Appendix 4: Groundwater Optimization Modeling





Technical Memorandum

To:Lanya Ross, Anneka LaBelle, Ali ElhassanFrom:Evan Christianson, Ray WuoloSubject:Metro Pumping Optimization 3Date:April 2, 2015Project:23/62-1087.01

1.0 Introduction

This technical memorandum describes the optimization of pumping in the seven-county metropolitan area. The goal of the optimization was to maximize total pumping from existing permitted wells while meeting constraints on baseflow, hydraulic head, flow direction, and flux to/from surface water features as specified by the Metropolitan Council. The optimization uses the steady-state version of the Twin Cities Metropolitan Area Groundwater Flow Model, Version 3.0 (Metro Model 3; Metropolitan Council, 2014)

Optimizations described in technical memorandums dated August 15, 2014 and October 13, 2014 (Barr, 2014a and Barr, 2014b), herein referred to as Optimization 1 and Optimization 2, are similar and complimentary to the optimization described in this technical memorandum, herein referred to as Optimization 3.

2.0 Optimization Software, GWM-VI

The Groundwater Management (GWM) Process for MODFLOW, developed by the USGS (Ahlfeld et al., 2000), was used for the optimization. The version used was GWM-VI (Banta and Ahlfeld, 2013) which allows for parallel processing. No changes were made to the source code of GWM-VI for implementation of this project. All optimization algorithms described in Banta and Ahlfeld (2013) and Ahlfeld et al. (2005) are implemented with no change. However, several pre- and post-processing steps were used to overcome hardwired limitations on the type of constraints available with the standard GWM-VI implementation and are discussed in Section 2.3. Optimizations utilizing GWM-VI require two main inputs: decision variables and constraints; each is discussed below.

2.1 Decision variables

Decision variables are quantifiable controls that are to be determined by the GWM-VI optimization algorithms (Ahlfeld et al., 2000). Decision variables for both Optimizations 1, 2, and 3 were identical and were provided to us by Metropolitan Council. They include existing permitted wells in the seven-county metropolitan area open to any aquifer, except the Mt. Simon Hinckley aquifer, and with use codes from

the SWUDS database shown in Table 1. A total of 2,074 wells were included in the optimization. The goal of the optimization was to maximize the objective function, which is essentially the sum of the pumping from all decision variable wells.

Use Code	Description	Use Code	Description
211	Municipal	248	Non-metallic processing
212	Private waterworks	249	Industrial processing
213	Commercial and Institutional	263	Quarry dewatering
215	Fire protection	264	Sand/gravel pit dewatering
229	Power generation	266	Dewatering
232	Institutions	271	Pollution containment
241	Agricultural processing	277	Sewage treatment
242	Pulp and paper processing	289	Non-crop irrigation
246	Petroleum-chemical processing, ethanol	290	Major crop irrigation
247	Metal processing		

Table 1. SWUDS use codes for decision variable wells included in the optimization

2.2 Constraints

Constraints impose restrictions on the values that can be taken by the decision variables (Ahlfeld et al., 2000). Three types of constraints were used: hydraulic head, flux between groundwater and surface-water features (baseflow and basin leakage and/or gain), and groundwater flow-direction. In general, Optimization 3 and Optimization 2 are constrained significantly less than Optimization 1. A summary of constraints imposed for each optimization is shown in Table 2 and details describing each constraint type are presented below.

Constraint Type	Optimization 1	Optimization 2	Optimization 3
Drawdown from available head for confined bedrock aquifers above the Mt. Simon-Hinckley	75%	75%	50%
Drawdown in the Mt. Simon-Hinckley aquifer	1 foot	1 foot	1 foot
Drawdown at groundwater dependent surface-water features (cancerous fens)	1 foot	1 foot	1 foot
Change in net baseflow to trout streams	-10%	-10%	-10%
Change in net baseflow to other river reaches	Not included	-15%	-15%
Change in net baseflow to the Mississippi River	Not included	-15%	-25%
Change in net groundwater flux for high and outstanding biodiversity	Not included	-15%	-15%
Change in net groundwater flux to potentially vulnerable lakes with wide littoral zone	Not included	-10%	-10%
Change in net groundwater flux for remaining lakes at grouped by Township	Not Included	-15%	-15%
Change in flow directions at site of groundwater contamination	10 degrees	10 degrees	10 degrees

Optimization 1 constrained the flux between groundwater and surface water for trout streams only. As described in more detail below, Optimizations 2 and 3 constrained the flux between groundwater and surface water for all lakes, streams, and wetlands simulated by Metro Model 3 within the seven-county metropolitan area.

2.2.1 Hydraulic Head Constraints

Hydraulic head constraints were used to impose three conditions on the optimization: 1) hydraulic head in confined bedrock aquifers can't drop below a "safe yield" threshold, 2) hydraulic head in the Mt. Simon– Hinckley aquifer can't drop more than 1 foot from the baseline condition, and 3) hydraulic head at groundwater dependent surface-water features (e.g. calcareous fens) can't drop more than 1 foot from the baseline condition. Hydraulic head, representing "safe yield" thresholds, were defined as:

SafeYieldHead=(Hb-Z)*0.50+Z

Where:

 H_b is the base head condition for the aquifer, defined using pumping from the Metro Model 2; Z is the elevation of the top of the aquifer

The base condition from which drawdown for the Mt. Simon-Hinckley aquifer and groundwater dependent surface-water features were determined was the hydraulic head from the steady-state version of the Metro Model 3.

Hydraulic head constraints representing "safe yield" and limits on drawdown of the Mt. Simon-Hinckley aquifer were implemented at the cell location (row and column) of all pumping wells in the seven-county metro area. Including these head constraints in every model cell is not practicable as it would dramatically increase the total run time for the optimization. These head constraints are more likely to be violated at the location of high pumping stress, compared to distances far from the wells. Vertically, at each cell location, constraints were included only for model layers representing bedrock aquifers being pumped and layers above these aquifers. For example, if the Prairie du Chien is being pumped and lower aquifers are not being pumped, "safe yield" constraints were only included for the Prairie du Chien and St. Peter aquifer, not the deeper aquifers.

2.2.2 Flux between groundwater and surface-water features

All surface-water features in the Metro Model 3 are simulated using the River Package for MODFLOW. The River Package simulates the exchange of water between groundwater and surface water. River Package boundary cells were compiled into groups and the water fluxes into or out of the boundary cells were tracked and summarized for each group. Constraints were imposed to limit the change in flux from the baseline condition resulting from increased pumping. The baseline condition used was the flux simulated with the steady-state version of Metro Model 3.

