



Summary of Groundwater-Lake Modeling Analyses

White Bear Lake Comprehensive Plan Work Group

09/15/2026

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Executive Summary

The White Bear Lake Area Comprehensive Plan Work Group (Work Group) is developing a plan to ensure adequate and sustainable water supply for the communities in the White Bear Lake Area. The Work Group is considering methods for conserving and recharging groundwater and alternative supply sources. The Minnesota Department of Natural Resources (DNR) evaluated the potential impacts of scenarios that meet projected water demands at ultimate development (Ultimate scenario) on water levels in White Bear Lake using the revised Northeast Metro Lakes and Groundwater (NMLG) numerical groundwater-flow model (DNR, 2018a).

Scientific and engineering analyses are organized into 15 project studies that analyzed potential solutions that could have effects on White Bear Lake surface water elevations. DNR performed modeling analyses to support the studies that considered changes to groundwater pumping and lake augmentation with surface water. Model-estimated increases in White Bear Lake water levels for each scenario relative to business-as-usual groundwater supplies (baseline) are summarized in Table 1. Model scenarios are projected onto the climate history for 1988 through 2016 and compared during 2008 through 2015. Observed lake levels were below the protective elevation of 922 feet (Ramsey County Datum, 1912) during 2008 through 2015, with the lowest level measured in January 2013. See the corresponding study reports for additional information about the studied alternatives (<https://metro council.org/Council-Meetings/Work-Groups/White-Bear-Lake-Work-Group.aspx>).

Table 1: Summary of modeling-based estimates of lake-level increases relative to a business-as-usual Ultimate scenario (feet) for study scenarios

Study	Winter 2012-13, Ultimate Demand Scenario	Winter 2012-13, Ultimate (Hugo 2) Demand Scenario	2008-15 Average, Ultimate Demand Scenario	2008-15 Average, Ultimate (Hugo 2) Demand Scenario
Study 1 – Redirect outflow from Bald Eagle Lake to augment White Bear Lake	--	2.4	--	2.1
Study 2 – Convey treated surface water to replace groundwater supplies for public water systems with and without water-demand reductions	3.2 – 3.3	3.5 – 3.9	3.1	3.3 – 3.6
Study 3 – Reuse treated wastewater for industrial and agricultural users	--	--	~ 0.1	--
Study 4 – Use stormwater for irrigation	--	0.10 to 0.14	--	0.10 to 0.14

Study	Winter 2012-13, Ultimate Demand Scenario	Winter 2012-13, Ultimate (Hugo 2) Demand Scenario	2008-15 Average, Ultimate Demand Scenario	2008-15 Average, Ultimate (Hugo 2) Demand Scenario
Study 5 ¹ – Use water discharged from proposed remediation wells (Project 1007)	~ 0.1 to 0.2	--	~ 0.1 to 0.2	--
Study 6 – Treat wastewater from interceptors and inject into Jordan aquifer (1 mgd or 2 mgd) ²	0.7 – 1.46	--	0.7 – 1.44	--
Study 7B – Lake augmentation with treated surface water from the chain of lakes ³	--	3.8	--	2.9
Study 10 – Conversion to or installation of smart irrigation controllers, 20% - 50%	0.10 – 0.22	--	0.10 – 0.22	--
Study 11 – Non-potable water use for irrigation and industrial processing	0.39 - 0.48	--	0.39 - 0.48	--
Study 13 – Adoption of low input turf grasses, 20% - 50%	0.16 – 0.42	--	0.16 – 0.42	--
Study 15 – Construct two additional wells in Shoreview and expand treatment capacity to serve North Oaks	Included as part of baseline Ultimate scenario	Included as part of baseline Ultimate (Hugo 2) scenario	Included as part of baseline Ultimate scenario	Included as part of baseline Ultimate (Hugo 2) scenario

¹ Project 1007 option designs are based on previously estimated 2040 water demands. Multi-benefit well options considered could not meet projected Ultimate water demands. Compared to the Existing Use scenario, multi-benefit well options increased White Bear Lake levels 0.1 to 0.2 feet.

² Met Council requested follow-up analysis of direct augmentation from this source under current/recent conditions. Direct augmentation of up to 2 million gallons per day during the open-water season with the Existing Use scenario as a baseline produced modeled, winter 2012-13 lake level 2.0 feet above baseline and 2008-15 average level 1.4 feet above baseline. Results depend on augmentation trigger elevation.

³ Computed lake-level differences depend on operational choices such as triggers for starting and ending augmentation pumping. Scenario assumed augmentation of up to 780 million gallons per year during the open-water season.

Model analysis results should be used with appropriate caution. DNR incorporated the best available information at the time of model development, but the model does not represent a unique solution. In addition to uncertainties in future water demands and scenario details, the hydrological model results are subject to predictive uncertainty.

