: Data Collection

| | 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 |

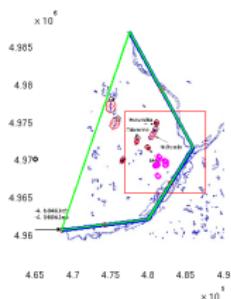
Error Mitigation: Line Sink Quantity



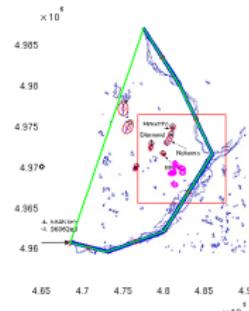
$nLS = 2$



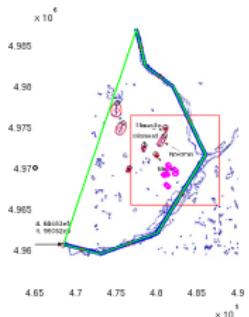
$nLS = 4$



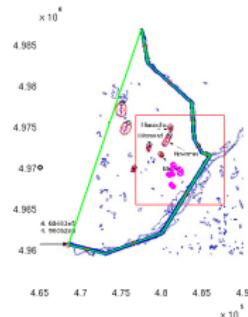
$nLS = 3$



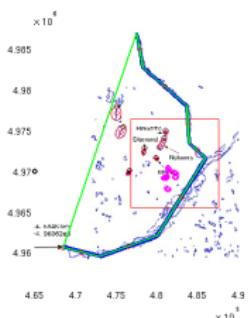
$nLS = 5$