Groundwater flux to all streams (baseflow) in the seven-county metropolitan area was constrained for the optimization (Figure 1). Each stream was divided into reaches approximately 5 miles in length. Baseflows for trout stream reaches are not allowed to be reduced by more than 10 percent from the baseline conditions. Baseflows for all other reaches, with the exception of the Mississippi River, are not allowed to be reduced more than 15 percent from baseline conditions. Baseflows for the Mississippi River were allowed to be reduced up to 25 percent. A total of 13 trout stream baseflow constraints and 79 non-trout stream baseflow constraints were imposed for the optimization.

River boundary cells that intersect sites of high and outstanding biodiversity identified by the Minnesota County Biological Survey (2013) were grouped together (Figure 1). The groundwater flux into these features was not allowed to decrease more than 15 percent and/or flux out of these features was not allowed to increase more than 15 percent from the baseline simulation. A total of 108 biodiversity area constraints were imposed.

River Package boundary cells that represent lakes identified as being potentially vulnerable to groundwater pumping and having a wide littoral zone (Barr, 2010) were grouped together (Figure 1).

Lakes are considered to have a wide littoral zone if they are less than five feet deep over more than 20 percent of the total surface area. These lakes have a greater potential of being negatively impacted by reductions in stage. For these lakes (68 in the seven county metropolitan area), the water flux out was not allowed to increase more than 10 percent and/or the groundwater flux into these lakes was not allowed to decrease more than 10 percent.

All remaining River Package boundary cells that were not included in groups described above were grouped based on the public land survey township they are located in (Figure 1). This resulted in an additional 103 constraints. For these grouped boundary cells, the total groundwater flux in was not allowed to be reduced by more than 15 percent and/or total water flux out was not allowed to increase more than 15 percent. Grouping these River Package cells, rather than imposing constraints on individual cells or surface water features, was necessary to help keep the total number of constraints to a manageable level to maintain reasonable solution times for the optimization algorithm.

2.2.3 Flow Direction Constraints

Flow direction constraints for Optimizations 1, 2, and 3 are identical and were included for areas of existing groundwater contamination provided by the Metropolitan Council. The flow direction in the vicinity of these contamination areas was not allowed to deviate from the baseline condition by more than 10 degrees. The baseline condition used was the flow direction simulated with the steady-state version of Metro Model 3.

2.3 Substitution of MMProc

GWM-VI uses a stand-alone executable, *MMProc.exe*, to write MODFLOW input files, execute MODFLOW, and extract head and cell-by-cell flow values from MODFLOW output files. *MMProc.exe* is hardwired to only read output from a small number of MODFLOW packages. Two major limitations of *MMProc.exe* necessitated the development of a separate and much more flexible pre- and post-processor: inability to read/write data for the River Package, and implementation of groundwater flow-direction constraints. Pre- and post-processing for Optimization 2 and Optimization 3 are identical. Pre- and post-processing Optimization 1 involved less constraints associated with River Package boundary cells. Description of the pre- and post-processing steps described in the technical memo from August 14, 2014 and is repeated below for completeness.

A python script, *pyMMProc.py*, was developed to handle the capabilities of *MMProc.exe* while being more flexible and allowing use of the River Package and flow-direction constraints. A comparison of how *MMProc.exe* and *pyMMProc.py* interact with GWM-VI and MODFLOW is shown on Figure 2a and Figure 2b.

The source code for this script is provided with the project deliverables and is documented internally. A brief description of how the script works is provided below for those not familiar with the python programing language.

GWM-VI creates a file called *MMProc.in.jtf* at the start of an optimization run that acts as a template file for well pumping rates. Throughout the optimization, GWM-VI (or a runner program called *jrunner* if running in parallel mode) uses *MMProc.in.jtf* to create a file called *MMProc.in* which contains pumping rates for MODFLOW to use. Updated pumping rates are pulled from *MMProc.in* and used by *pyMMProc.py* to generate a new Well (WEL) Package and Revised Multi-Node Well (MNW2) Package files for MODFLOW. *pyMMProc.py* then executes MODFLOW.

After MODFLOW is completed, *pyMMProc.py* extracts hydraulic head and river flux data from MODFLOW output files associated with the head and river observation packages. Selected hydraulic head data are used to calculate groundwater flow-directions by solving a three-point problem. The deviation in groundwater flow direction from a provided base condition is then determined. The change in river flux from the base condition is also calculated. All hydraulic head, change in flow direction, and change in river flux are written to a file called *Simulated_Values.out* which is read directly by GWM-VI.

pyMMproc.py also checks to make sure that MODFLOW converged and that no pumping rates were reduced by the MNW2 or Upstream Weighting (UPW) Package. Convergence status and pumping rate status are written to a file called *modflow.status* which is read directly by GWM-VI.

The use of pyMMproc.py necessitates slight modifications on how GWM-VI input files are set up that may not be initially intuitive. Input files were set up to treat all constraints, including baseflow and flow-direction constraints as head constraints. All constraint types are included in the head constraints (HEDCON) input file. This was necessary due to GWM-VI only supporting the Stream Package, whereas the Metro Model 3 uses the River Package. If GWM-VI input files were set up using the stream constraints (STRMCON) input file, GWM-VI would expect to find a Steam Package, which does not exist for Metro Model 3.

2.4 Limitations of GWM-VI

During the course of this optimization several hindrances were encountered that relate to the GWM-VI software. We have notified the developers of GWM-VI about these issues; however, there is currently no timeline for fixing them. A discussion of these issues and current workarounds to each are described below.

1.) **Solving of the linear program (LP) is not optimized or parallelized**. The SLP solver used by GWM-VI has two main phases: 1) calculation of the response matrix, which requires MODFLOW to

be run once for every decision variable and 2) solving the LP. Previous versions of GMW (prior to GWM-VI) were not able to run is a parallel or distributed fashion. So, calculation of the response matrix was by far the most time consuming phase of solving the optimization problem. With the introduction of parallel processing in GWM-VI, calculation of the response matrix can be completed in a fraction of the time previously required, given that enough processors are available. During this project, we used up to 75 processors for calculating the response matrix. Solving the LP is not parallelized and must be completed on a single processor. The solution time for a single LP problem is roughly proportional to the number of constraints cubed.