Background

Building on previous work by the US Geological Survey and a nationally recognized groundwater modeling firm, DNR developed a new groundwater flow model, completed in August 2018. The model helps us understand the effects of weather and groundwater uses on groundwater flow and water levels in White Bear Lake. To develop the model, DNR consulted other agencies and experts, and used the best available data on water use, precipitation, and evaporation (DNR, 2018a, 2018c). DNR has revised and improved the groundwater model used for the 2018 sustainability analysis and continues to use the model to inform water-supply planning.

DNR established the protective elevation of 922 feet above sea level (Ramsey County Datum, 1912) for White Bear Lake in 2016 to protect recreational uses and the lake ecosystem (DNR, 2016; DNR, undated). The protective elevation is not a lake level that is guaranteed to be maintained in all circumstances. To satisfy the protective elevation, permitted water withdrawals in the White Bear Lake area must be limited to keep White Bear Lake above the protective elevation when the lake level would not drop below 922 feet in the absence of groundwater pumping. Permitted groundwater withdrawals must comply with other requirements and limitations in statute and rule, but the application of the protective elevation is generally the most restrictive. Future field-data collection and local-scale analysis may reveal potential local impacts that could limit or restrict some planned groundwater uses, however (i.e., during water appropriation permit / amendment review).

The White Bear Lake Area Comprehensive Plan Work Group (Work Group) is developing a plan to ensure adequate and sustainable water supply for the communities in the White Bear Lake Area. These communities include Hugo, Lake Elmo, Lino Lakes, Mahtomedi, New Brighton, North Oaks, North Saint Paul, Oakdale, Shoreview, Stillwater, Vadnais Heights, White Bear Lake, White Bear Township, and Woodbury. The Work Group is considering methods for conserving and recharging groundwater and alternative supply sources. The Minnesota Department of Natural Resources (DNR) evaluated the potential impacts of Ultimate development scenarios on water levels in White Bear Lake using the revised NMLG numerical groundwater-flow model (DNR, 2018a).

Analysis Methods

To evaluate the potential effects of a proposed water-use scenario, DNR projects each pumping scenario onto the climate history from 1988 through 2016 and evaluates lake levels over the period 2002 through 2016, allowing for scenario effects to largely stabilize before the evaluation period. This period experienced a multi-year period of declining groundwater and lake levels during which White Bear Lake water levels fell below the protective elevation of 922 feet, followed by recovering water levels (DNR, 2018b).

DNR also developed a no-use scenario in which groundwater withdrawals authorized by permits within 5 miles of White Bear Lake and other permits that may have comparable effects on lake levels were set to zero beginning in 1988, as a reference for comparison to the pumping scenarios (DNR, 2018b). Based on the results

of the no-use scenario, DNR estimates that, in the absence of groundwater pumping, White Bear Lake water levels would have varied by just over three feet during the evaluation period and would have remained above the protective elevation (Figure 1). The 2002 through 2016 period is, therefore, a useful reference frame to evaluate proposed scenarios relative to the protective elevation.

This approach does not evaluate the effects that future-pumping scenarios might have in the intervening years between the changes and the time at which pumping changes and their effects have largely stabilized. Such an analysis would be sensitive to the specific timing of pumping changes and the way those changes intersect with future weather variations.

The Metropolitan Council provided DNR with projected, average water demands or water savings by community or, in some cases, for private water users for each scenario to be evaluated, and DNR developed corresponding time sequences of modeled pumping rates following a similar approach to DNR (2018b). Pumping rates for permits within the model domain that are not included in the future demand projections were taken from the previously developed “existing use” scenario (DNR, 2018b). Pumping under these latter permits is expected to change little and/or has a relatively small to negligible influence on White Bear Lake levels.

