CITY OF SHOREVIEW
AGENDA
CITY COUNCIL WORKSHOP
DECEMBER 14, 2015
IMMEDIATELY FOLLOWING SPECIAL MEETING

1. DISCUSSION REGARDING THE COMMUNITY SURVEY
2. REVIEW OF TURTLE LAKE AUGMENTATION STUDY
3. OTHER ISSUES
4. ADJOURNMENT

TO: MAYOR, CITY COUNCIL, AND CITY MANAGER

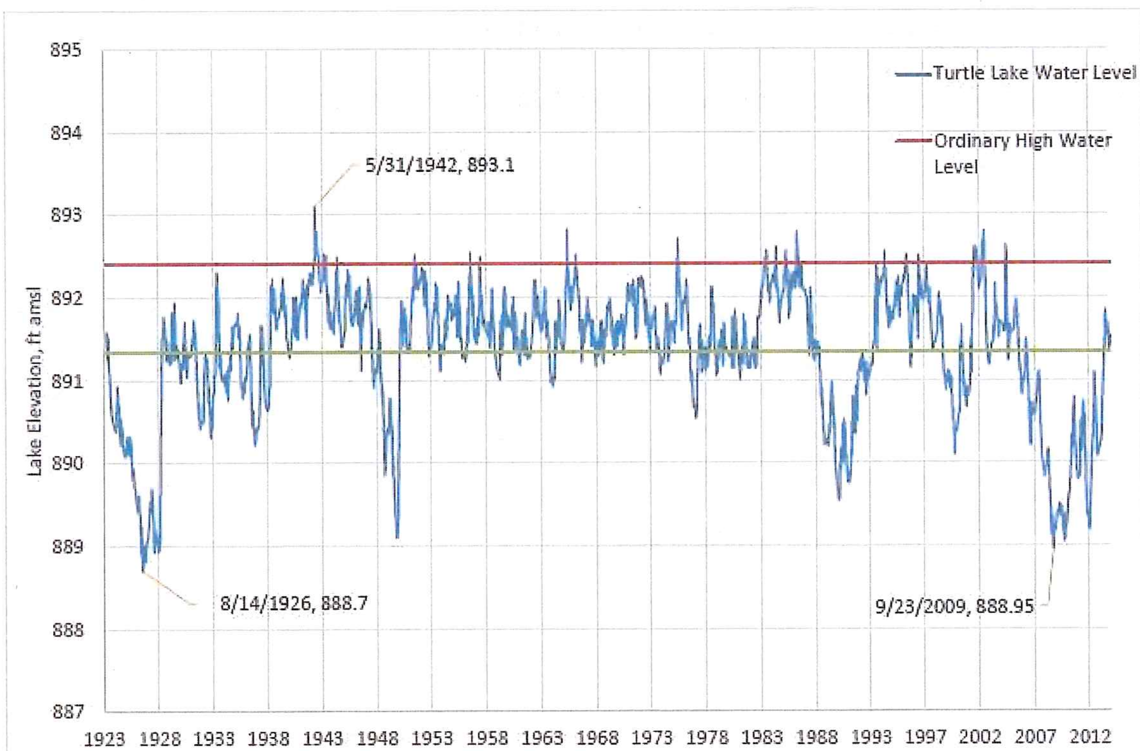
FROM: MARK MALONEY, PUBLIC WORKS DIRECTOR

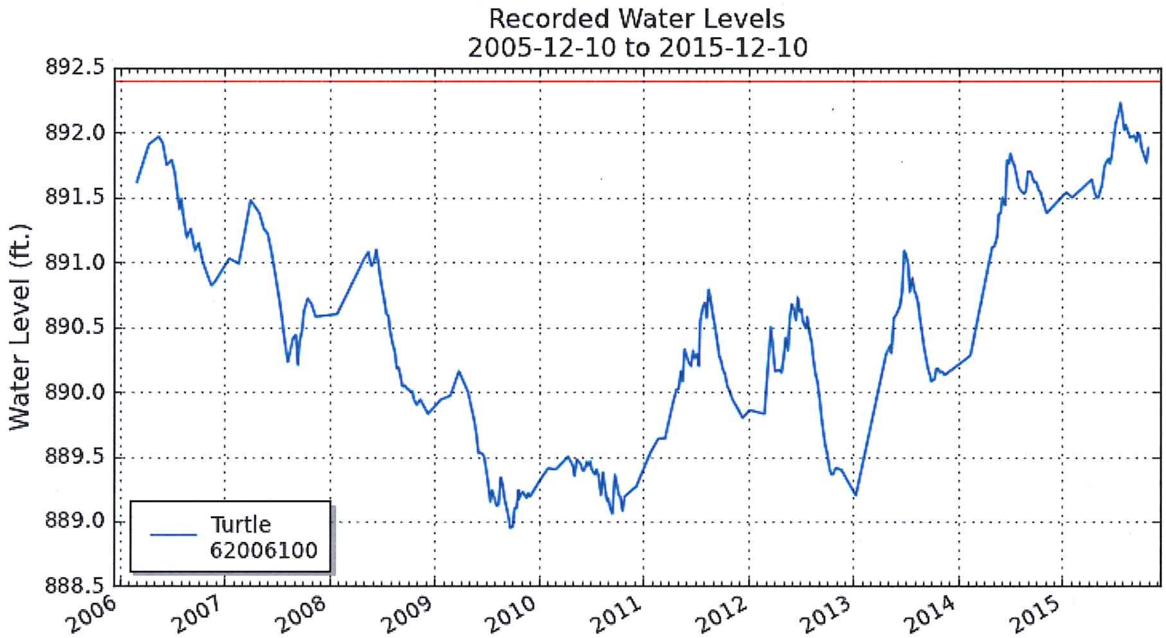
DATE: DECEMBER 10, 2015

SUBJECT: TURTLE LAKE AUGMENTATION STUDY

Over the past year the City has been overseeing the preparation of a study (see attached) examining the technical feasibility of managing the level of Turtle Lake through augmentation. The report was prepared by the firm SEH, Inc. with the consideration of State and regional water related agency perspectives as well as the Turtle Lake Homeowners Association. That report is complete and presented to the Shoreview City Council for their review. The City can now request State reimbursement for $75,000 of the $100,000 cost of the Study per the previous actions of the State Legislature. No official City Council action is required at this time.

Provided for reference are graphs showing historical levels of Turtle Lake. The first graph below shows the levels between 1923 and 2012. The second graph shows details of the levels between 2006 and 2015. The lake level from approximately 1950 to 1988 was managed by lake augmentation via a deep aquifer well operated by Ramsey County, resulting in a relatively narrow range of lake levels between 891.0 and 892.4. After State law required that pumping to be suspended, the lake levels have naturally fluctuated between 889.0 (2009) and 892.3 (2015). The lake level at the time of this report to the City Council is 891.8.





The 2015 Turtle Lake Augmentation Study is presented at this time for informational purposes. Should there be an interest in advancing the concept of lake augmentation, the City would need to develop a strategy for facilitating the creation of a Lake Improvement District and policies regarding the funding of a potential public improvement project.

City staff and a SEH, Inc. representative will be available for discussion.

December 2015

Turtle Lake Augmentation Study

Prepared for City of Shoreview

1.0 Conclusions and Recommendations

Conclusions reached by the Turtle Lake Augmentation Feasibility Analysis include:

- Turtle Lake's water levels have varied by a larger magnitude and have been lower on average since augmentation was ceased in 1989.
- Turtle Lake is highly susceptible to changes in precipitation and evaporation due to its low watershed to surface area ratio.
- Groundwater and/or other heretofore unmeasured factors account for a substantial portion of Turtle Lake's water balance.
- Augmentation has successfully been used to raise and maintain lake levels of Turtle Lake historically, and currently is in use on other nearby lakes.
- Several potential augmentation source waters exist in close proximity to Turtle Lake.
- Augmentation of Turtle Lake would require zebra mussel filtration and/or phosphorus removal depending on the source option selected and flow volume pumped per year.
- Costs for piping and pumping infrastructure and phosphorus removal infrastructure would alternately dominate the total cost for an augmentation system depending on the source water option selected.
- Permits required for implementation of an augmentation system would be administered through the Minnesota Department of Natural Resources, and depending on the source water alternative selected may include an invasive species transport permit, a water appropriations permit, and/or a public waters work permit.