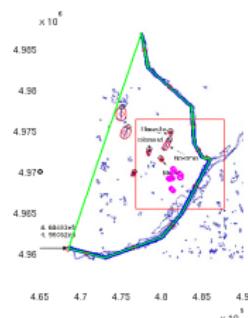
$n_{LS} = 6$



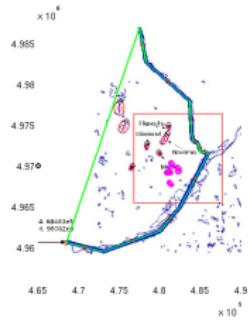
$n_{LS} = 8$



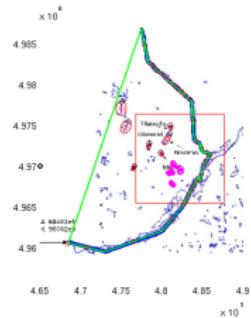
$n_{LS} = 7$



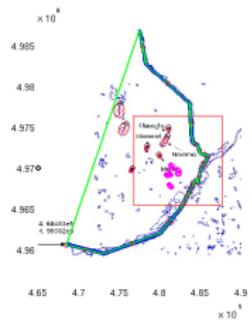
$n_{LS} = 9$



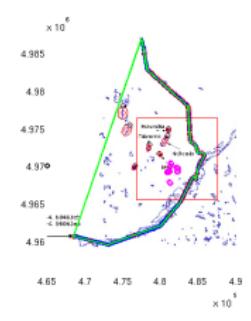
$n_{LS} = 10$



$n_{LS} = 30$

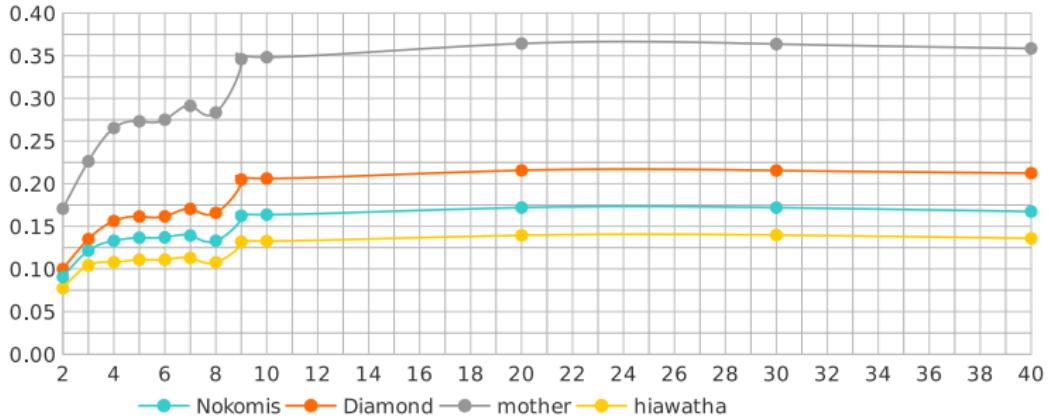


$n_{LS} = 20$