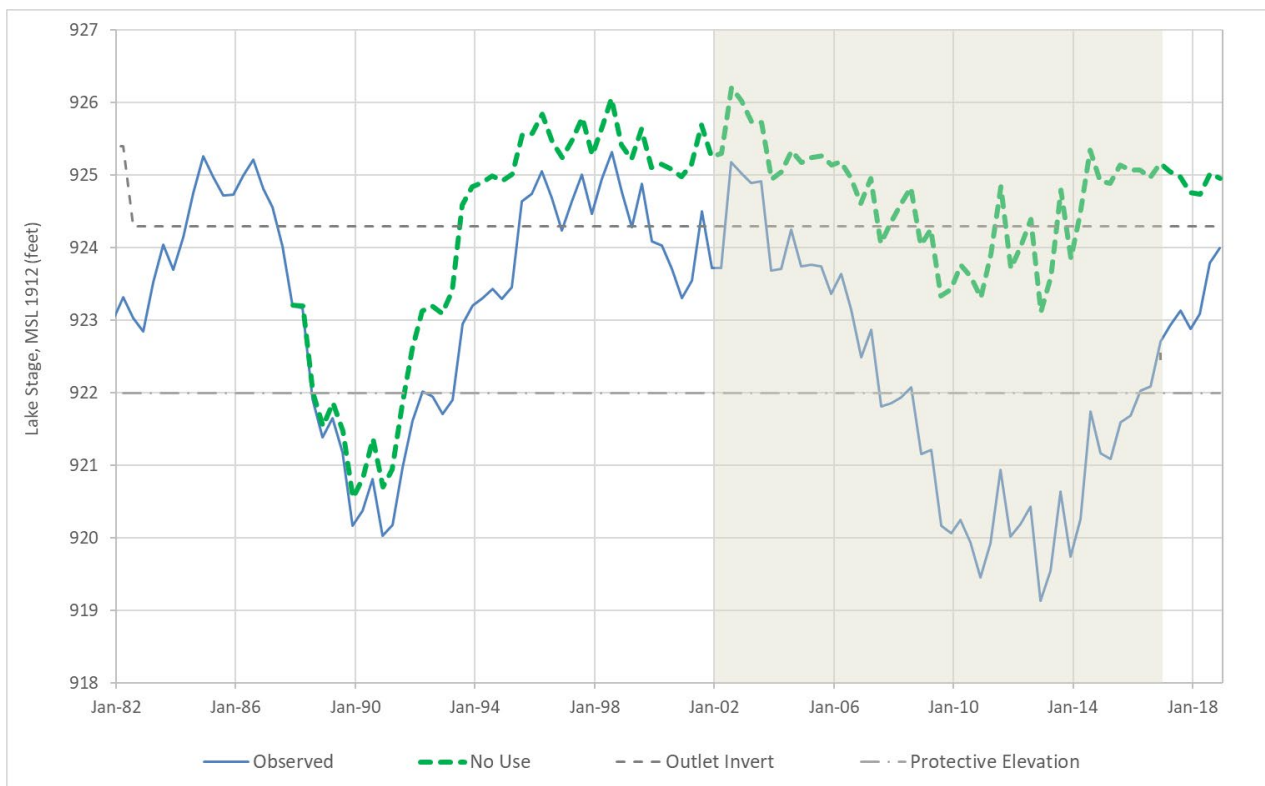


Figure 1: Triannual observed and No-Use scenario, modeled lake stages. Model scenario changes are begun in 1988, and results are evaluated from 2002 through 2016.

Model Scenarios and Results

Metropolitan Council estimated water demands for each community at 2050 and “Ultimate” projected populations (Greg Johnson, pers. comm., November 2024). There were two versions of the Ultimate projections, which differed only for the City of Hugo.

The City of Hugo provided two versions of ultimate development, designated in this report as Hugo 1 and Hugo 2. The Hugo 1 scenario confines urban development in Hugo to the 2030/2040 Metropolitan Urban Service Area (MUSA), whereas the Hugo 2 scenario expands development into the eastern part of the city outside the currently planned MUSA. One of the Ultimate population scenarios (Hugo 1 or Hugo 2) served as the baseline or starting point for each evaluated scenario.

The Ultimate scenarios included the alternative considered in Study No. 15 in which a new water distribution system would be developed for North Oaks, with wholesale water supplied by Shoreview. The model implicitly assumes that North Oaks would also develop a sanitary sewer system and connect to the Metropolitan Council interceptor system (i.e., the model does not account for low-volume private wells or discharges to the water table from individual treatment systems). Metropolitan Council included the North Oaks system in the baseline as a conservative assumption (Greg Johnson, pers. comm.).

Metropolitan Council staff wanted to consider the effects of proposed alternatives for municipal water supplies and groundwater remediation developed for the Minnesota Pollution Control Agency (PCA) under the Project 1007 feasibility study (AECOM, 2026), referred to as Study No. 5. The alternative recommended in the feasibility study report and several other options included “multi-benefit well arrays” and treatment systems that would pump groundwater from bedrock aquifers, abandon some existing municipal wells, inject some treated water back into the aquifers, and use treated water to replace municipal groundwater supplies. These options were based on previously developed projections of 2040 municipal water demands.

The systems as currently proposed would not supply sufficient volumes to meet projected 2050 and/or Ultimate water demands in those cities. Therefore, the alternatives that include multi-benefit well arrays were not included in the scenarios evaluated by DNR for the Work Group.

Feasibility study Alternative 4, which included pumping and injection remediation wells near pollution source areas but did not include multi-benefit well arrays that would replace municipal water supplies, was selected as the most applicable Project 1007 (Study No. 5) scenario to incorporate into the modeling analysis. This alternative would require new municipal water wells and treatment systems in Oakdale and Lake Elmo.

DNR tested several scenarios that included multi-benefit well arrays for the PCA during development of the feasibility study and compared the results to the previously developed “existing use” scenario, however. Computed White Bear Lake water levels were slightly higher in these scenarios than in the “existing use” scenario. Therefore, it appears that other alternatives under consideration for Project 1007 remediation would not exacerbate water-level impacts to White Bear Lake relative to the baseline Ultimate development scenario.

The scenarios DNR evaluated along with the corresponding Metropolitan Council study are summarized in Table 2. Further description and discussion of these scenarios and the modeling analysis results follow. See the Appendix for a summary of the Ultimate demand volumes.