Based on the conclusions, it is recommended that:

- Augmentation should be used to manage lake levels to maintain a target elevation range of 891.0 to 892.0 to mimic pre-1989 historic waters levels.
- Phosphorus in augmentation source water should be reduced with mechanical and chemical means to prevent the increase in phosphorus concentrations in the lake.
- Water quality treatment should include the use of rapid sand filtration and aquatic invasive species (zebra mussel) screening to protect lake water quality.
- A Lake Improvement District should be established to implement the initial construction as well as the long term maintenance and operation of the augmentation system.
- Saint Paul Regional Water Service water along Country Road I be approved as the preferred augmentation source water based on low infrastructure costs and the ability to treat source water to protect lake water quality.

2.0 Executive Summary

Lake level fluctuation and lake level control on Turtle Lake have been part of the Lake's history. The constructed outlet for the lake has and continues to allow water to flow from the lake, reduce high water conditions from persisting and causing property damage. From 1928 to 1989, Turtle Lake was augmented in 40 of the 62 years. During this period, lake levels generally fluctuated between elevations 891.0 and 892.0

Turtle Lake has excellent water quality. In-lake conditions are significantly better that the Minnesota Pollution Control Agency's (MPCA's) standards for lakes in the North Central Hardwood Forest Ecoregion. Lake quality is enhance by the low watershed to lake surface are ratio, which minimizes the impact of storm water runoff.

The water budget for Turtle Lake is a critical consideration for a proposed augmentation system. The water budget, calibrated to historic water level fluctuations defines the volume of water necessary to maintain the target operating water level range for Turtle Lake. The volume of augmentation water in turn dictates the size of the pumps and transmission infrastructure, as well as the design of the water quality and aquatic invasive species (AIS) features to protect lake water quality.

Based on the volume of augmentation to maintain lake levels between 891.0 and 892.0, a 1000 gallon per minute (gpm) pump and transmission infrastructure is recommended. This system would provide an adequate volume of augmentation, based on historical conditions and the water budget, to allow the system to operate during the ice-free months of the year. Based on previous augmentation experience, it is expected that the system will operate two out of every three years, on average.

Four augmentation sources were considered; Saint Paul Regional Water Service (SPRWS) conduits along County Road I, Charley Lake and Pleasant Lake in North Branch, and Snail Lake. The SPRWS is the most economical from an infrastructure standpoint, while Snail Lake has the best water quality and would require no additional treatment before pumping into Snail Lake. The SPRWS source would require water quality treatment measures to remove 47% of the phosphorus in order to protect lake water quality.

The augmentation system would utilize an Aquatic Invasive Species (AIS) screens similar to those in place as part of the Snail Lake system. Because the SPRWS source include the chemical addition of ferric chloride at the Fridley intake, the screens are able to remove up to 50% of the phosphorus as the ferric chloride induce floc is caught, flushed from the screens and returned to the conduit. The addition of rapid sand filtration and a chemical feed system will enhance phosphorus removal and further protect lake water quality.

While there are no specific permits required based on input from a variety of regulatory agencies, implementation will be coordinated with those same agencies to ensure the long term viability of the improvements. A water purchase agreement would be developed with the SPRWS, similar to the agreement in place for the Snail Lake system. A Lake improvement District would be used to support the cost of system implementation as well as ongoing operation and maintenance.

Turtle Lake Augmentation Study

City of Shoreview, Minnesota

SEH No. SHORE 131106

December 10, 2015

SEH

Building a Better World
for All of Us®

Engineers | Architects | Planners | Scientists

SEH

Building a Better World for All of Us®

December 10, 2015

RE: Turtle Lake Augmentation Study
City of Shoreview, Minnesota
SEH No. SHORE 131106

Honorable Mayor and Council Members
City of Shoreview
4600 Victoria St. N.
Shoreview, MN 55126

Honorable Mayor and Council:

In accordance with your authorization, we have prepared the attached report entitled Turtle Lake Augmentation Study.

This report includes an analysis of historic water level fluctuation and augmentation, augmentation source quality and infrastructure, lake response and estimated construction costs. The report also includes recommendations for necessary permits and approvals, annual operating scenarios, Lake Improvement District (LID) establishment and a tentative project schedule.

We recommend that the Council carefully consider this report and consult with City staff. We are available to review this report with you at your convenience.

Sincerely,

Mark L. Lobermeier, PE
Project Manager

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Turtle Lake Augmentation Study
City of Shoreview, Minnesota

SEH No. SHORE 131106

December 10, 2015

I hereby certify that this report was prepared by me or under my direct supervision, and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Mark L. Lobermeier, PE
Project Manager

Date: December 9, 2015 Lic. No.: 18789

Reviewed By: Kate Waring Date: December 8, 2015

Short Elliott Hendrickson Inc.
3535 Vadnais Center Drive
St. Paul, MN 55110-5196
651.490.2000

SEH

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December 2015

Turtle Lake Augmentation Study

Prepared for City of Shoreview

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3.0 Introduction

In the fall of 2009 Turtle Lake water levels were approximately 2.3 feet below its 93 year average water level of 891.4 feet above mean sea level (amsl) (MSL 1912 datum; MnDNR1, 2015). This is the lowest lake levels have been since 1927, surpassed only by slightly shallower levels in 1926 and 1927 in the 93 years that levels have been recorded. Levels rebounded to within about six inches of the average level in late 2011; however, the experience left citizens concerned about future fluctuations of this sort.

In February of 2015, Short Elliot Hendrickson, Inc. (SEH) was retained by City of Shoreview to explore the feasibility of augmentation options for Turtle Lake. This report is intended to update and expand on a previous 2011 report (SEH) which looked at the same issue, but to perform a greater level of analysis in the examination of options. Herein is provided a water balance for Turtle Lake, calculations of potential augmentation volumes, detailed discussion and comparison of potential source waters, a lake response model for augmentation, invasive species and water quality treatment options, potential route and treatment system layouts, and cost analyses for proposed infrastructure.

4.0 Background

4.1 Preliminary Concept Report

In 2011, a high level study was prepared to examine augmentation alternatives for Turtle Lake (SEH, 2011). The Preliminary Concept Report documented lake water balance, lake response to augmentation, invasive species review, permits and approvals, estimated capital improvements and overall costs. A public meeting was conducted with the Turtle Lake Homeowners Association (TLHA) was held to review the report and discussion next steps.

4.2 Metropolitan Council Funded Study

In 2014, the State Legislature provided $75,000 to the Metropolitan Council to help prepare a more detailed examination of the feasibility of resuming augmentation of Turtle Lake. The City of Shoreview and the THLA agreed to share the cost for an additional $25,000 needed to complete the study.

4.3 History of Lake Level Fluctuation

Fluctuating lake levels have been an issue within Ramsey County since the early 1900s, and the first recorded use of augmentation started in 1903 at White Bear Lake. A report released in 1926 discussed the issue of low lake levels throughout Ramsey County, as well as area hydrogeological characteristics, restoration considerations, and legislative matters (Coates, 1926). The report highlighted seepage losses as the primary driver of low water levels across Ramsey County, and concludes that "we are at a point where, for the best interests of the County and the public at large, it is necessary to resort to artificial means [of water level restoration]..." This finding resulted in the installation of lake augmentation systems fed by groundwater across Ramsey County in the early 1900s. Discussion of existing lake augmentation systems near Turtle Lake is included as Appendix A.

Turtle Lake also received such a system. Water levels in Turtle Lake have varied by about 4.4 feet since measurements began in 1923. Prior to the initial startup of an augmentation system in 1928, the lowest level recorded for Turtle Lake was reached: 888.7 ft amsl in 1926 (MnDNR1, 2015). The augmentation system was operated to maintain levels within about one foot of the 93 year average until it was turned off in 1947 for unknown reasons, and a sharp decline in lake levels followed (RCDPW, 1991). A new pump was installed in 1950 and levels were rebounded. From 1950 to 1989, levels generally stayed in an approximately 1.5

foot range between 891 and 892.5 feet amsl. When augmentation ceased in 1989, water level fluctuations became more pronounced, varying by more than 3.5 feet.