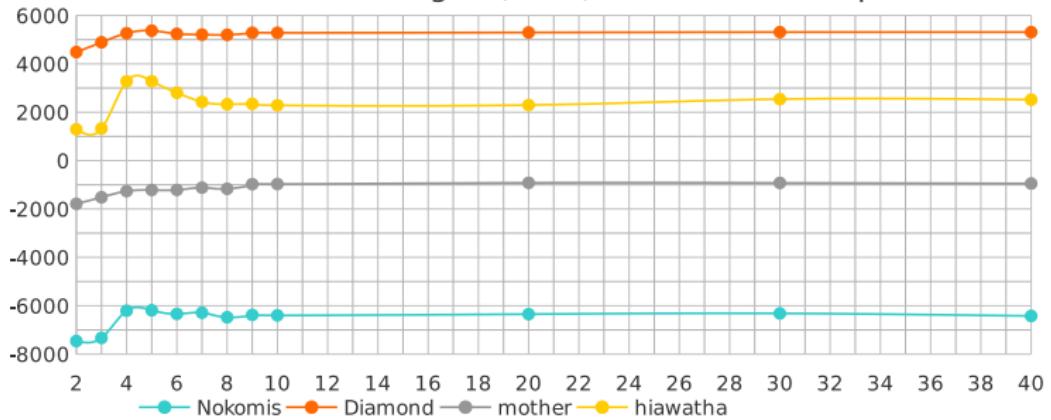
$n_{LS} = 40$

Lake Level Drops (m) vs. Line Sink Quantity, $\gamma = 0$

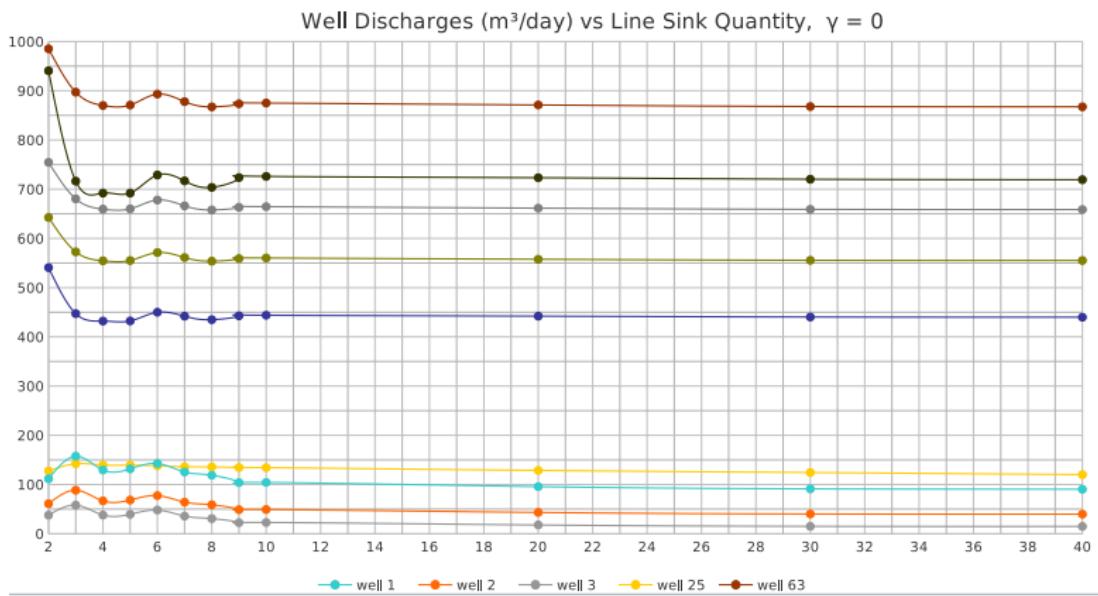


$$\gamma = 0$$

Lake Discharges (m^3/s) vs. Line Sinks, $\gamma = 0$

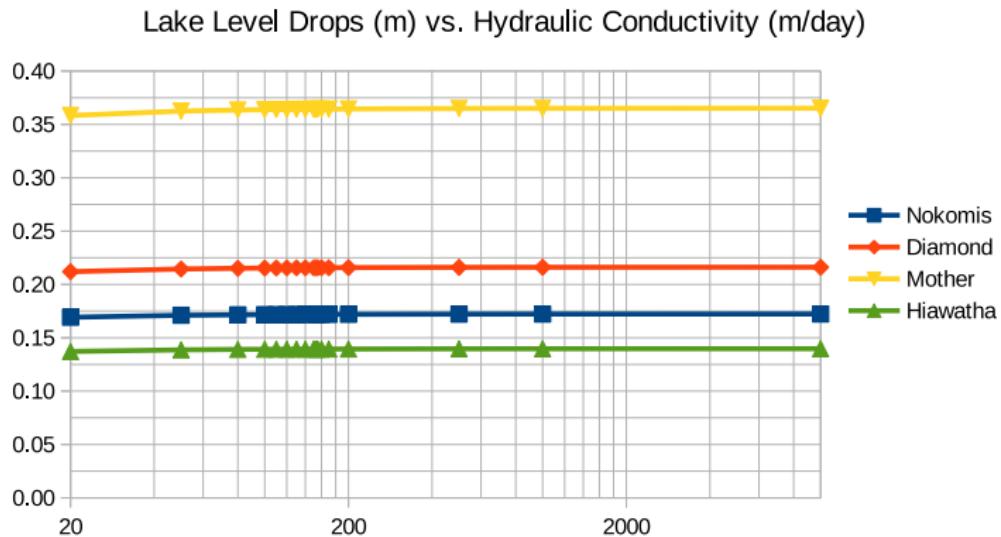


$$\gamma = 0$$



$$\gamma = 0$$

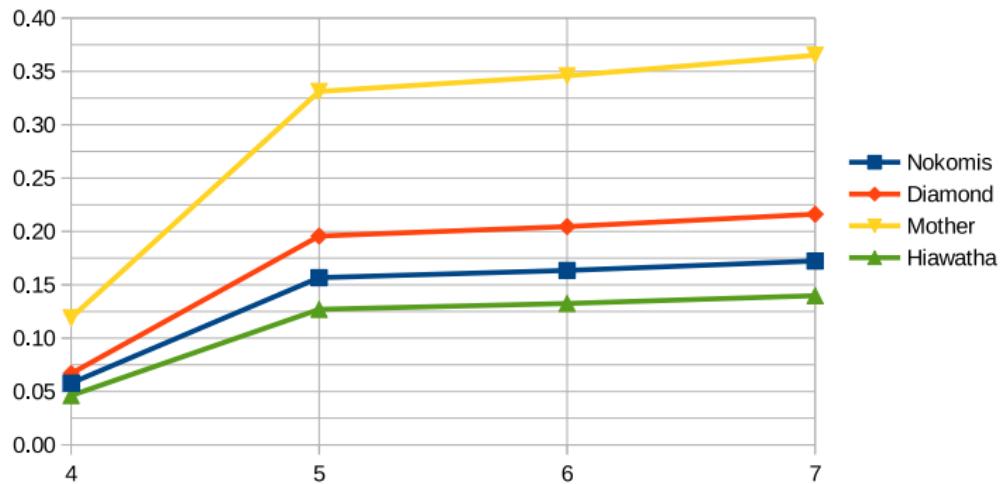
Error Mitigation: Hydraulic Conductivity