Table 2: Summary of DNR modeling analysis scenarios.

Type	Demand Scenario	Scenario Name / Description	Corresponding Study(ies)
Direct augmentation of White Bear Lake with water sourced from surface-water sources	Ultimate (Hugo 2)	Augmentation from Clearwater Creek Augmentation from chain of lakes	1, 7B
Replace groundwater supplies with surface-water supply	Ultimate (Hugo 1)	SW 2 – Replace 6 permits SW 2a - Replace 6 permits and reduce demands SW 2b – Replace 6 permits and reduce demands (one different from SW 2a) SW 3 and SW 5 – Replace 7 permits SW 4 – Replace 9 permits ⁴	2
Replace groundwater supplies with surface-water supply	Ultimate (Hugo 2)	SW 3-2 – Replace 7 permits and reduce demands ¹ SW 4-2 – Replace 9 permits ⁴	2
Reuse treated wastewater for industrial and agricultural users	--	Estimated from “individual permit analysis” in DNR (2018b)	3
Capture and use stormwater for lawn/landscape irrigation	Ultimate (Hugo 2)	Future stormwater irrigation - use in 25% of future development/redevelopment area Combination stormwater irrigation - use in 25% of future development/ redevelopment area and retrofitting of 5% of existing developed areas	4
Use water discharged from proposed remediation wells (Project 1007)	--	Estimated from previously developed modeling scenarios relative to existing uses	5
Direct augmentation of White Bear Lake with treated wastewater	Existing Use	Augmentation of 2 MGD (425 MGY)	6
Direct augmentation of White Bear Lake with treated wastewater	Ultimate (Hugo 2)	Augmentation of 3.8 MGD (780 MGY)	6
Treated wastewater injection	Ultimate (Hugo 1)	1 mgd injection 2 mgd injection	6

Type	Demand Scenario	Scenario Name / Description	Corresponding Study(ies)
Replace groundwater supplies combined with treated wastewater injection	Ultimate (Hugo 1)	SW 2 with 1 mgd injection SW 6 with 1 mgd injection – Replace 6 permits (one different from SW 2) SW 7 with 2 mgd injection – Replace 4 permits	2, 6
Replace groundwater supplies for irrigation and industrial supplies with a non-potable surface-water supply	Ultimate (Hugo 1)	Infrastructure based User based	11
Increase use of smart irrigation controllers	Ultimate (Hugo 1)	20% adoption 50% adoption	10
Adoption of low-input turf grasses	Ultimate (Hugo 1)	20% adoption 50% adoption	13

Lake augmentation from surface-water sources

Project studies considered two different groups of possible surface-water sources for augmenting White Bear Lake: stormwater/local streams and lakes (Study No. 1), and the chain of lakes in the Saint Paul Regional Water, raw water conveyance system from the Fridley pumping station on the Mississippi River (Studies 7A and 7B).

Treated surface water from Clearwater Creek

Study No. 1 provided an initial evaluation of the benefits, challenges, issues and concerns associated with augmenting White Bear Lake with redirected stormwater and water from other local surface waters including Bald Eagle Lake, Centerville Lake, and Clearwater Creek.

Withdrawals directly from lakes are generally limited by statute to one-half acre-foot per acre of lake area per year. During most years, this withdrawal limit would be less than the outflow volume from Bald Eagle Lake. In addition, permitted withdrawals from lakes are suspended when the lake level falls below a protected elevation set through the water-appropriation permitting process. Of the options considered in Study No. 1, the source with the largest potential volume is Clearwater Creek, which receives outflows from Bald Eagle Lake and from the additional watershed area downstream from Bald Eagle Lake. This option was selected for DNR modeling analysis.

Withdrawals from watercourses can be suspended during periods of specified low flows to safeguard water availability for in-stream uses and downstream, higher priority users. Determining the protected low flow was beyond the scope of the evaluation, however, and water-appropriation limits would be determined through the permitting process. Although flows in Clearwater Creek at the pumping-station locations considered in Study No. 1 could exceed Bald Eagle Lake outflows, permitted withdrawals could be suspended during low-flow periods, limiting the volumes available for augmentation below the volumes applied in the analysis reported here.

DNR developed an augmentation modeling scenario for the Study No. 1 option that evaluated a pumping station with a 3,600 gpm (5.184 million gallons per day) pumping capacity, a 3-acre (4 million gallon) storage basin, and a water treatment plant adjacent to Clearwater Creek. The potential effects on White Bear Lake water levels would depend on the operational plan and water-appropriation permit limits, in addition to system capacity. DNR developed an example scenario based on the following assumptions⁴:

- Augmentation occurs only during the period April through November.
- The maximum augmentation rate is 3,600 gpm (5.184 million gallons per day).
- The daily volume available for augmentation is the minimum of estimated Bald Eagle Lake outflow plus basin storage volume or the system pumping capacity.
- Potential suspension of withdrawals from Clearwater Creek during periods of specified low flows is not considered.
- Augmentation would start if the lake level was 923 feet or lower, and the level was not rising.
- Groundwater uses correspond to the Ultimate (Hugo 2) scenario.