2.) **Pumping from multi-node wells being reduced.** Wells simulated with the MNW2 Package can have their pumping rate automatically reduced if the head in the well or surrounding aquifer drops to levels that would not be able to supply the specified pumping rate for a well. This is an unfavorable occurrence for the GWM-VI algorithms because constraints may be met only because the pumping was automatically reduced by MODFLOW. GWM-VI overcomes this issue by checking information in the *modflow.status* file written by MMproc (or pyMMproc). If any wells have their pumping reduced it is indicated in the *modflow.status* file and GWM-VI automatically reduces pumping rates for all wells based on equation 73 in Ahlfeld (2005) and attempts an additional MODFLOW simulation. This continues iteratively until all MNW2 wells pump at the specified rates. The problem with this approach is that all wells have their pumping reduced if just a single MNW2 well is causing a problem. So, if many iterations of reducing pumping from all wells are required to prevent a single MNW2 well from pumping at a rate less than specified there is very little change in the total pumping.

Overcoming this issue required stopping GWM-VI at each iteration of the SLP solver and adjusting pumping rates wells that were causing problems. Implementing this process dramatically increased progress of the optimization. The process of adjusting pumping rates was automated for Optimization 2 and Optimization 3 but still required manually stopping and restarting GWM-VI at each iteration.

3.0 Results of Optimization

3.1 Pumping Rates

Total optimized pumping from the wells included in the optimization is 374 million gallons per day (MGD). This represents a 43-percent increase in the base pumping of 261 MGD, which is the pumping from the steady-state version of the Metro Model 3 and represents average pumping from 2003 to 2011. A comparison of optimized total pumping rates for Optimizations 1, 2, and 3 is shown in Table 3.

Optimization	Total optimized pumping (MGD)
1	743
2	368
3	374

Table 3. Comparison of results from Optimization 1, 2, and 3.

Further analysis of the optimized pumping is beyond the scope of this project but it is our understanding that it will be completed by the Metropolitan Council. However, we have tried to provide the Metropolitan Council with some insight, based on what we learned during the optimization process and a cursory inspection of the results. A discussion is provided in Section 4.0 below.

3.2 Binding constraints and shadow prices

While 5,237 constraints were imposed for the optimization, only a subset actually controls the formulation of an optimal solution. These constraints are said to "bind" the solution because they prevent decision variables (well pumping) from taking values that would further improve the optimization. Each binding constraint has a "shadow price" which reflects how sensitive the optimization is to the constraint. For additional discussion of binding constraints and shadow prices the reader is referred to Ahlfeld et al. (2005) pg. 51. Binding constraints and associated shadow prices calculated by GWM-VI during the last iteration of the optimization are presented in Attachment A. A total of 184 (out of 5,237 total) constraints were found to be binding. Overall, baseflow constraints (trout and other streams) were the most sensitive, constituting 12 of the top 30 constraints with the largest shadow price. Table A2 summarizes binding constraints by constraint type. Figure 3 shows the spatial distribution of binding constraints.

4.0 Discussion

Analysis of the optimization results are not part of the scope of this project and it is our understanding that such analysis is planned to be completed by Metropolitan Council staff. However, the following observations were noted during this project and may warrant further review, discussion, or follow-up optimization.

 Optimization 1 showed large increases in pumping sustained by induced leakage from River Package boundary cells. Significantly increasing the constraints imposed on River Boundary cells for Optimization 2 greatly reduced these issues, and hence reduced the total optimized pumping volumes. Optimization 3 imposed strictor constraints regarding safe yield (50% available head vs. 75% available head) and less restrictive constraints on baseflow to the Mississippi River. Overall Optimization 3 resulted in slightly more pumping than Optimization 2, primarly because the optimization is very sensitive to constraints imposed on baseflow of the Mississippi River. There may still be areas where induced leakage may be occurring beyond sustainable levels but are highly local and smaller than the scale to which we can impose constraints.

- 2.) Many of the constraints with the largest shadow price (see Section 3.2) are reaches of the Mississippi River. A constraint imposing no more than a 25 percent reduction in baseflow from baseline conditions was used for these reaches. Because these reaches are major groundwater discharge zones for the region, many wells, particularly in the deeper aquifers, affect baseflow to these reaches by capturing flow that would go to the river under lower pumping conditions. It should be noted that the constraint imposed does not represent a 25 percent reduction in total flow; the vast majority of flow comes from upstream. Allowing for a greater reduction in baseflow to these reaches would result in a higher optimized pumping volume, potentially significantly higher given the magnitude of the shadow price for these constraints.
- 3.) For some communities, the optimized pumping scheme results in municipal pumping being reduced to nearly zero. The reality and feasibility of such a scenario is uncertain.
- 4.) This type of optimization is very non-linear and typically non-unique. It is very likely that different distributions may result in nearly identical total pumping. We believe the addition of more constraints for Optimizations 2 and 3 has helped move toward the more unique solution. However, the level of uniqueness has not been quantified.

Limitations of the model, optimization, and choice of wells and constraints should be carefully considered when using these results for long-term planning. The optimization was limited to only existing wells and assumes that conditions have reached steady-state. New wells, added in undeveloped areas or aquifers, would certainly increase the total pumping of the region while still meeting imposed constraints. Also, in certain areas local concerns such as well interference or impacts to surface waters not accurately simulated at the scale of the Metro Model 3 may be deemed unacceptable even though all constraints imposed were met.

5.0 References

- Ahlfeld, D.P., Barlow, P.M. and Mulligan, A.E., 2005. GWM—A ground-water management process for the U.S. Geological Survey modular ground-water model (MODFLOW-2000): U.S. Geological Survey Open-File Report 2005-1072, 124p.
- Banta, E.R. and Ahlfeld, D.P., 2013. GWM-VI—Groundwater Management with parallel processing for multiple MODFLOW versions: U.S. Geological Survey Techniques and Methods, book 6, chap. A48, 33p.

- Barr Engineering. 2014a. Metro Pumping Optimization, Technical Memorandum from Evan Christianson and Ray Wuolo to Lanya Ross, Anneka LaBelle, and Ali Elhassan, August 15, 2014.
- Barr Engineering. 2014b. Metro Pumping Optimization 2, Technical Memorandum from Evan Christianson and Ray Wuolo to Lanya Ross, Anneka LaBelle, and Eli Elhassan, October 13, 2014.
- Metropolitan Council, 2014. Twin Cities Metropolitan Area Regional Groundwater Flow Model, Version 3.0. Prepared by Barr Engineering. Metropolitan Council: Saint Paul, MN.
- Minnesota County Biological Survey. 2013. MBS Sites of Biodiversity Significance, Minnesota Department of Natural Resources, Division of Ecological Resources, shapefile geospatial data.