4.3.1 Augmentation History

Turtle Lake received augmentation water for 40 years between 1928 and 1989. The source of water varied over this time period. Initially, water was purchased from St Paul Water Utility and occasionally supplemented from a Ramsey County well and 910 gallon per minute (gpm,) pump. In 1950 a new well cased in the Prairie du Chien-Jordan aquifer and a 2,200 gpm rated pump were installed. This well and pump provided all of the augmentation water for Turtle Lake from 1950 to 1989, at which time the MnDNR mandated the end of lake augmentation with groundwater.

Characteristics of augmentation during this time period can be seen in Tables 1 and 2 below. Figure 1 illustrates the historic water level fluctuations for Turtle Lake.

Table 1 - Historical Augmentation Summary

Time period of augmentation	1928-1989
Years in time period	62
Years augmented	40

Source: Ramsey County Department of Public Works (RCDPW). Correspondence with between Terry Noonan and Dan Reid. 7/10/1991.

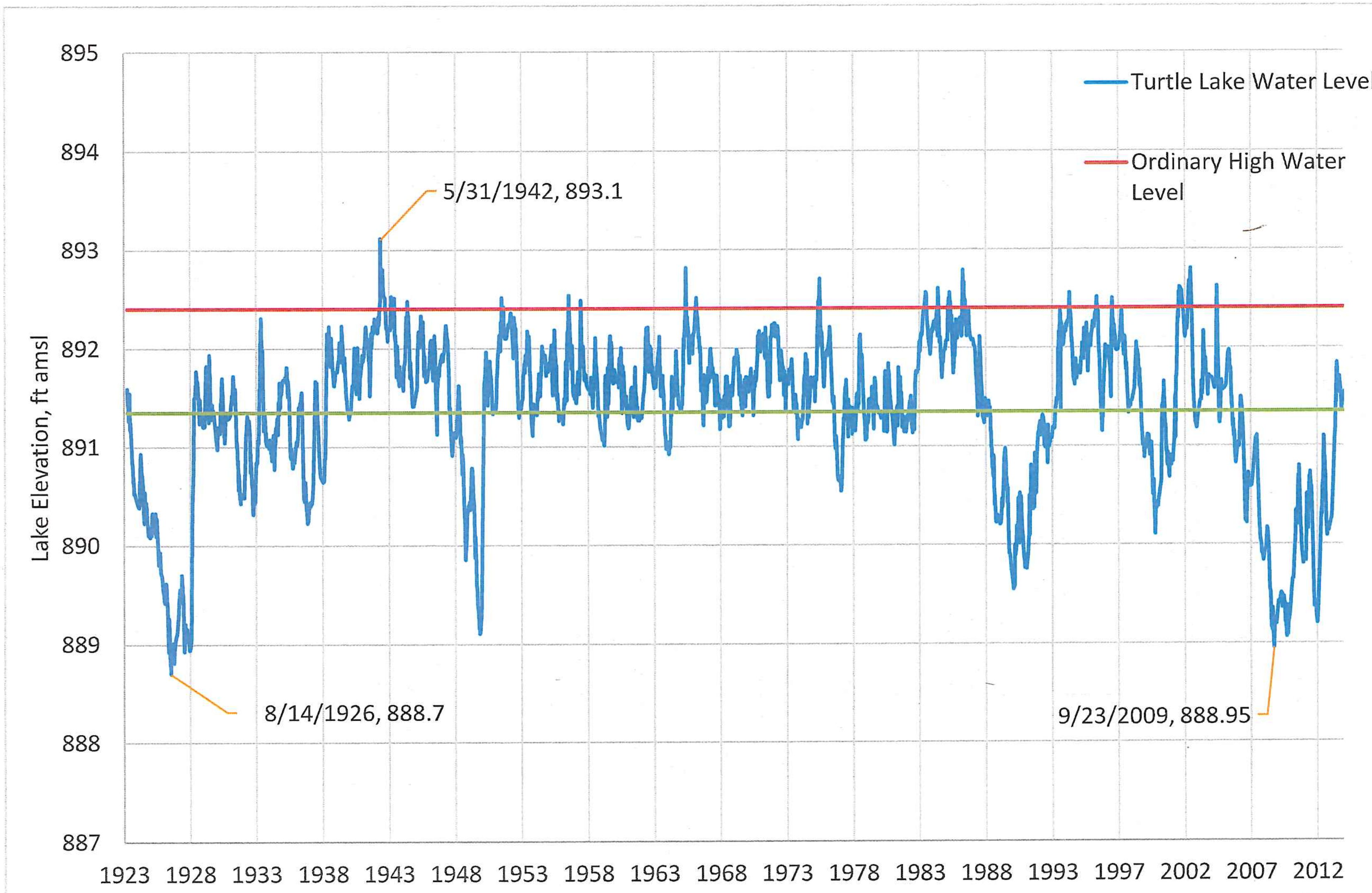
Table 2 - Characteristics of Annual Augmentation

Augmentation Characteristics	*Average*	*Minimum*	*Maximum*
Augmentation frequency, days	54	5	168
Augmentation volume, million gallons	157	20	437
Augmentation volume, inches over Turtle Lake	12.8	1.7	35.6

Note: Calculations only reflect years during which augmentation occurred.

Source: Ramsey County Department of Public Works (RCDPW). Correspondence with between Terry Noonan and Dan Reid. 7/10/1991.

Figure 1 – Historical Turtle Lake Fluctuations



Source: Minnesota Department of Natural Resources (MnDNR). "LakeFinder: Lake Water Level Report." Accessed 11/1/2015.

4.4 Water Quality

Turtle Lake has historically had excellent water quality, as evidenced by low phosphorus and chlorophyll levels and deep Secchi depths (MPCA, 2014). See Table 3 below with Turtle Lake's average growing season water quality parameters as compared to the MPCA's beneficial use ("fishable and swimmable") standards. Turtle Lake's water quality is primarily due to the lake's very small watershed in comparison to its surface area, which doesn't allow for large amounts of polluted runoff to enter the lake.

Table 3 - Turtle Lake 2004-2014 Average Growing Season Water Quality Parameters

Parameter	Value	NCHF Class 2B
Phosphorus, ppb	19.5	<40
Chlorophyll-a, ppb	4.9	<14
Secchi Depth, m	2.8	>1.4

Note: These standards correspond to the "cool and warm water fisheries (not protected for drinking water)" beneficial use category for the North Central Hardwood Forest Ecoregion.
Sources: MPCA, 2014 and MPCA, 2009.

Because of this exceptional level of water quality, Turtle Lake is regularly used for boating and swimming by residents and visitors to Turtle Lake Park. Mercury in fish tissue is listed as an impairment by the MPCA, common in Minnesota lakes due to atmospheric deposition of mercury from both natural sources and human activities such as coal burning (MPCA, 2013; FS, 2009).

5.0 Water Budget

In order to understand the required volumes of water to maintain Turtle Lake within a desired operating range of elevations, a water budget is needed. The water budget looks at all the inflows and outflows, and then uses augmentation volumes to make up for any deficiencies. Based on the water budget and water quality of the augmentation source, the response of the lake to augmentation can also be modelled.

5.1 Overview

A water budget reflecting historical data for Turtle Lake was first created to observe the degree to which measurable data is reflected in Turtle Lake's historical lake level fluctuations discussed in Section 6.1 above. The equation for Turtle Lake's water balance can be seen below:

$$\Delta L = P + RO - SO - E +/- GWex + PA$$

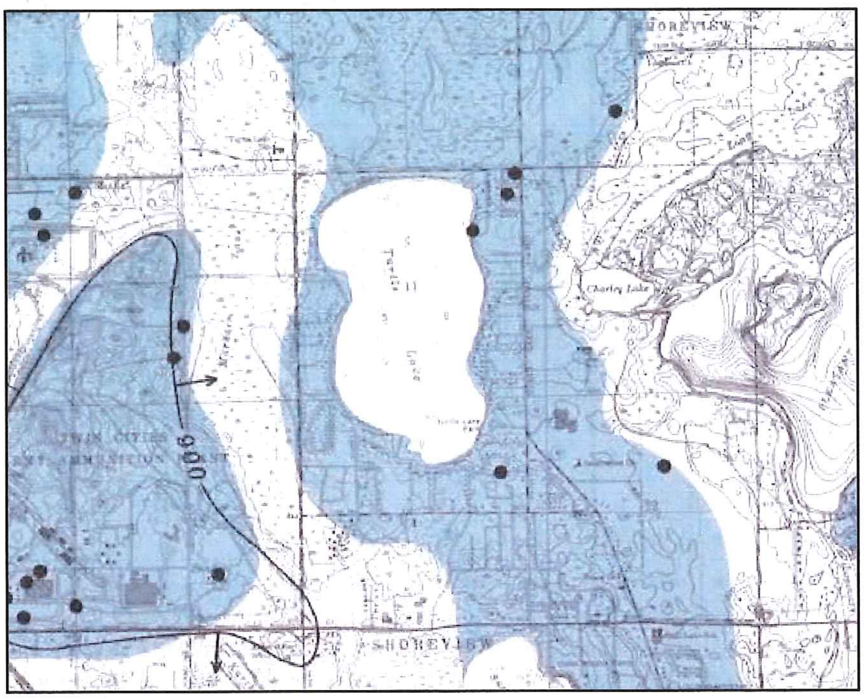
ΔL = Change in lake level
P = Direct precipitation (rainfall and snowfall)
RO = Runoff (rainfall and snowmelt)
SO = Surface outlet overflow
E = Evaporation
GWex = Groundwater exchange
PA = Pumped augmentation