Based on these assumptions, the annual augmentation volume varied from 0 to 913 million gallons per year (MGY), and augmentation during the analysis period (2002 – 2016) would have been first initiated in spring 2006. The computed effects on White Bear Lake levels are summarized in Table 3. There was no outflow from Bald Eagle Lake during 2009-10. Computed lake levels fell to a minimum of 919.9 feet in the winter of 2010-11. The computed lake levels were below 922 feet from 2008 through 2011, for most of 2012, and for part of 2013. During the period of minimum observed lake levels in winter 2012-13, the computed lake level was 2.4 feet above the Ultimate (Hugo 2) baseline. Computed lake levels would be about 0.2 feet higher if using the Ultimate (Hugo 1) scenario as the baseline.

Treated surface water from the chain of lakes

The costs and engineering feasibility of augmenting White Bear Lake have been evaluated in previous studies (Metropolitan Council, 2014; DNR, 2016). These studies determined that treated surface water from the chain of lakes in the SPRWS raw-water conveyance system would be the most reliable and feasible source. The potential effects on White Bear Lake water levels would depend on the operational plan in addition to system capacity. DNR developed an example scenario based on the following operational assumptions:

- Augmentation would occur only during the open-water season and less than 200 days per year.
- The maximum augmentation rate would be 4 mgd.
- Augmentation would start if the lake level were 923 feet or lower, and the level was not rising.
- Groundwater uses correspond to the Ultimate (Hugo 2) scenario.

⁴ DNR estimated Bald Eagle Lake outflows for the model period through 2015 using lake-level measurements and a lake-level-outflow relationship for the outlet spillway structure that was replaced in 2015. Lake levels between measurements were estimated using linear interpolation.

Based on these assumptions, the maximum annual augmentation volume would be about 780 million gallons per year (MGY), and augmentation during the analysis period (2002 – 2016) would have been first initiated in spring 2006. Computed lake levels fall to a minimum just above 922 feet in summer 2009 and remained above 922 feet through the end of the simulation. Augmentation was not triggered after 2012. During the period of minimum observed lake levels in winter 2012-13, the computed lake level was 3.8 feet above the Ultimate (Hugo 2) baseline. These results are summarized in Table 3.

Increasing the system capacity, increasing the triggering lake level, and/or combining augmentation with other measures to increase lake levels would decrease the risk that lake levels could drop below 922 feet during a period like the analysis period. Computed lake levels would be about 0.2 feet higher if using the Ultimate (Hugo 1) scenario as the baseline.

The modeling analysis approach cannot directly assess the frequency of augmentation needs, but the historical lake-level record suggests that there would have been periods of 5 to 10 years during which lake levels would have remained above 923 feet without any augmentation even with the projected increases in groundwater pumping.

The modeling analysis did not evaluate system design, water treatment needs, or the effects of augmentation on lake water quality, which are addressed in the corresponding studies (1, 7A and 7B).

Table 3: Scenarios that evaluate augmentation with treated water from surface-water sources

Scenario	Communities / Permits	Minimum, Computed Lake Levels Above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
Augmentation from Clearwater Creek, Hugo 2	New surface-water appropriation permit	No	2.4
Augmentation from chain of lakes, Hugo 2	New or amended surface-water appropriation permit	Yes	3.8

Replace groundwater supplies with surface-water supply

The analyses in DNR (2018b) and subsequent work identified which existing groundwater appropriation permits have the largest relative impacts on White Bear Lake water levels at recent and projected future water demands. A previous feasibility assessment found that the most feasible raw water source for replacement supplies for several combinations of communities in the White Bear Lake area is the Saint Paul Regional Water Services (SPRWS) supply sourced from the Mississippi River and the chain of lakes in the SPRWS conveyance system terminating at East Vadnais Lake (Metropolitan Council, 2014).

Guided by the evaluated relative impacts and the previous feasibility study, Metropolitan Council selected several alternative groupings of groundwater-sourced water-supply systems. The systems included in these groupings included: Mahtomedi, North Oaks, North Saint Paul, Saputo Cheese USA, Inc. dba Saputo Dairy Foods, Vadnais Heights, White Bear Lake, White Bear Township (North system), and White Bear Township (South system). Note that Study No. 2 for the Work Group subsequently found that infrastructure improvements to the

SPRWS raw-water pumping and conveyance system would be required to meet projected demands for both current SPRWS customers and these replacement systems. The model scenarios and corresponding Study No. 2 Alternatives are summarized in Table 4.