River Packge Boundary Cell Constraints



Biodiversity Area Stream/River

Trout Stream

Township Range Group

Vulnerable Basin





Figure 1

RIVER PACKAGE BOUNDRY CELL CONSTRAINTS Pumping Optimization 3 Metropolitan Council

1a. Interaction of MMProc with GWM-VI and MODFLOW



1b. Interaction of pyMMProc with GWM-VI and MODFLOW





Binding Hydraulic Head and Safe Yield Constraints

Shadow Price

- > 1.50e+008
- 1.26e+008 1.50e+008
- 1.01e+008 1.25e+008
- 7.51e+007 1.00e+008
- 5.01e+007 7.50e+007
- 2.51e+007 5.00e+007
- < 2.50e+007

Binding River Boundary Constraints









BINDING CONSTRAINTS Pumping Optimization 3 Metropolitan Council

Attachment A

Binding Constraints and Shadow Prices

Table A-1
Binding Constraints and Shadow Price

Constraint Name	Description	Row	Col	Absolute Shadow Price
Riv 016	Mississippi River (Downtown St. Paul)			3.14E+08
Riv 013	Mississippi River (N. Minneapolis, Fridley, Brooklyn Center)			2.96E+08
r28 R22	Township 28, Range 22			2.56E+08
ГЗ2 R21	Township 32 Range 21			2.04E+08
Riv 165	Mississippi River / Sping Lake			2.00E+08
T115_R23	Township 115, Range 23			1.84E+08
Riv 018	Mississippi River (S. St. Paul, Invergrove Heights, Newport, St. Paul Park)			1.84E+08
Riv 136	Cannon River (Northfield, Randolph)			1.73E+08
/ul_083	Crosby Lake			1.62E+08
Riv_120	Minnehaha Creek (Minnetonka, Hopkins, St. Louis Park)			1.57E+08
Riv_055	Minnesota River (Chaska, Carver)			1.54E+08
Γ29_R21	Township 29 Range 21			1.50E+08
Riv_017	Mississippi River (St. Paul)			1.48E+08
Г30_R20	Township 30 Range 20			1.33E+08
T29 R23	Township 29 Range 23			1.32E+08
	Chub Creek			1.20E+08
/ul 023	Powers Lake			1.14E+08
Frout 03	Eagle Creek			1.13E+08
	Township 27 Range 21			
F27_R21				1.12E+08
F115_R19	Township 115 Range 19			1.12E+08
Bio_083	Ravenna 17			1.11E+08
Riv_121	Minnehaha Creek (St. Louis Park, Edina)			1.05E+08
Riv_033	Crow River (Rogers, St. Michael)			1.04E+08
Frout_07	Trout Brook			9.39E+07
Frout 12	Vermillion River (Empire)			9.00E+07
Riv 041	Crow River (Watertown, Delano)			8.60E+07
Bio 026	Rice Lake Natural Area			8.50E+07
T119 R21	Township 119 Range 21			8.19E+07
Bio 038				
	Chub Lake South			8.06E+07
/ul_066	Bryant Lake			7.91E+07
T28_R24	Township 28 Range 24			7.70E+07
3io_031	Sedil East			7.61E+07
3io_009	Mud Hen Lake Area			7.44E+07
Riv_113	Elm Creek (Maple Grove, Champlin, Dayton)			7.42E+07
Г119 R22	Township 119 Range 22			7.40E+07
	Township 32 Range 23			7.29E+07
Г114 R16	Township 114 Range 16			6.85E+07
ГЗ1 R22	Township 31 Range 22			6.78E+07
Trout 11	Vermillion River (Farmington, Empire Twp)			6.76E+07
T32 R25	Township 32 Range 25			
				6.69E+07
/ul_005	Coon Lake			6.65E+07
Г117_R24	Township 117 Range 24			6.53E+07
3io_068	Linwood 5 Natural Area			5.99E+07
/ul_004	Byllesby Lake			5.63E+07
F28_R20	Township 28 Range 20			5.57E+07
/ul_016	George Lake			5.33E+07
Г34_R23	Township 34 Range 23			5.29E+07
CM207 296	Mt. Simon Hinckley	207	296	5.07E+07
r29 R24	Township 29 Range 24			4.71E+07
/ul 064	Centerville Lake			4.62E+07
				1
/ul_035	Medicine Lake			4.48E+07
Bio_002	Ninninger West			4.35E+07
/ul_065	Ham Lake			4.31E+07
Riv_011	Mississippi River (Champlin, Coon Rapids, Brooklyn Park)			4.22E+07
Г115_R21	Township 115 Range 21			4.11E+07
Riv_148	S. Branch Vermillion River (Castle Rock Twp.)			4.10E+07
Г113_R19	Township 113 Range 19			3.88E+07
Frout 13	S. Branch Vermillion R. (Castle Rock Twp, Empire Twp., Vermillion Twp.)			3.88E+07
Г120 R23	Township 120 Range 23			3.82E+07
T31 R20	Township 31 Range 20			3.74E+07
CM296 141	Mt. Simon Hinckley	296	141	3.48E+07
—			141	
/ul_058	Gervais Lake			3.42E+07
Bio_007	St. Lawrence 13			3.32E+07
Frout_09	Vermillion River (Eureka Twp.)			3.29E+07
Riv_115	Rice Creek (Mounds View, Arden Hills, Shoreview)			3.26E+07
CM219_107	Mt. Simon Hinckley	219	107	3.19E+07
Bio 074	Conley Lake Backwaters			3.17E+07
/ul 003	Turtle Lake			3.13E+07
Bio 078	North Ninninger 34			3.12E+07
rout 10				
	Vermillion River (Lakeville, Farmington)			3.07E+07