Historical data from 1984 to 2013 was available for lake levels, rainfall, snowfall, evaporation, and pumped augmentation. The remaining parameters (surface outlet overflow and groundwater exchange) were calculated. Runoff from snowmelt and rainfall was calculated as a function of rainfall/snowmelt and land characteristics. Limited information was available for the surface outlet to Turtle Lake, which is described as a 24" metal culvert located at a private residence adjacent to the northwest shore of the lake (RCWD1, 2015). This information was used to calculate estimated overflows from Turtle Lake as no monitoring data for outflows was available.

5.2 Groundwater Exchange

Calculation of groundwater exchange in water budgets is a complex and imprecise endeavor. This calculation is further complicated by the fact that Turtle Lake lies open on all sides to the groundwater table, as depicted in Figure 2 and determined from lake and groundwater table elevations (USGS, 1992), and the water table's sediments are described as having high hydraulic conductivity (USGS[1], 1992; USGS[2], 1992). Methods used to measure groundwater flux have included seepage meters, networks of monitoring wells, chemical tracers, chemical mass balances (LaBaugh et al, 1997); however, perhaps the most common method is that of a water mass balance approach given in section 5.1. The application of this approach is described below.

Figure 2 – Turtle Lake's Position in the Water Table



Note: Labelled contours represent water table elevation in feet amsl. Blue areas represent the approximate extent of water table, while white areas are shown where geologic materials do not yield significant quantities of water and over larger lakes.

Source: United States Geological Service. "Surficial Hydrogeology." Authors: Roman Kanivetsky and Jane Cleland. 1992.

5.3 Default Water Budget

A default water budget was created to reflect only measurable data for Turtle Lake, i.e. groundwater was excluded. This was done to gauge the effect of groundwater on Turtle Lake's water levels, as determined by the variation of modelled levels from recorded levels. The default water budget calculation was performed by summing each month's water budget parameters and adding that value, referred to as the "residual", to the current month's predicted water level to get the subsequent month's predicted water level. Detailed calculations are included as Appendix A. Table 4 illustrates the calculation process for 1984, which is the first year included in the water budget. Any predicted water levels over the outlet elevation of 892.5 ft initiated an overflow parameter that was also reflected in the subsequent month's water level. Figure 3 depicts the default model's predicted water levels versus the observed lake levels. It is clear from the large deviation between the two that groundwater and potentially data error and other unknown variables comprise a large outflow from Turtle Lake.

Table 4- Default Water Budget for 1984

Date	Starting Lake Level, feet amsl	Direct Rainfall (P) inches	Rainfall Runoff (RO), inches	Direct Snowmelt, inches	Snowmelt Runoff (RO), inches	Evaporation (E), inches	Residual, inches	Surface Outlet Overflow (SO), inches	Default Expected Lake Level, feet amsl
January	892.15	0.73	0.01	0.04	-	-	0.78	0	892.22
February	892.22	1.51	0.06	0.72	0.00	-	2.29	0	892.41
March	892.41	0.86	0.02	0.55	0.00	-	1.43	0	892.53
April	892.53	3.04	0.18	5.62	0.13	-1.78	7.19	-0.01	893.13
May	893.12	2.94	0.11	3.33	0.10	-5.35	1.13	-0.68	893.16
June	893.16	8.39	1.06	-	-	-5.16	4.29	-0.85	893.45
July	893.45	3.01	0.09	-	-	-6.66	-3.56	-2.02	892.99
August	892.98	3.63	0.19	-	-	-5.45	-1.63	-0.17	892.83
September	892.83	3.53	0.16	-	-	-3.93	-0.24	-0.12	892.80
October	892.8	4.91	0.25	-	-	-0.77	4.39	-0.11	893.16
November	893.16	0.43	0.00	0.06	0.00	-	0.49	-0.85	893.13
December	893.13	2.04	0.08	0.22	0.00	-	2.34	-0.72	893.27

Note: The Default Expected Lake Level is calculated by adding the Residual (which is the sum of rainfall, snowmelt, runoff, and evaporation) to the previous month's Default Expected Lake Level. This elevation was then adjusted for Surface Outlet Overflow if the previous month's elevation exceeded 892.5 feet. No augmentation occurred in 1984, otherwise it would have been included in the Residual.

5.4 Modified Predicted Water Levels

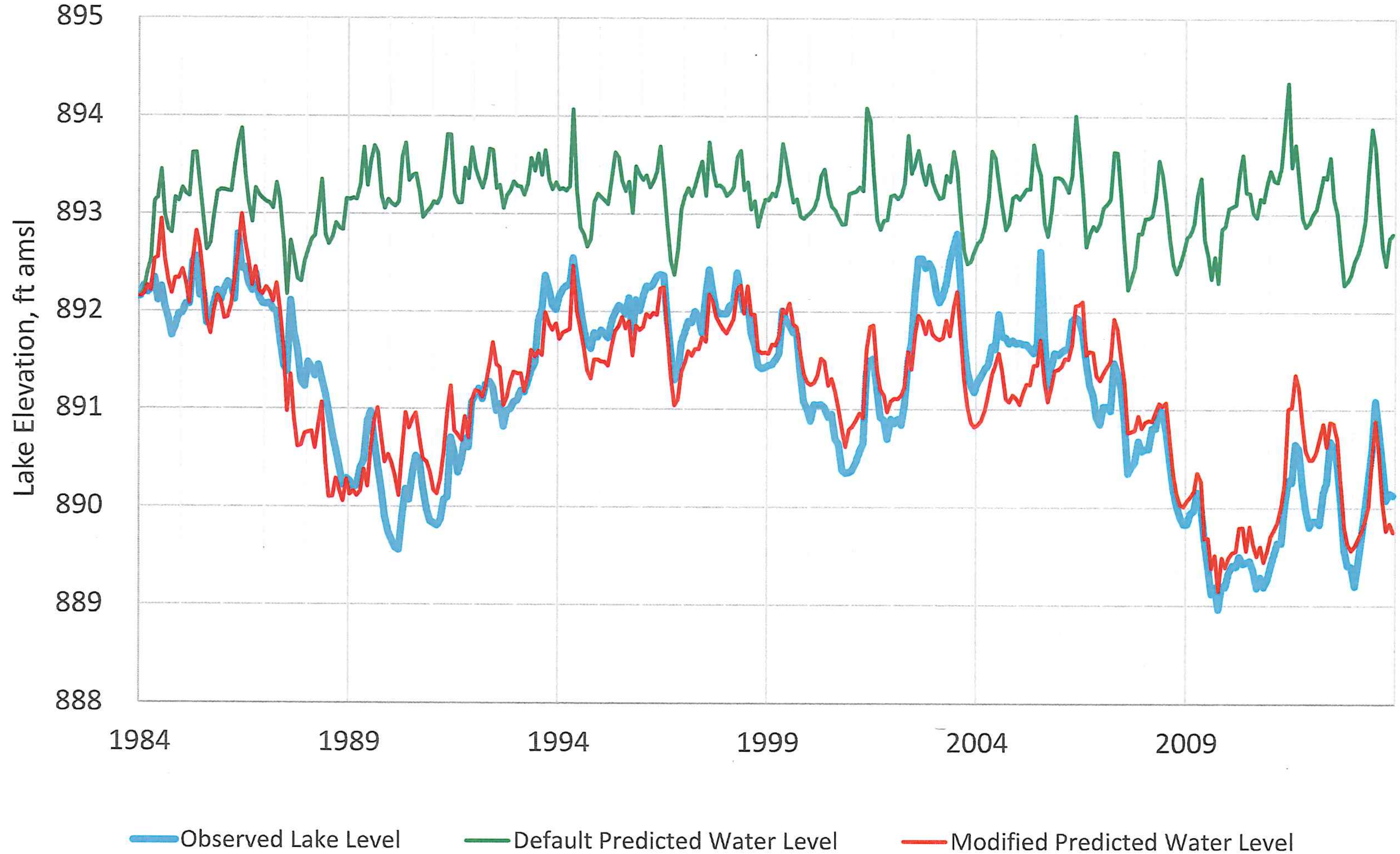
A modified version of the water budget was calculated to reflect groundwater flux. Groundwater flux was calculated as the difference between the change in observed water levels and the monthly water budget residual. For example, if a month's residual calculation indicated that lake levels should have gone up by 2 inches but observed levels showed a decrease of 6 inches over the month, 8 inches of outflow was attributed to groundwater flux. The groundwater flux calculations were averaged on a monthly basis for 1984-1993, 1994-2003, and 2004-2013. Within each of these decades, the appropriate monthly average was added to the water budget residual, which was in turn added to the current month's predicted water level to get the subsequent month's predicted water level. Detailed calculations are included as Appendix A. Figure 3 illustrates the modified model's predicted water levels compared to those of the default model, as well as the observed water levels. Results of this modified calculation reflect observed lake levels much more closely than those of the default calculation. An example of the calculations can be seen for 1984 can be found in Table 5.