The modeled lake level did not remain above the protective elevation for several of the tested scenarios. To achieve the goal of keeping computed lake levels above the protective elevation during the evaluation period, replacing water sources can be combined with measures designed to reduce water demands. To test hypothetical demand reductions, DNR tested scenarios in which average, residential demand was reduced to the target maximum of 75 gallons per capita per day in communities where the average was above the target: North Oaks and Woodbury (Scenarios SW 2a and SW 2b in Table 4).

Note that minimum computed lake levels for the different scenarios that replaced 6 permits (SW 2, SW 2a, and SW 2b) differed by less than 0.2 feet. Although the computed lake levels for scenario SW 2a remained above the protective elevation of 922 feet, the protective elevation is within the range of uncertainty in modeling results. If Study No. 2, system Alternative 1 were pursued, it would be judicious to combine it with additional mitigation and/or demand-reduction measures in addition to or in place of the reductions tested in model Scenario SW 2a.

Table 4: Model scenarios that replace groundwater supplies.

Model Scenario, Study 2 Alternative	Brief Description	Communities / Water Systems	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
SW 2 (Hugo 1), Alternative 1	Replace 6 permits	Mahtomedi, Saputo Cheese USA, Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	No	3.2
SW 2a (Hugo 1), Alternative 1	Replace 6 permits with reduced demands	Mahtomedi, Saputo Cheese USA, Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	Yes	3.3
SW 2b (Hugo 1), Not a Study No. 2 Alternative	Replace 6 permits with reduced demands	Mahtomedi, North St. Paul, Saputo Cheese USA, White Bear Lake, White Bear Township (2 systems)	No	3.1
SW 3 (Hugo 1), Alternative 2	Replace 7 permits	Mahtomedi, North St. Paul, Saputo Cheese USA, Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	Yes	3.5
SW 3-2 (Hugo 2), Alternative 2a	Replace 7 permits with reduced demands	Mahtomedi, North St. Paul, Saputo Cheese USA, Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	No	3.5

Model Scenario, Study 2 Alternative	Brief Description	Communities / Water Systems	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
SW 4 (Hugo 1), Alternative 4	Replace 9 permits	Mahtomedi, North St. Paul, Saputo Cheese USA, Shoreview and North Oaks(joint system), Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	Yes	3.8
SW 4-2 (Hugo 2), Alternative 4a	Replace 9 permits	Mahtomedi, North St. Paul, Saputo Cheese USA, Shoreview and North Oaks(joint system), Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	Yes	3.9
SW 5 (Hugo 1), Alternative 3	Replace 7 permits	Mahtomedi, North Oaks, Saputo Cheese USA, Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	Yes	3.4
SW 6 (Hugo 1), Not a Study 2 Alternative	Replace 6 permits	Mahtomedi, North Oaks, Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	No	3.2

Reuse treated wastewater for industrial and agricultural users

Study No. 3 evaluated opportunities to replace individual groundwater appropriation permits for industrial and agricultural users with a treated wastewater supply. DNR did not develop a new model scenario to evaluate this option. Previous analyses of the relative impacts of individual permits (DNR, 2018b) indicated that replacing the considered agricultural and industrial groundwater permits would increase White Bear Lake water levels by no more than about 0.1 feet.

Use stormwater for irrigation

Study No. 4 evaluated the potential for using stormwater for irrigation. The study estimated three potential geographic extents for capturing and using stormwater for irrigation in each community: retrofitting 5% of existing developed areas, 25% of future development/redevelopment area, and 100% of future development/redevelopment area. The study considered two rates of average irrigation use over the May through September period, 0.2 and 0.8 inches per week. Metropolitan Council requested that DNR develop and analyze two modeling scenarios based on these options: a future development areas scenario with 25% coverage and a combination scenario with 25% of future development areas and 5% of existing developed areas, both applying an average of the irrigation rates.

In each scenario, potential usable stormwater volumes replace a corresponding volume of groundwater pumping in each community. The baseline groundwater pumping scenario was the Ultimate, Hugo 2 scenario because Study No. 4 used the Hugo 2 version of projected future land uses for the City of Hugo.

In some cases, the irrigation volumes for 5% of the existing developed areas exceeded estimates for actual irrigation-use volumes when pro-rated to the whole community (i.e., actual, historical irrigation volumes). A reasonable ceiling for irrigation volume each year is the excess water use during the irrigation season (May through September) relative to the average daily use rate throughout the rest of the year. If the Study No. 4 irrigation rate for existing developed areas exceeded the summer excess use rate, the potential volume of groundwater pumping replaced by stormwater was scaled to the summer excess use rate rather than the directly estimated, average volume of stormwater usage for irrigation. This ensured a degree of consistency between the pumping volumes in the scenario and the pumping volumes in the Ultimate scenario used for comparison.

The results of these model analyses are summarized in Table 5. An important caveat to these modeling results is that they assume that capturing and using stormwater for irrigation would not have any effect on groundwater recharge. In some cases, the stormwater that would be captured contributes minimally to groundwater recharge, but, more generally, this may not always be the case. Runoff can seep from ditches and stormwater basins, even if not designed to be infiltration features, for example. In some locations, stormwater is directed to natural wetlands, lakes, and ponds that interact with groundwater. If runoff is intercepted prior to discharge to these features, that could reduce groundwater recharge.