Jul 089Bore lakeImage 23Image 2		Binding Constraints and Shadow Price			
MJ 089Bone biaSouth 0South 0AU 047Whete Bare Lake2.946-00AU 047Whete Bare Lake2.946-002.946-00AU 242, M32Mt Some Hinsky2.246-00SWA1Gun Cab Lake South2.246-00SWA1Gun Cab Lake South2.246-00SWA1Assumption Creek2.246-00MU 128Mt Some Hinsky2.246-00MU 129Mt Some Hinsky<					Absolute
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Jul 001Optimate SizeImage SizeImage SizeSize Size SizeSize Size SizeSize Size SizeSize Size SizeSize Size SizeSize Size Size SizeSize Size Size SizeSize Size Size Size Size Size SizeSize Size Size Size Size Size Size Size					
bit Num Mile Creek					
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M322 143Mt. Sinon Hinckey2211432734-00115 1627Township 115 Range 22	T114_R20				2.83E+07
SWM1 Dur Club lake South - - - - 2.245-00 W1_26 Purgatory Creek - - 2.2454-00 Trout_D1 Assumption Creek - - 2.2454-00 W1_Ston Township 138 Range 21 - - 2.2454-00 W1_Ston Durnship 138 Range 21 - - 2.3454-00 W1_920 Canver Creek - - 2.3454-00 W1_920 Canver Creek - - 2.2124-00 W1_920 Hermillon Riser (Vermillion) - - 2.2124-00 W1_920 Herminia Lake - - 2.2124-00 W1_920 Herminia Lake - - 2.2124-00 W1_920 Herminia Lake - - 2.2124-00 W1_921 Township 27 Range 22 - - 1.8454-00 W1_924 Township 27 Range 22 - - 1.924-00 W1_924 Township 219 Range 24 - - 1.924-00	CM232_143	Mt. Simon Hinckley	232	143	2.73E+07
N: 126 Purgatory Creek	T115_R22				
Inst. Assumption Creek Inst. Inst. <thinst.< th=""> <thinst.< th=""> Inst.</thinst.<></thinst.<>					
M217 218 Mt. Simon Hindley 127 218 2 0 2006-00 NU 128 Township 138 Range 21	-				
T18 ft12 Township 118 Range 21 2 2565-00 No 122 Umanuel (furmwille) 2 406-00 No 071 Carver Creek 2 406-00 No 070 Carver Creek 2 255-00 No 080 Empire 15 2 255-00 No 060 Ear Northigh Range 22 2 125-00 No 060 Ear Rosemourt 18	CM217 218			<u> </u>	
1117 B23 Township 117 Range 23	T118_R21	Township 118 Range 21			2.56E+07
Number of the symbolCaracter of the	Riv_132				2.48E+07
Bin 099 Empire 15 main 12			-		2.40E+07
wiy 150 Vermillion River (Vermillion) 2.234-00 vij 062 Hannan Lake 2.124-00 129. B22 Township 9 Range 22 2.124-00 150. 066 East Roemount 18 2.034-00 1701 U. 05. Pine Creek 1.884-00 1729. R22 Township 27 Range 22 1.884-00 180. MS Basset Creek (Pymouth, Golden Valley) 1.884-00 190. MZ20 116 Mt. Simon Hinckley 1.884-00 101. 050 Upper Prior Lake 1.584-00 101. 090 Upnamed (Cottage Grove) 1.584-00 101. 091 Dean's Lake 1.584-00 112. R22 Township 118 Range 13 1.514-00 113. R18 Township 118 Range 13 1.514-00 114. R22 Township 116 Range 12 1.514-00 114. R18 Township 116 Range 13 1.514-00 1114. R19 Town					
Vul 062 Hannan Lake	_				
12912912012012					
Bio. 066 East Rosemouri 18 2.114-00 Torut, 06 Pine Creek 2.031-00 Ty, 118 Basset Creek (Pymouth, Golden Valley) 1.881-00 MV 118 Basset Creek (Pymouth, Golden Valley) 1.881-00 MU 050 Upper Prior Lake 1.672-00 Vul 059 Upper Prior Lake 1.681-00 Vul 059 Upper Prior Lake 1.684-00 Vul 059 Upper Nor Lake 1.684-00 Vul 021 Big Marine Lake 1.684-00 Vul 021 Big Marine Lake 1.514-00 Vul 021 Big Marine Lake 1.	T29 R22				-
127. 622 Township 27. Range 22 - - - - 188-00 Wh 118 Baset Creek (Pymouth, Golden Valley) 260 116 18.90-00 T19. R2A Township 119 Range 24 - - - 17.77-00 Vul. 050 Upper Prior Lake - - 17.77-00 1.982-00 Vul. 049 Unnamed (cottage Grove) - - - 1.684-00 Vul. 049 Densit Lake - - 1.684-00 130. 019 Densit Lake - - 1.684-00 132. R24 Township 134 Range 18 - - 1.514-00 1114. R18 Township 114 Range 17 - - 1.514-00 N124. Zownship 116 Range 22 Its mange 17 - - 1.514-00 N116. R32. Township 116 Range 21 - - - 1.514-00 N126 Sand Creek (prockn) - - 1.054-00 N116 Township 116 Range 21 - - 1.054-00	Bio_066				2.11E+07
Number Basset Creek (Plymouth, Golden Valley)	 Trout_06				2.03E+07
XM260 INT. Simon Hinckley Xm Tills PAX Township 119 Range 24	T27_R22				1.88E+07
T19. R24 Township 118 Range 24 1.772-00 Vul 050 Upper Prior Lake 1.681-00 Vul 050 Long Lake 1.681-00 030 019 Dean's Lake 1.681-00 123 gE24 Township 23 Range 24 1.611-00 124 gE24 Township 131 Range 17 1.515-00 1114 R18 Township 118 Range 17 1.515-00 1154 R17 Township 116 Range 22 1.195-00 1154 R12 Township 116 Range 22 1.195-00 1156 R22 Township 116 Range 19 1.095-00 N100 Sand Creek (lordan)					
Vul. 050 Upper Prior Lake 1.72E-00 Vul. 049 Unnamed (Cottage Grove) 1.68E-00 Vul. 049 Long Lake 1.68E-00 030. 019 Dean's Lake 1.68E-00 132. R24 Township 32 Range 24 1.68E-00 Vul. 021 Big Marine Lake 1.55E-00 Vul. 024 Township 114 Range 18 Vul. 024 Marine Lake 1.55E-00 Vul. 024 Mission Hinckley 264 254 1.36E-00 Vul. 024 Mission Hinckley 1.35E-00 Vul. 044 Nice Mile Creek 1.35E-00 Vul. 100 Sand Creek (Jordan) 1.05E-00 Vul. 045 Sand Creek (Jordan) 1.05E-00 Vul. 046 Unnamed (Enpire Twp.) 1.05E-00 01. 097 Camp Hiduhapi 7.20E-00					