Table 5- Modified Water Budget for 1984

Date	Residual, inches	1984-1993 Average Monthly Groundwater Flux, inches	Surface Outlet Overflow (SO), inches	Modified Expected Lake Level, feet amsl
January	0.78	(0.52)	-	892.15
February	2.29	(1.27)	-	892.17
March	1.43	(2.01)	-	892.26
April	7.20	(3.33)	-	892.21
May	1.13	(0.91)	0.01	892.53
June	4.29	0.43	0.01	892.55
July	(3.56)	(1.06)	0.16	892.94
August	(1.63)	(1.18)	0.01	892.54
September	(0.24)	(1.26)	-	892.31
October	4.39	(2.55)	-	892.18
November	0.49	(0.52)	-	892.34
December	2.34	(1.27)	-	892.33

Note: The Modified Expected Lake Level is calculated by adding the Residual and the 10 Year Average Monthly Groundwater Flux to the previous month's Modified Expected Lake Level. This elevation is then adjusted for Surface Outlet Overflow if the previous month's Modified Expected Lake Level exceeded 892.5 feet.

Figure 3 – Observed Versus Predicted Water Levels



5.5 Evaluation of Periods of Low Lake Levels

Individual water budget parameters were assessed for periods of historical lake level lows to determine how well the water levels during those periods could have been predicted from measurable data and groundwater calculations. This served as a check of the modified predicted water level calculations, as well as an indication of how closely Turtle Lake's water levels reflect weather patterns. The periods assessed were 1987-1994, 1997-2003, and 2006-2013. These three time periods encompass the decrease in lake levels, historic low, and return to normal levels for each of the low lake level periods.

5.5.1 1987-1994 Historic Low

Water levels began to decline in 1987, reached a low in 1990, and then climbed until 1994. Within this period, 1987-1989 were below average precipitation years accompanied by above average evaporation values. Additionally, groundwater outflow was calculated to be much larger than average for 1988 and 1989. Lake levels did not immediately rebound following augmentation during 1988 and 1989, in fact they reached their lowest in 1990. It wasn't until 1991 when the precipitation and evaporation trends reversed that water levels rose.

Table 6 below compares the deviation of the water budget parameters during this time period from the 1984-2013 averages for these years. During this period, water levels were influenced partially by measured water budget parameters and partially by calculated changes to groundwater or groundwater flux.

Table 6- Deviation of Annual Water Budget Parameters from 30 year Average, 1987 - 1994

Year	Evaporation, inches	Direct Rainfall, inches	Direct Snowmelt, inches	Groundwater Flux, inches	Augmentation, inches	Sum of Deviations, inches
1987	-6.6	-5.9	-2.8	10.2	0.0	**-5.0**
1988	-11.5	-8.8	0.0	-9.2	18.8	**-11.5**
1989	-2.7	-9.2	0.2	-11.2	20.1	**-3.7**
1990	-0.6	5.0	-1.9	1.7	0.0	**4.3**
1991	1.5	12.6	-1.2	4.7	0.0	**17.5**
1992	0.3	-1.5	5.7	-3.2	0.0	**1.4**
1993	2.4	8.6	-2.5	6.5	0.0	**15.0**
1994	0.0	0.8	-0.1	-2.3	0.0	**-1.5**
30 year Avg.	27.1	30.7	7.4	-15.4	0.0	**NA**

Note: Negative evaporation and groundwater flux values indicate greater than average outflows, while negative rainfall and snowmelt values indicate lower than average inflows. Negative Sum of Deviation values indicate overall water loss for that year.

5.5.2 1997-2003 Historic Low

Water levels plateaued after rebounding in 1994, until in 1997 they started a downward trend again. A low was reach during 2000, then water levels rebounded from 2001-2003. During the period of decline rainfall was about average and evaporation was slightly below average. The water budget predicted higher levels than those observed, indicating groundwater outflow was larger than average and strongly affecting lake levels during this time period. Above average precipitation from 2001 to 2003 paired with below average groundwater outflow values marked rebounding lake levels.

A comparison of the water budget parameters during this period to the 1984-2013 average parameters for these years can be found in Table 7. In this period, water levels were influenced partially by measured water budget parameters but to a greater degree by calculated groundwater flux.

Table 7- Deviation of Annual Water Budget Parameters from 30 year Average, 1997 – 2003

Year	Evaporation, inches[1]	Direct Rainfall, inches	Direct Snowmelt, inches	Groundwater Flux, inches[2]	Augmentation, inches	Sum of Deviations, inches
1997	3.4	0.3	3.0	-2.1	0.0	**4.5**
1998	1.4	2.4	-2.6	-4.7	0.0	**-3.6**
1999	1.9	-0.7	-1.8	-3.8	0.0	**-4.4**
2000	2.0	-1.9	-1.8	-1.7	0.0	**-3.5**
2001	1.9	2.9	1.8	1.5	0.0	**8.1**
2002	2.6	10.5	-2.4	7.8	0.0	**18.6**
2003	1.1	-5.1	-2.4	-1.1	0.0	**-7.4**
30 year Avg.	27.1	30.7	7.4	-15.4	0.0	**NA**

Note: Negative evaporation and groundwater flux values indicate greater than average outflows, while negative rainfall and snowmelt values indicate lower than average inflows. Negative Sum of Deviation values indicate overall water loss for that year.

5.5.3 2006-2013 Historic Low

Lake level decline from 2006-2009 was accompanied by below average values for precipitation and snowmelt. A reverse of this trend in 2010, characterized by above average precipitation and snowmelt and below average evaporation, brought an increase in lake levels.

A comparison of the water budget parameters during this period to the 1984-2013 average parameters for these years can be found in Table 8. During this period water levels were influenced primarily by measured water budget parameters.

Table 8- Deviation of 2006-2013 Annual Sum Water Budget Parameters from 30 year Average

Year	Evaporation, inches[1]	Direct Rainfall, inches	Direct Snowmelt, inches	Groundwater Flux, inches[2]	Augmentation inches	Sum of Deviations, inches
2006	1.1	-2.6	1.9	-4.4	0.0	**-4.1**
2007	-2.5	-0.3	-1.5	2.2	0.0	**-2.2**
2008	-1.0	-5.5	-1.3	1.8	0.0	**-6.0**
2009	0.3	-4.0	-1.5	2.5	0.0	**-2.7**
2010	1.0	2.9	-0.1	-0.5	0.0	**3.3**
2011	0.3	1.0	8.4	-2.5	0.0	**7.2**
2012	-3.4	-0.3	-5.5	4.1	0.0	**-5.2**
2013	-0.9	2.8	1.3	11.6	0.0	**14.9**
30 year Avg.	27.1	30.7	7.4	-15.4	0.0	**NA**

Note: Negative evaporation and groundwater flux values indicate greater than average outflows, while negative rainfall and snowmelt values indicate lower than average inflows. Negative Sum of Deviation values indicate overall water loss for that year.