Table 5: Scenarios that evaluate stormwater use for irrigation

Scenario	Communities / Permits	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
25% of future development areas, Ultimate (Hugo 2)	All 14 White Bear Lake area communities	No	0.10
25% of future development areas and 5% of existing developed areas, Ultimate (Hugo 2)	All 14 White Bear Lake area communities	No	0.14

Groundwater injection or direct lake augmentation with treated wastewater

Study No. 6 found that up to two (2) million gallons per day (mgd) of treated wastewater could be supplied from an interceptor sewer near White Bear Lake at current wastewater flows and up to 3.8 mgd could be supplied at projected, Ultimate wastewater flows. Study No. 6 considered systems that would supply either 1 or 2 mgd of treated wastewater to groundwater injection wells near White Bear Lake or that would directly discharge into White Bear Lake either 2 mgd or 3.8 mgd. The study also provided preliminary locations where injection wells may be constructed.

DNR developed model scenarios in which either one or two million gallons per day (mgd) is injected into the Jordan aquifer via one or two injection wells at these locations. The modeling analysis did not assess the feasibility or risks of adverse effects of the proposed injection. DNR also developed and evaluated scenarios in which treated wastewater injection is combined with replacement water supplies, building from the evaluations conducted for Study No. 2.

A model scenario representing directly augmenting White Bear Lake with up to 3.8 mgd can be considered as equivalent to the modeling scenario that directly augmented White Bear Lake with up to 4 mgd (780 MGY) of treated surface water if one assumes a slightly longer augmentation season that allows for the same annual volume. Therefore, DNR did not develop a separate model scenario to represent direct augmentation with treated wastewater at Ultimate groundwater use rates and wastewater flows.

The baseline model scenario that most closely represents current groundwater uses is the “existing-use scenario” (DNR, 2018a, b). DNR developed a model scenario that applied up to 2 mgd directly to White Bear Lake based on the existing-use scenario. In that model scenario, computed lake levels were very close to 922 feet on three occasions, dropping slightly below 922 feet in winter 2010-11. Although 3.8 mgd of treated wastewater would not be currently available, at Met Council request, DNR also developed a model scenario that applied 3.8 mgd directly to White Bear Lake based on the existing use scenario. The computed lake levels remained above 922 feet and only briefly fell below 923 feet in that scenario. Combined with the previously developed augmentation scenario, these model results indicate that there would be a risk of lake levels dropping below 922 feet with augmentation sourced from currently available wastewater flows, but projected wastewater flows are expected to eventually be sufficient, despite the concurrent, projected increases in groundwater pumping.

The results of these model analyses are summarized in Table 6.

Table 6: Scenarios that inject or directly augment treated wastewater near White Bear Lake

Scenario	Brief Description	Communities / Permits	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
Inject 1 mgd	Inject 1 mgd into the Jordan aquifer	--	No	0.7
Inject 2 mgd	Inject 2 mgd into the Jordan aquifer	--	No	1.5
SW 2c (Hugo 1)	Replace 6 permits and inject of 1 mgd into aquifer	Mahtomedi, Saputo Cheese USA, Vadnais Heights, White Bear Lake, White Bear Township (2 systems)	Yes	3.7

Scenario	Brief Description	Communities / Permits	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
SW 7, Study No. 2 Alternative 5	Replace 4 permits and inject 2 mgd into aquifer	Saputo Cheese USA, White Bear Lake, White Bear Township (2 systems)	Yes	3.45
Augmentation with treated wastewater, 2 mgd	Direct lake augmentation with 2 mgd with existing groundwater uses	--	No	--
Augmentation with treated wastewater, 3.8 mgd	Direct lake augmentation with 3.8 mgd	--	Yes	~ 3.8

Conversion to smart irrigation controllers

Study No. 10 evaluated the potential water savings of lawn-watering restrictions and enhanced adoption of efficient irrigation technologies. Most of the 14 study-area communities have implemented one or more watering restrictions such as odd/even days or time-of-day restrictions. Because of the limitations and variability of available information, the study did not produce quantitative estimates of water savings that may result from potential future watering restriction policies. The study did estimate potential water savings from adoption of smart irrigation controllers at rates from 20 percent to 50 percent of households that have irrigation control systems. DNR developed model scenarios representing the end-member scenarios and the reported average water savings for each community (Table 7).