Wul_049 Umamed (cottage Grove) 1.668-00 040 Deg Lake 1.668-00 030 D19 Dean's Lake 1.668-00 032 R24 Township 32 Range 24 1.618-00 01/021 Big Marine Lake 1.518-00 01/021 Big Marine Lake 1.518-00 1114 R18 Township 114 Range 18 1.518-00 M1264 Mt. Simon Hinckley 264 254 1.348-00 N124 Nine Mile Creek 1.108-00 Ni 100 Sand Creek Lordan) 1.008-00 Ni 124 Nine Mile Creek 1.008-00 1.008-00 Ni 144 Sange 19 1.056-00 1.056-00 Ni 120 Camp Hduhapi 1.056-00 1.056-00	-				
Vul. 009 Long Lake 1.68E-00 100 Dean's Lake 1.64E-00 132, R24 Township 32 Range 24 1.64E-00 132, R24 Township 32 Range 24 114, R18 Township 114 Range 18 1115, R17 Township 114 Range 18 1115, R17 Township 116 Range 21 1116, R22 Township 116 Range 22 1117, R18 Township 116 Range 19 1114, R19 Township 114 Range 19 114, R19 Township 114 Range 17 114, R19 Township 114 Range 17 112, R17 Township 120 Range 21 1120, R21 <td>Vul_030</td> <td></td> <td></td> <td></td> <td></td>	Vul_030				
Jio 019 Dean's Lake 1.664-00 J32 124 Township 124 Range 24 1.517-00 J01 021 Big Marine Lake 1.537-00 J114 R18 Township 114 Range 13 1.538-00 J114 R18 Township 114 Range 17 1.518-00 J116 R22 Township 114 Range 22 1.958-00 Nine Mile Creek 1.958-00 Nin 100 Sand Creek (Jordan) 1.958-00 Nin 100 Sand Creek (Jordan) 1.958-00 Sin 097 Camp Hothapi	Vul_009				1.68E+07
Jul 201 Big Marine Lake	Bio_019	Dean's Lake			1.64E+07
T114 R18 Township 114 Range 18 1.55E-00 T115 R17 Township 115 Range 17 264 254 1.35E+00 M264_254 Mt. Simon Hinckley 264 254 1.36E+00 N124 Nine Mile Creek 1.19E+00 Niv 124 Nine Mile Creek 1.09E+00 Niv 124 Nine Mile Creek 1.09E+00 Niv 100 Sand Creek (Jordan) 1.09E+00 Sile Spession Mt. Simon Hinckley 159 255 1.07E+00 Sile Og07 Camp Hduhapi 9.37E+00 Niv 146 Unnamed (Empire Twp.) 8.25E+00 Sile Og0 Pigs Eye SNA 7.28E+00 Sile Og1112 R12 Township 120 Range 21 7.28E+00 Sile Og1 Belwin Gravel Pit 7.28E+00 Sile Og1 Belwin Gravel Pit 5.35E+00 Sile Og1 Downship 13 Range 21	T32_R24				1.61E+07
T115 Bt7 Township 115 Range 17 1515-00 DX264 254 Mt. Simon Hinckley 264 254 1.34 Ev0 Township 116 Range 22 Township 116 Range 22 1.19 Ev0 Nin 200 Sand Creek (Jordan) 1.19 Ev0 Nin 100 Sand Creek (Jordan) 1.09 Ev0 T14 R19 Township 114 Range 19 1.09 Ev0 N159, 255 Mt. Simon Hinckley 159 255 1.07 Ev0 Sin 097 Camp Hduhapi 9.37 Ev0 N257 178 Mt. Simon Hinckley 257 178 8.48 Ev0 Sio_060 Pigs Eve SNA 7.28 Ev0 Sio_0511 Belwin Gravel Pit 7.80 Ev0 Sio_0511 Belwin Gravel Pit 6.81 Ev0 Sio_0511 Belwin Gravel Pit 6.31 Ev0 Sio_0511 Belwin Gravel Pit 6.31 Ev0 Sio_0511 Belwin Gravel Pit	-				
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T116 R22 Township 116 Range 22 1.19E+00 Niv 124 Nine Mile Creek 1.19E+00 Niv 100 Sand Creek (Jordan) 1.09E+00 T114 R19 Township 114 Range 19 1.09E+00 N159 255 Mt. Simon Hinckley 159 255 1.07E+00 N159 257 Mt. Simon Hinckley 9.37E+00 N257 178 Mt. Simon Hinckley 257 178 8.48E+00 N257 178 Mt. Simon Hinckley 257 178 8.48E+00 SWSW4 Savage Fen 9.37E+00 SWSW4 Savage Fen 7.32E+00 Silo 060 Pigs Eye SNA 6.38E+00 Silo 071 Belwin Gravel Pit 6.38E+00 Silo 091 Belwin Gravel Pit 6.38E+00 Silo 010 Sala Pite 6.38E+00 Silo 02 Credit River (Credit River Twp, Savage) 5.38E+00	-				
Nine Mile Creek Inite Mile Creek <thinite creek<="" mile="" th=""> <thinite creek<="" mile="" td="" th<=""><td></td><td></td><td></td><td></td><td></td></thinite></thinite>					
T114 R19 Township 114 Range 19 1.09F403 CM159 255 Mt. Simon Hinckley 159 255 1.07E403 Si0_097 Camp Hduhapi 1.05E403 Si0_097 Camp Hduhapi 1.05E403 Si0_097 Camp Hduhapi 9.37E400 CM257_178 Mt. Simon Hinckley 257 178 8.48E400 Si0_060 Pigs Eye SNA 8.25E400 SWV44 Savage Fen 7.28E400 SW 102 Credit River Cred	Riv_124				1.19E+07
CM159 255 Mt. Simon Hinckley 159 255 1.07E40; Bio_097 Camp Hduhapi 1.05E40; Ny 146 Unnamed (Empire Twp.) 9.37E40; CM257_178 Mt. Simon Hinckley 257 178 8.48E40; Bio_060 Pigs Eye SNA 8.25E40; SWSW4 Savage Fen 7.92E40; F1120_R21 Township 120 Range 21 7.82E40; Bio_091 Belwin Gravel Pit 6.81E40; Bio_010 Delwin Gravel Pit 6.81E40; Bio_022 Credit River (Credit River Twp, Savage) 6.81E40; Bio_030 Minnewashta Lake 6.38E40; Bio_130_R22 Township 30 Range 22 5.38E40; Bio_1113_R21 Township 130 Range 21 5.38E40; CM172_237 Mt. Simon Hinckley 168 195 4.55E40; DP32_5_247 Praire du Chein Group	Riv_100				1.09E+07
Bio_097 Camp Hduhapi 1.05E407 Nr_146 Unnamed (Empire Twp.) 9.37E+007 SW257_178 Mt. Simon Hinckley 257 178 8.48E+00 SW000 Pigs Eye SNA 8.25E+00 SWW4 Savage Fen 7.92E+00 T120_R21 Township 120 Range 21 7.23E+00 Bio_091 Belwin Gravel Pit 7.23E+00 Sin_091 Belwin Gravel Pit 6.81E+00 Sin_002 Credit River (Credit River Twp, Savage) 6.81E+00 Sin_012 Credit River (Vredit River Twp, Savage) 5.35E+00 Sin_202 Township 31 Range 21 5.33E+00 Sin_212 Township 13 Range 21 4.82E+00 Sin_213 R21 Township 13 Range 21 4.82E+00 Sin_213 R21 Township 13 Range 21 4.82E+00 Sin_214 Township 13 Rang	-				
Riv_146 Unnamed (Empire Twp.) 9.37E400 CM257_178 Mt. Simon Hinckley 257 178 8.48E400 Sio_060 Pigs Eye SNA 8.25E400 GWSW4 Savage Fen 7.92E400 GWSW4 Savage Fen 7.92E400 GWSW4 Savage Fen 7.92E400 GWSW4 Savage Fen 7.92E400 GW12_R17 Township 120 Range 17 7.32E400 Sio_091 Belwin Gravel Pit 6.31E400 Mu_0102 Credit River Credit River Twp, Savage) 6.03E400 VI_0 039 Minnewashta Lake 5.35E400 GW1_014 Lake Waconia 5.35E400 GW1_014 Lake Waconia 5.35E400 GW1_014 Lake Waconia 5.35E400 GW1_014 Lake Waco	—				