5.6 Understanding Groundwater Fluctuations

As discussed in Section 5.5, groundwater fluctuation is a major part of Turtle Lake's water level fluctuation. Fluctuation in the water table, and thus in the groundwater flux values in Turtle lake's water balance, can be expected to follow seasonal trends. A seasonal summary of Turtle Lake's water budget parameters, including groundwater flux, is shown Table 9 below. It can be seen from this table that spring experiences the largest average water budget inputs (a net positive 3.18 inches) along with the largest average groundwater flux (outflow of 2.15 inches). Conversely, summer has a net output of 0.91 inches due to high evaporation rates and the least groundwater outflow (0.40 inches).

Table 9- Seasonal Fluxes in Turtle Lake's Water Budget Parameters

Season	Average, 1984 - 2013			
	Sum of Inputs, inches[1]	Sum of Outputs, inches[2,3]	Net change, inches[3]	Groundwater flux, inches
winter	1.06	-	1.06	-0.68
spring	5.30	-2.12	3.18	-2.15
summer	4.54	-5.45	-0.91	-0.40
fall	2.63	-1.51	1.12	-1.88

[1] Sum of direct and runoff rainfall and snow melt.

[2] Sum of evaporation and overflow.

[3] Negative values indicate outflow from Turtle Lake.

Groundwater fluxes also vary temporally. Average groundwater outflows for the three 10-year averaging periods used are shown in Table 10 below. The most recent ten years have had about 2 inches/year less groundwater outflow than the preceding twenty years.

Table 10 - Decadal trends in Turtle Lake Groundwater Outflows

Date Range	Average Groundwater Flux, in/yr
1984-1993	-15.9
1994-2003	-16.2
2004-2013	-14.0

6.0 Augmentation Volume

6.1 Augmentation Efficiency

Turtle Lake's relationship to the ground water table has been shown from analysis of the water budget to account for substantial water outflow. An artificial increase in Turtle Lake's water levels from augmentation without a similar increase in water table levels could be expected to lead to an increased outflow of Turtle Lake water to the water table. The Turtle Lake water balance for 1988 and 1989 was assessed to determine an estimate of increased seepage due to augmentation, and resulting augmentation efficiency. The groundwater flux values during these years were compared to the largest groundwater flux during a non-augmentation year, in this case, 1984. The difference between augmentation year and non-augmentation year flux was considered an approximation of additional seepage to the water table. This value was used with the augmentation volumes for 1988 and 1989 to calculate augmentation efficiencies of 81% and 72% respectively, as shown in Table 11.

Table 11- Augmentation Efficiency

Year	Groundwater Flux, inches	1984 Groundwater Flux, inches	Seepage Losses Attributed to Augmentation, inches	Augmentation, inches	Augmentation less Seepage losses, inches	Pumping Efficiency
1988	-24.5	-21.0	-3.5	18.8	15.3	81.3%
1989	-26.5	-21.0	-5.5	20.1	14.6	72.6%

6.2 Method of Analysis

The objective of the augmentation system operation is to minimize the extremely low water level periods and allow the lake to fluctuate "normally" within an established operating range. For the purposes of this study, it is assumed that lake levels will be managed so as to mimic lake level fluctuations prior to 1989. The proposed operating range for the lake would be 891–892 feet, or a one foot "normal" fluctuation. Augmentation would be used to keep the lake within this operating range, but not at a fixed or static elevation. In other words the lake would be allow to fluctuate somewhat; it would not be operated like a bathtub.

Sizing an augmentation system requires knowledge of the range of volumes needed on an annual basis. Two methods were used to generate a range of expected augmentation volumes for determination of a pumping rate for Turtle Lake: 1) summarizing historical pumping data and 2) calculating augmentation volumes that could have been added to Turtle Lake to attain a minimum elevation of 891 feet following the end of historical pumping in 1990.

6.2.1 Historical Augmentation

Augmentation volumes from 1928 to 1989 are summarized in Table 2 in Section 4.3.1. Turtle Lake's maximum augmentation volume of 437 MG occurred in 1950, following a three year shut off of the system during which below average precipitation levels were also experienced, ultimately resulting in lake levels about 2 feet below the 93 year average level (RCDPW, 1991; MnDNR1, 2015).

One caveat to historical reported volumes is that no flow meter was installed on the pumping system. Rather, pump operators recorded a pump rating and the approximate length of time that the pump was on, and summarized this data to the nearest million gallons on a yearly basis. These annual pumped volumes may not reflect the exact amount of water that went into Turtle Lake during those years.

6.2.2 Theoretical Augmentation

In the water budget's post-augmentation years, 1990 to 2013, for each month that experienced lake levels below 891 feet, a volume sufficient to raise the lake level to 892 feet was calculated. The effect of this theoretical addition was carried over in subsequent months by adding the historical rise or fall in lake level for that subsequent month to the adjusted elevation of 892 feet.

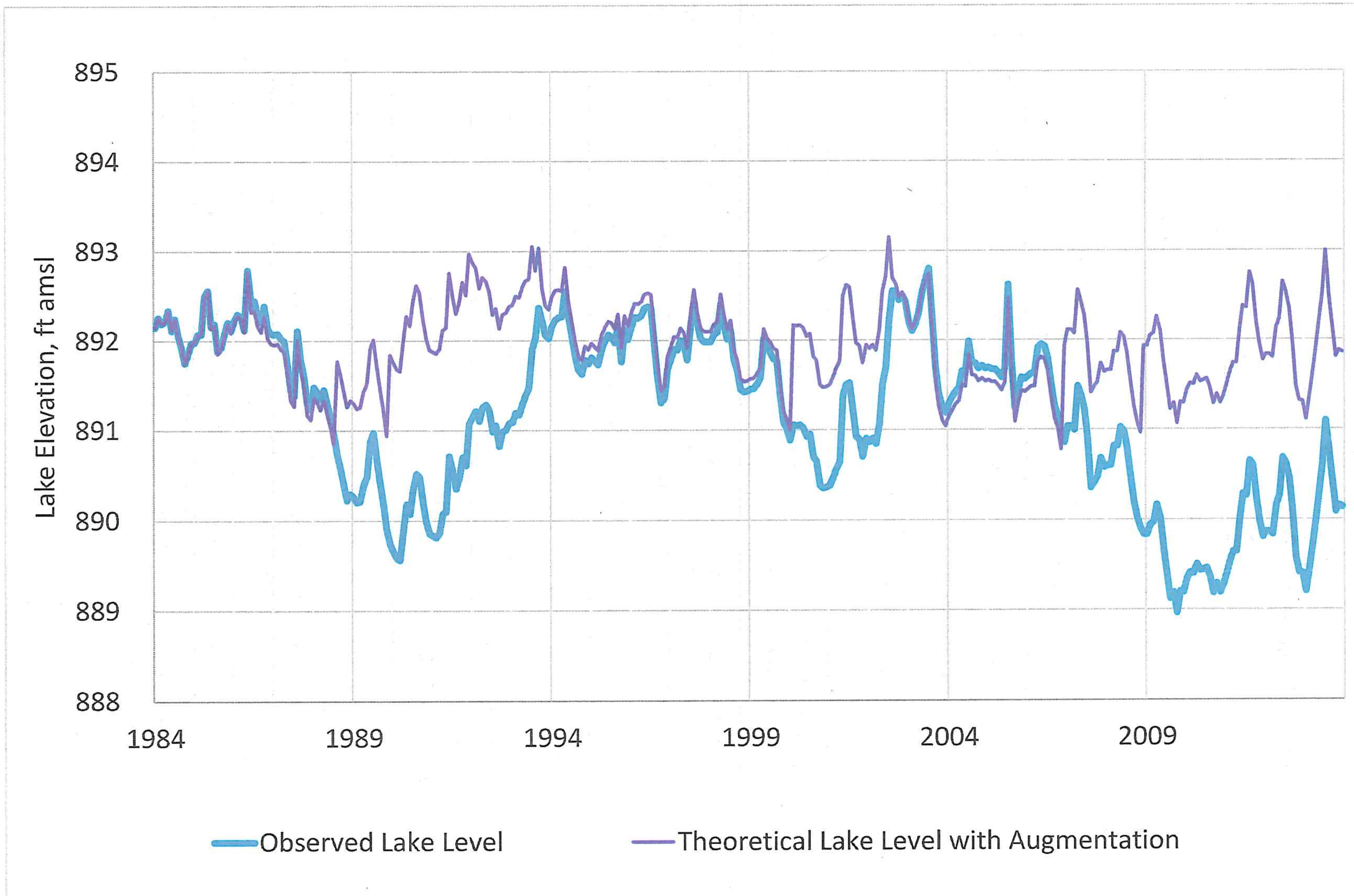
The estimated 1989 augmentation efficiency calculated of in Section 6.1 above (72.6%) was applied to the volumes calculated. The application of this efficiency is intended to account for increased seepage from Turtle Lake with the increase in hydrostatic head from the addition of augmentation water. Table 12 summarizes the theoretical augmentation volumes that would have been required to maintain the 891–892 foot operating range for the lake.