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

Error Mitigation: Number of Lakes Modeled

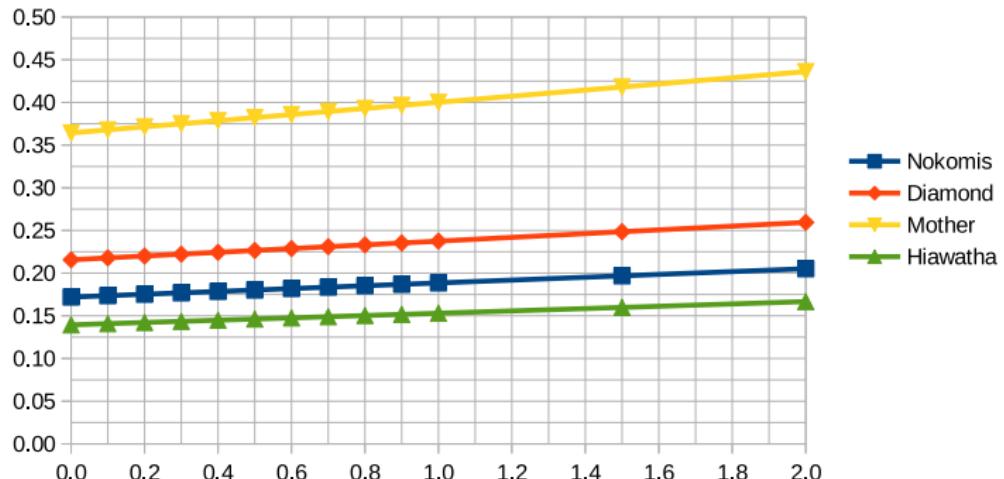
Lake Level Drops (m) vs. Quantity of Lakes Modeled



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

Error Mitigation: Uniform Flow

Lake Level Drops (m) vs. Uniform Flow (m/day)



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

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

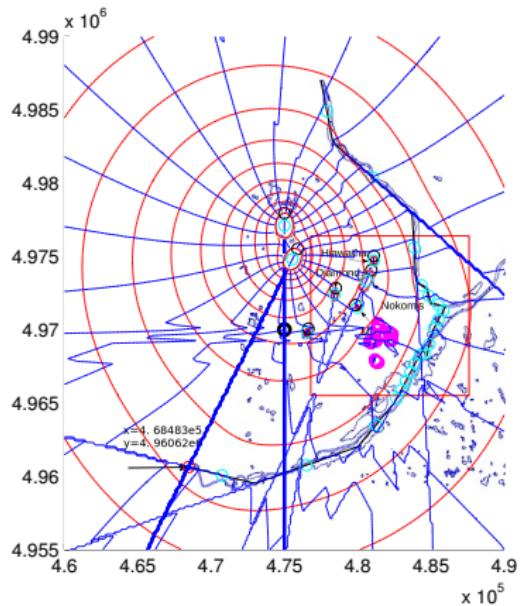
Introduce models for, and most recent lake level readings for:

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

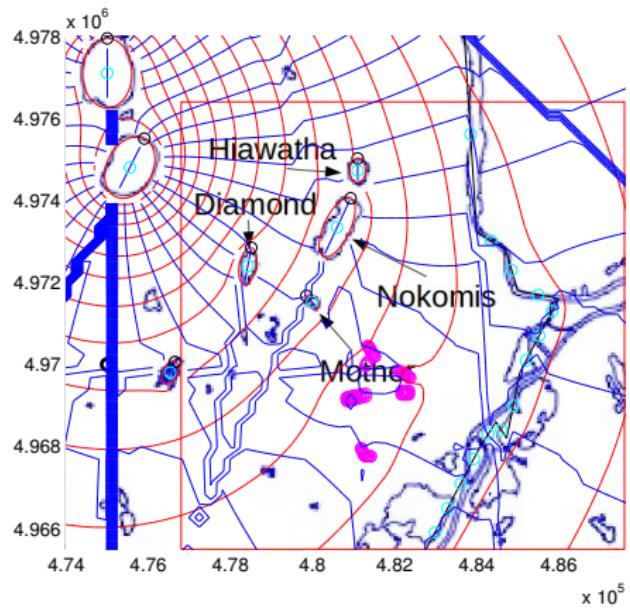
As well as:

- ▶ 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

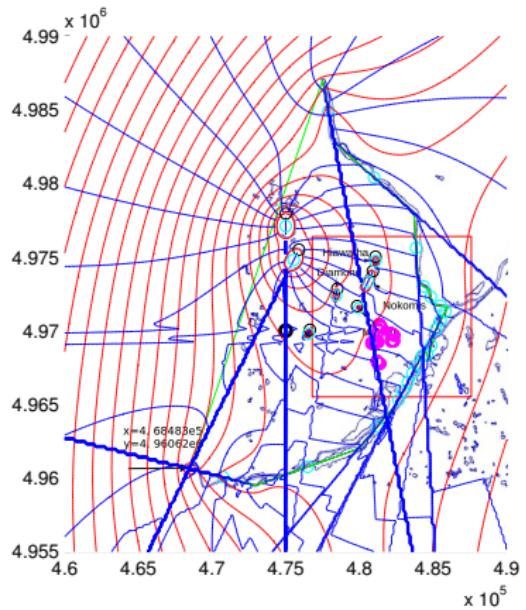
Questions/Comments?