CM257_178 Mt. Simon Hinckley 257 178 8.48E+06 Bio_060 Pigs Eye SNA 8.25E+06 SWSW4 Savage Fen 7.92E+00 F1120_R21 Township 120 Range 21 7.80E+00 F112_R17 Township 120 Range 17 7.83E+00 Bio_091 Belwin Gravel Pit 6.81E+00 Ns_102 Credit River (Credit River Twp, Savage) 6.03E+00 Vul_039 Minnewashta Lake 6.03E+00 F30_R22 Township 31 Range 21 5.58E+00 F31_R21 Township 131 Range 21 5.03E+00 CM17_237 Mt. Simon Hinckley 5.03E+00 CM17_237 Mt. Simon Hinckley 177 237 4.59E+00 CM17_237 Mt. Simon Hinckley 177 237 4.59E+00 CM168_195 Mt. Simon Hinckley	_				
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SWW4 Savage Fen 7.92E+00 1120_R21 Township 120 Range 21 7.92E+00 1120_R21 Township 120 Range 21 7.23E+00 30_091 Belwin Gravel Pit 6.81E+00 30_091 Minnewashta Lake 6.14E+00 30_30 Minnewashta Lake 5.85E+00 130_R22 Township 30 Range 22 5.33E+00 131_R21 Township 31 Range 21 5.08E+00 113_R21 Township 113 Range 21 5.08E+00 113_R21 Township 112 Range 20 4.82E+00 CM177_237 Mt. Simon Hinckley 117 237 4.59E+00 CM168_195 Mt. Simon Hinckley 168 195 4.55E+00 CM313_170 Mt. Simon Hinckley 313 170 4.05E+00 CM32_2_155 Mt. Simon Hinckley 313 170 4.05E+00<	Bio 060				8.25E+06
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Bio_091 Belwin Gravel Pit 6.81E+00 Riv_102 Credit River (Credit River Twp, Savage) 6.03E+00 Vul_039 Minnewashta Lake 6.03E+00 130_R22 Township 30 Range 22 5.85E+00 131_R21 Township 31 Range 21 5.33E+00 Vul_014 Lake Waconia 5.33E+00 DP325_247 Praire du Chein Group 4.82E+00 CM17_237 Mt. Simon Hinckley 177 237 4.59E+00 CM148_195 Mt. Simon Hinckley 168 195 4.55E+00 CM128_210 Township 112 Range 20 4.42E+00 DP257_186 Praire du Chein Group 4.21E+00 Sio 058 Black Dog Lake area 4.21E+00 CM313_170 Mt. Simon Hinckley 313 170 4.05E+00 CM222_155 Mt. Simon Hinckley 2.98E+00 CM22_155 Mt. Simon Hinckley 222	T120_R21				7.80E+06
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Wul_039 Minnewashta Lake 6.03E+06 T30_R22 Township 30 Range 22 5.85E+00 T31_R21 Township 31 Range 21 5.53E+00 Vul_014 Lake Waconia 5.33E+00 T113_R21 Township 113 Range 21 5.33E+00 D9325_247 Praire du Chein Group 4.82E+00 CM177_237 Mt. Simon Hinckley 177 237 4.59E+00 CM177_237 Mt. Simon Hinckley 168 195 4.55E+00 CM172_200 Township 112 Range 20 4.42E+00 D9257_186 Praire du Chein Group 4.42E+00 D9257_186 Praire du Chein Group 4.16E+00 CM313_170 Mt. Simon Hinckley 313 170 4.05E+00 Vul_029 Olsen Lake 2.98E+00 CM222_155 Mt. Simon Hinckley 222 155 2.96E+00 Silo_107 Grey Cloud Dunes East </td <td></td> <td></td> <td></td> <td></td> <td></td>					
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OP325_247 Praire du Chein Group 4.82E+06 CM177_237 Mt. Simon Hinckley 177 237 4.59E+06 CM168_195 Mt. Simon Hinckley 168 195 4.55E+06 CM168_195 Mt. Simon Hinckley 168 195 4.55E+06 CM128_20 Township 112 Range 20 4.42E+06 OP257_186 Praire du Chein Group 4.42E+06 OP257_186 Praire du Chein Group 4.42E+06 Sio_058 Black Dog Lake area 4.16E+06 CM313_170 Mt. Simon Hinckley 313 170 4.05E+06 Vul_029 Olsen Lake 2.98E+06 CM222_155 Mt. Simon Hinckley 222 155 2.96E+06 Silo_107 Grey Cloud Dunes East 2.78E+06 G13_1R24 Township 31 Range 24 2.60E+06 G12_127 Riley Creek (Chanhassen, Eden Prairie) <td>Vul_014</td> <td></td> <td></td> <td></td> <td>5.33E+06</td>	Vul_014				5.33E+06
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Vul_029 Olsen Lake 3.92E+06 T27_R24 Township 27 Range 24 2.98E+06 CM222_155 Mt. Simon Hinckley 222 155 2.96E+06 Bio_107 Grey Cloud Dunes East 2.78E+06 T31_R24 Township 31 Range 24 2.78E+06 Riv_127 Riley Creek (Chanhassen, Eden Prairie) 2.60E+06 Vul_025 Lotus Lake 2.56E+06 Bio_087 Wilder Forest 2.64E+06	Bio_058		-		4.16E+06
T27_R24 Township 27 Range 24 2.98E+06 CM222_155 Mt. Simon Hinckley 222 155 2.96E+06 Bio_107 Grey Cloud Dunes East 2.78E+06 T31_R24 Township 31 Range 24 2.78E+06 Riv_127 Riley Creek (Chanhassen, Eden Prairie) 2.60E+06 Vul_025 Lotus Lake 2.56E+06 Bio_087 Wilder Forest 2.46E+06	CM313_170		+		4.05E+06
CM222_155 Mt. Simon Hinckley 222 155 2.96E+00 Bio_107 Grey Cloud Dunes East 2.78E+00 F13_R24 Township 31 Range 24 2.78E+00 Riv_127 Riley Creek (Chanhassen, Eden Prairie) 2.60E+00 vul_025 Lotus Lake 2.56E+00 Bio_087 Wilder Forest 2.46E+00	Vul_029		-		3.92E+06
Bio_107 Grey Cloud Dunes East 2.78E+06 T31_R24 Township 31 Range 24 2.78E+06 Riv_127 Riley Creek (Chanhassen, Eden Prairie) 2.60E+06 Vul_025 Lotus Lake 2.56E+06 Bio_087 Wilder Forest 2.46E+06			1		
T31_R24 Township 31 Range 24 2.78E+06 Riv_127 Riley Creek (Chanhassen, Eden Prairie) 2.60E+06 Vul_025 Lotus Lake 2.56E+06 Bio_087 Wilder Forest 2.46E+06					
Riv_127 Riley Creek (Chanhassen, Eden Prairie) 2.60E+06 Vul_025 Lotus Lake 2.56E+06 Bio_087 Wilder Forest 2.46E+06					
Vul_025 Lotus Lake 2.56E+06 Bio_087 Wilder Forest 2.46E+06	Riv 127				2.60E+06
Bio_087 Wilder Forest 2.46E+06	Vul_025				2.56E+06
CM178_198 Mt. Simon Hinckley 178 198 2.35E+06	 Bio_087				2.46E+06
	CM178_198	Mt. Simon Hinckley	178	198	2.35E+06