Table 12- Theoretical Augmentation Summary

	Average	Maximum
Volume per year augmented, MG	174	195
Volume per year augmented, inches over Turtle Lake	17.0	19.1
Portion of Turtle Lake augmented	10%	12%

Figure 4 illustrates water levels that could have been expected from 1990-2013 if this theoretical augmentation had been added. Figure 4 compares the observed water levels to the theoretical water levels assuming theoretical augmentation had occurred.

Figure 4 – Turtle Lake Water Levels: Observed versus Theoretical with Augmentation



6.2.3 Comparison of Theoretical and Historical Augmentation

The range of volumes presented by these two approaches are compared in Table 13 below.

Table 13 - Comparison of Potential and Historical Augmentation Summary Data

Method	Average, MG	Maximum, MG
Theoretical	174	195
Historical[1]	157	437

1 - See Table 2

Historical values differ from those calculated for 1990-2013 for a few reasons. The historic values represent a wider range of volumes as they reflect a larger range of years and weather conditions. Also, historically pumped volumes reflect the true filling efficiency of Turtle Lake; this efficiency may have varied annually or even over a one year time period, and in doing so affected the filling volume in unknown ways. Finally, records keeping may not have been accurate as no flow monitoring device was installed during the period of record.

6.3 Pumping Rate Selection

The selection of a pumping rate for Turtle Lake depends on how much water needs to be added seasonally and on an annual basis. This volume can be expected to vary from year to year. While a large size pump capable of providing a very fast refill rate for worst case conditions may be thought to be the ideal, designing for such a system quickly escalates system cost. Additionally, the MnDNR water appropriation for lake augmentation during severe drought would likely be restricted, as discussed in Section 11.2. Rather, the pump size selection should balance cost with an acceptable refill rate. Table 14 below shows the expected refill time for the volumes shown in Table 13 above based on varying refill rates.

Table 14 - Comparison of Pumping Times

Scenario	Method	Pump Size, GPM		
		500	*1000*	*2000*
Average Volume	Theoretical, days	242	121	61
	Historical, days	218	109	54
Maximum Volume	Theoretical, days	271	136	68
	Historical, days	607	304	152

In order to preserve equipment, pumping would only be able to occur when the lake is ice-free. Thus, up to six months of the year will be eliminated from the potential pumping window. The volume needed in Turtle Lake should be able to be delivered in six months' time, i.e. about 180 days. A pump size of 1000 gpm under continuous operation would be capable of delivering the needed annual volume within six months for all conditions except the historical worst case scenario. Due to the fact that the historical maximum augmentation volume occurred during drought conditions, during which future pumping would likely be restricted as described in Section 11.2, this scenario's volume was excluded from pump sizing considerations.

7.0 Water Source Alternatives

7.1 Overview

Four potential water source options for Turtle Lake have been assessed:

- Saint Paul Regional Water Service (SPRWS) conduit water.
- Charley Lake.
- Pleasant Lake.
- Snail Lake.

Figure 5 below illustrates an aerial overview of these sources in relation to Turtle Lake.

Figure 5 – Location of Source Water Options

7.2 Route Logistics and Pumping/Piping Infrastructure

Each source alternative requires a combination of piping systems and pumping station to deliver augmentation water. The length of pipe required varies greatly between options and is the primary factor in determination of the required horsepower. Elevation head between options varies as well, however this factor will change depending on relative lake levels. The construction cost analyses provided below are for the purpose of comparing alternatives and therefore are focused only on major cost elements, and does not account for easement purchases or energy costs to run the pump, etc.

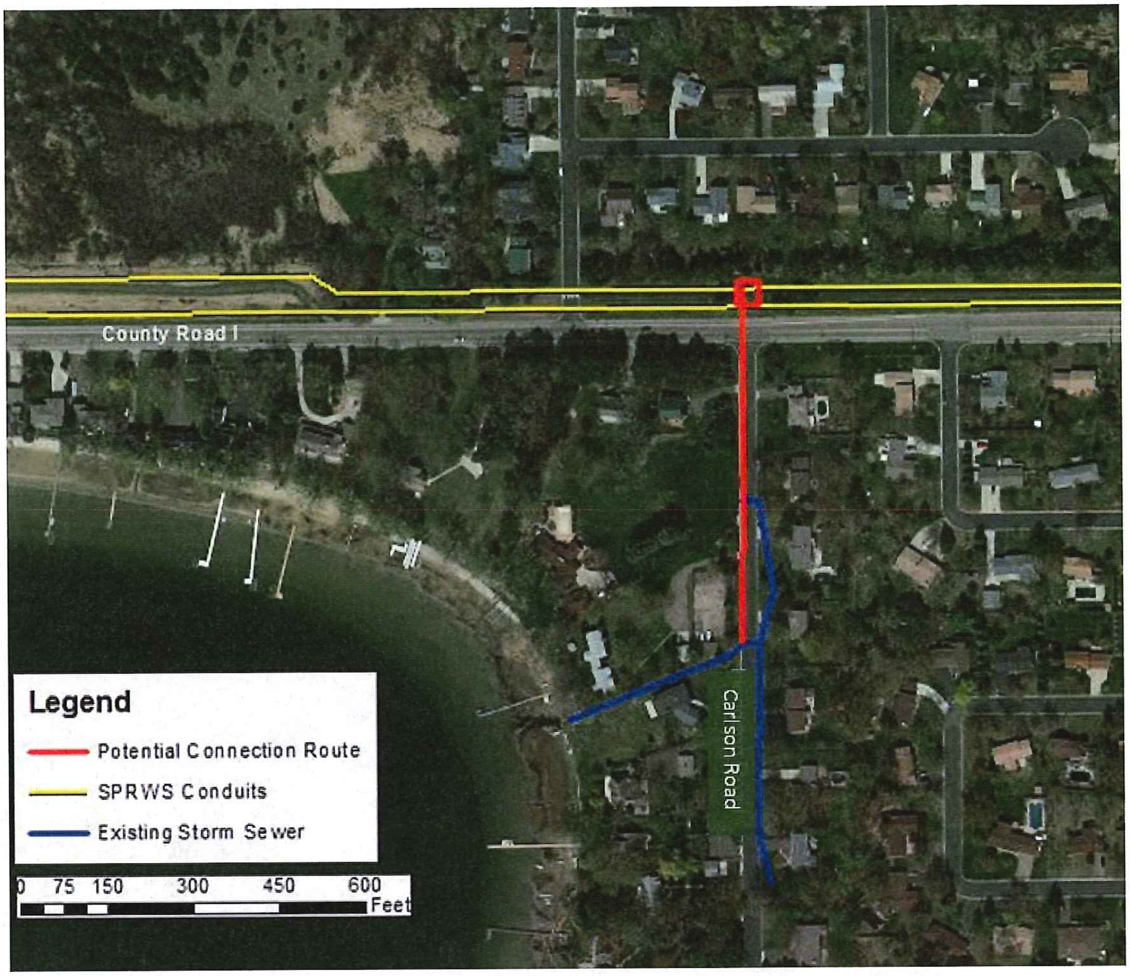
7.2.1 Saint Paul Regional Water Service (SPRWS) Conduit Water

SPRWS maintains two 60 inch diameter conduits that run west to east from the Mississippi River to Charley Lake in North Oaks, MN. These conduits run parallel to County Road I, which borders the north edge of Turtle Lake, passing within as close as 300 feet of Turtle Lake. The conduits have capacity for a combined 90 million gallons per day (MGD) and pass through a combined average of 45 MGD (SPRWS, 2012). The SPRWS water appropriation permit from the MnDNR allows for withdrawal of up to 20 billion gallons per year, approximately 55 MGD, from the Mississippi River.