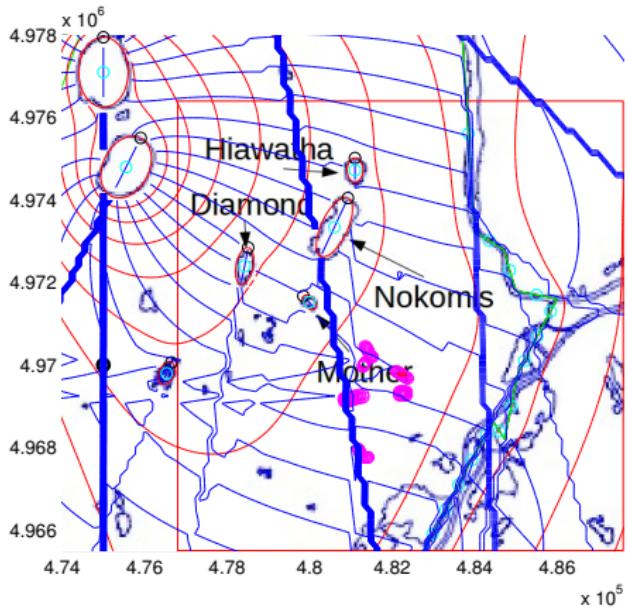
Post-development, no infiltration



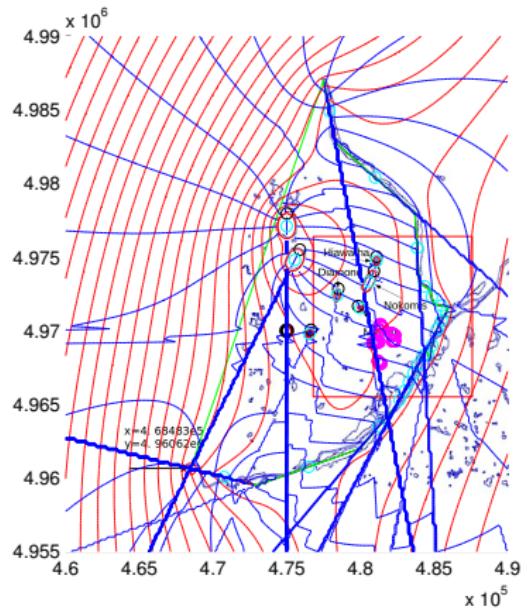
Zoom-in, no infiltration

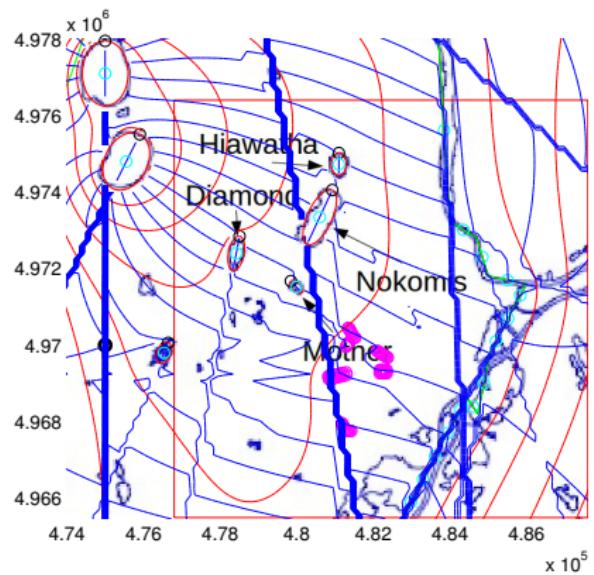


Post-development, $\gamma = 6 \frac{\text{in}}{\text{year}}$



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





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