Table A-1 Binding Constraints and Shadow Price

Binding Constraints and Shadow Price					
				Absolute	
Constraint Name	Description	Row	Col	Shadow Price	
Riv 131	Unnamed (Eagan)			2.23E+06	
Vul 028	Dutch Lake			1.92E+06	
Vul 008	Lake Elmo			1.81E+06	
Bio 076	Savage Fen, Credit River			1.75E+06	
CM191 219	Mt. Simon Hinckley	191	219	1.44E+06	
CJ269 278	Jordan Sandstone	269	278	1.16E+06	
	Weaver Lake			8.04E+05	
CJ203 291	Jordan Sandstone	203	291	7.44E+05	
Vul 011	Smetana Lake			7.12E+05	
	Pleasant Lake			6.14E+05	
	Murphy Lake			5.92E+05	
CT293 146	Tunnel City	293	146	4.41E+05	
Bio 072	Grey Cloud Dunes West			4.35E+05	
CT159 180	Tunnel City	159	180	3.57E+05	
OP236 263	Praire du Chein Group	236	263	2.94E+05	
 CJ205 289	Jordan Sandstone	205	289	2.87E+05	
 CJ246_287	Jordan Sandstone	246	287	2.82E+05	
 CT147 194	Tunnel City	147	194	2.74E+05	
CJ270 281	Jordan Sandstone	270	281	2.70E+05	
T116 R24	Township 116 Range 24			2.52E+05	
CT164 175	Tunnel City	164	175	2.05E+05	
 FlowDir3	TCAAP Plume (St Anthony, Minneapolis)			165000.00	
FlowDir2	TCAAP Plume (New Brighton)			145000.00	
CJ300 293	Jordan Sandstone	300	293	1.26E+05	
CJ302 293	Jordan Sandstone	302	293	9.49E+04	
OP258 213	Praire du Chein Group	258	213	9.02E+04	
 CJ264_254	Jordan Sandstone	264	254	7.80E+04	
CT172 203	Tunnel City	172	203	7.27E+04	
OP257 205	Praire du Chein Group	257	205	6.08E+04	
 OP241_280	Praire du Chein Group	241	280	6.04E+04	
OP257_206	Praire du Chein Group	257	206	5.96E+04	
 OP297_248	Praire du Chein Group	297	245	4.33E+04	
OP269 233	Praire du Chein Group	269	233	3.57E+04	
 CT185_206	Tunnel City	185	206	3.13E+04	
CJ298 292	Jordan Sandstone	298	292	2.09E+04	
CT186 207	Tunnel City	186	207	1.88E+04	
 Riv_114	Rice Creek (Fridley)			1.41E+04	
 CJ230_270	Jordan Sandstone	230	270	1.20E+04	
CT260_197	Tunnel City	260	197	9.75E+03	
 CT174_199	Tunnel City	174	199	7.56E+03	
 OP271_228	Praire du Chein Group	271	228	6.83E+03	
FlowDir7	St. Paul Park Refinery			6450.00	
CT279 287	Tunnel City	279	287	3.31E+03	
CT186_206	Tunnel City	186	206	2.53E+03	
0.100_200	rainer etc.	100	200	2.552105	

Table A-1 Binding Constraints and Shadow Price

Color Key

Trout streams baseflow constraint
Non-trout streams baseflow constraint
Groundwater dependent features hydraulic head constraint (calcerous fens)
Flow direction constraint
Mt. Simon-Hinckley aquifer change in hydraulic head constraint
Safe yield for confined bedrock aquifers constraint
Surface water flux constraint (Township and Range groups)
Vulnerable surface water features with wide litoral zone constraint
Sites of high biodiversity constraint

Table A-2Summary of Binding Constraints by Constraint Type

			Number of		Rank of
	Sum Total	Percent Total	Constraints with	Average	Average
Group	Shadow Price	Shadow Price	Shadow Price	Shadow Price	Shadow Price
Township Range	2.47E+09	33.66%	45	5.49E+07	3
Stream/River	2.39E+09	32.48%	28	8.52E+07	1
Vulnerable Surface Water Basin	9.32E+08	12.69%	29	3.21E+07	5
Biodiversity Area	7.52E+08	10.24%	22	3.42E+07	4
Trout Stream	5.13E+08	6.99%	9	5.70E+07	2
Mt. Simon Hinckley Hydraulic Head	2.41E+08	3.28%	15	1.61E+07	7
Groundwater Dependent Feature (Fen)	3.46E+07	0.47%	2	1.73E+07	6
Safe Yield for Confined Bedrock Aquifer	1.42E+07	0.19%	31	4.57E+05	8
Flow Direction	3.16E+05	0.00%	3	1.05E+05	9