Table 7: Scenarios that evaluate adoption of smart irrigation controllers

Scenario	Communities / Permits	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
20% conversion, Ultimate (Hugo 1)	All 14 White Bear Lake area communities	No	0.1
50% conversion, Ultimate (Hugo 1)	All 14 White Bear Lake area communities	No	0.2

Non-potable water use for irrigation and industrial processing

Study No. 11 evaluated development of two alternative, non-potable water supply systems that would replace municipal and private supplies for selected industrial and irrigation users in Vadnais Heights and White Bear

Lake with a surface-water source. The “Infrastructure” design model has more extensive water mains and could serve a larger number of businesses. The “User-Based” design model extends to the largest individual users and could connect other businesses that are located along the resulting water lines. Metropolitan Council provided DNR with estimated annual reductions in groundwater uses for each alternative, and DNR developed model scenarios by subtracting these pumping volumes from the Ultimate (Hugo 1) scenario (Table 8).

Table 8: Scenarios that evaluate non-potable water-supply systems

Scenario	Communities / Permits	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
Infrastructure Model	Vadnais Heights and White Bear Lake	No	0.5
User-Based Model	Vadnais Heights and White Bear Lake	No	0.4

Adoption of low input turf grasses

Study No. 13 assessed the potential for water-use reductions through conversion of conventional turf grass (primarily Kentucky Blue Grass) to low-input turf grasses such as fine fescue and tall fescue. The study considered irrigated turf grasses on residential, commercial, institutional, and public lands. The results include potential water savings estimates for existing and future development areas for each community assuming 20% to 50% adoption of low-input turf grasses. DNR developed model scenarios representing the end-member scenarios and the reported average water savings for each community at Ultimate (Hugo 1) development (Table 9).

Table 9: Scenarios that evaluate adoption of low-input turf grasses

Scenario	Communities / Permits	Minimum, Computed Lake Levels above Protective Elevation?	Difference with Baseline Scenario, Winter 2012-13 (ft)
20% conversion, Ultimate (Hugo 1)	All 14 White Bear Lake area communities	No	0.2
50% conversion, Ultimate (Hugo 1)	All 14 White Bear Lake area communities	No	0.4

Discussion – Application of Results

Model analysis results should be used with appropriate caution. DNR incorporated the best available information at the time of model development, but the model does not represent a unique solution. In addition to uncertainties in future water demands and scenario details, the hydrological model results are subject to predictive uncertainty.

The response of lake levels to changes in pumping and recharge vary depending on lake and groundwater levels. As a result, extrapolating scenario results to other situations could lead to misleading lake-level estimates.

One consequence of this nonlinear behavior is that the aggregate effect on lake levels of combining different potential infrastructure and water-savings scenarios is not equal to the sum of the computed lake-level differences. For example, combining groundwater pumping or other changes that individually differed from the baseline by 1.0 feet and 0.5 feet, respectively, would result in a net lake-level difference from the baseline of less than 1.5 feet.

Making the same changes relative to different baseline scenarios (e.g., Ultimate (Hugo 1), Ultimate (Hugo 2), or existing use) results in different lake-level differences. The larger the differences between two baseline scenarios, the larger the disparity in computed lake-level differences. For example, surface-water supply scenarios SW 4 and SW 4-2 applied the same groundwater-pumping reductions to the Hugo 1 and Hugo 2 baseline scenarios, respectively. The resulting lake-level differences from the respective baselines differed by about 0.1 feet. Lake-level differences computed for a scenario are larger for baseline scenarios with lower lake levels than for baseline scenarios with higher lake levels.

Therefore, to estimate the net effects of different combinations of changes to groundwater pumping, lake augmentation, or other changes, a corresponding model scenario should be run.

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Appendix

Table A1: Annual pumping in Ultimate demand scenarios for municipal (public) supply permits

Permittee	Ultimate Average (MGY)	Ultimate Range (MGY)
City of Hugo (1)	1142	962 - 1316
City of Hugo (2)	3119	2627 - 3595
City of Lake Elmo	1019	708 - 1449
City of Lino Lakes	1800	1562 - 2245
City of Mahtomedi	369	345 - 417
City of New Brighton	1248	1091 - 1374
City of North Saint Paul	387	371 - 415
City of Oakdale	1217	1116 - 1410
City of Shoreview ⁵	1741	1611 - 1862
City of Vadnais Heights	675	625 - 713
City of Stillwater	1106	1047 - 1241
City of White Bear Lake	1120	1187 - 1243
White Bear Township (North)	385	334 - 455
White Bear Township (South)	32	28 - 35
City of Woodbury	4029	3495 - 4327

⁵ Projected water demands for Shoreview include an average annual demand of 572 MGY for the City of North Oaks, which is served by additional capacity added to the Shoreview system in the Ultimate demand scenarios.

Table A2: Annual pumping in Ultimate demand scenarios for other permits modified in one or more scenarios

Permittee	Use Type	Current Authorized Volume (MGY)	Ultimate Average (MGY)	Ultimate Range (MGY)
Gem Lake Hills Golf Course	Golf course irrigation	30	20	11.5 - 32
HB Fuller	Once-through Systems (HVAC)	185	11	2.6 - 15
Ramsey County Parks and Recreation (Manitou Ridge Golf Club)	Golf course irrigation	60	22	12 - 30
Saputo Cheese USA, Inc	Agricultural/Food Processing	192	126	84 - 182