By connecting directly into one of the conduits, a water supply may be provided to Turtle Lake well within SPRWS's appropriation limits. This approach is similar to that taken in the recent Lake Gilfillan augmentation project in North Oaks. The water would be routed from a proposed pumping station located on the north side of County Road I, about 610 feet south along Carlson Road, after which a tie-in would be made to an existing stormwater outfall located on Carlson Road that drains west into Turtle Lake. This alternative would require minimal impact to arterial roadways and due to the multiple access points, would minimize residential traffic disruption.

Figure 6 illustrates the piping route for this option.

Figure 6 – SPRWS Conduit Option Route Map



The required pump size for this alternative would be 15 horsepower (hp). Estimated construction cost for the piping infrastructure and roadway reconstruction is shown in Table 15.

Table 15 – SPRWS Source Alternative Physical Infrastructure Cost

Major Item	Unit	Unit Cost	Estimated Quantity	Cost
Storm sewer pipe - 10"	LF	$60.00	610	$36,600
Roadway reconstruction	SY	$60.00	2,490	$149,400
Turf re-establishment	SY	$5.00	230	$1,150
1000 gpm pump	HP	$900.00	15	$13,500
			subtotal	**$200,650**

7.2.2 Charley Lake

Charley Lake is a small water body about one half mile east of Turtle Lake within the City of North Oaks. Charely Lake is the outfall point for the SPRWS conduits. Charley Lake's ordinary high water level (OHWL) is about 1.1 feet above that of Turtle Lake.

Augmentation of Turtle Lake using water from Charley Lake would require approximately 3,800 feet of pipe, starting from a proposed pumping station located adjacent to the southwest shore of Charley Lake. The proposed route would pass southwest through a new residential development on Maycomb Lane in North Oaks, then south on Hodgson road and west into an existing stormwater outfall in Turtle Lake Park than drains into Turtle Lake. See Figure 7 illustrates this route.

Figure 7 – Charley Lake Option Route Map

This route would require the construction of a pump house as well as about 2,050 feet of pipe in the City of North Oaks, in addition to 800 feet of pipe trenching along Hodgson Road and one roadway crossing. The pump size for this option was calculated to be 40hp.

Estimated construction cost for the piping infrastructure and roadway reconstruction is shown in Table 16.

Table 16 – Charley Lake Source Alternative Physical Infrastructure Cost

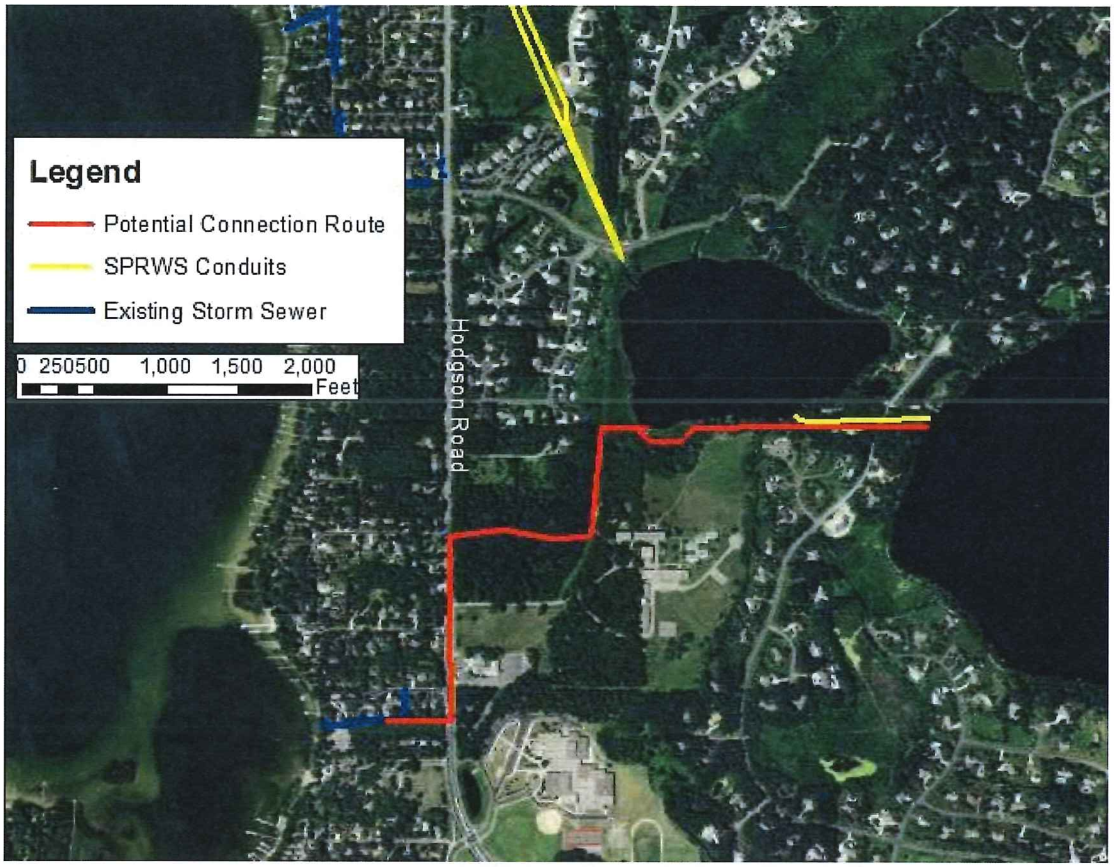
Major Item	Unit	Unit Cost	Estimated Quantity	Cost
Storm sewer pipe - 10"	LF	$60.00	3,800	$228,000
Roadway reconstruction	SY	$60.00	10,090	$605,400
Turf re-establishment	SY	$5.00	6,720	$33,600
1000 gpm pump	HP	$900.00	40	$36,000
			subtotal	**$903,000**

7.2.3 Pleasant Lake

Pleasant Lake lies southeast of Charley Lake, approximately one mile east of Turtle Lake, in City of North Oaks. An SPRWS channel carries water from Charley Lake southeast into Pleasant Lake. Pleasant Lake is the largest lake of the source alternatives based on both area and depth, and contains about two times the volume of Turtle Lake (MnDNR, 2014). An aeration system was installed in Pleasant Lake in 2011 to develop oxygenated conditions to reduce the release of phosphorus bound in the ferric chloride floc at the bottom of the lake (CH2M Hill, 2011). Pleasant Lake's OHWL is approximately equal to that of Turtle Lake (MnDNR1, 2015).

A pipe route to Turtle Lake would start with a proposed pumping station near the SPRWS channel outfall, then cross through about 1,960 feet of mostly undeveloped City of North Oaks land east of Charley Lake from Pleasant Lake's west bay and connect into the route described for Charley Lake. This route would have a total length of 5,880 feet and require a 50hp pump. Figure 8 illustrates this route.

Figure 8 – Pleasant Lake Option Route Map



This route would require the construction of a pump house as well as about 4,100 feet of pipe on City of North Oaks land, in addition to 800 feet of pipe trenching along Hodgson Road and one crossing of Hodgson. The estimated pump and piping cost for the Pleasant Lake alternative is shown in Table 17.

Table 17 – Pleasant Lake Source Alternative Physical Infrastructure Cost

Major Item	Unit	Unit Cost	Estimated Quantity	Cost
Storm sewer pipe - 10"	LF	$60.00	5,880	$352,800
Roadway reconstruction	SY	$60.00	10,270	$616,200
Turf re-establishment	SY	$5.00	15,740	$78,700
1000 gpm pump	HP	$900.00	50	$45,000
			subtotal	**$1,092,700**

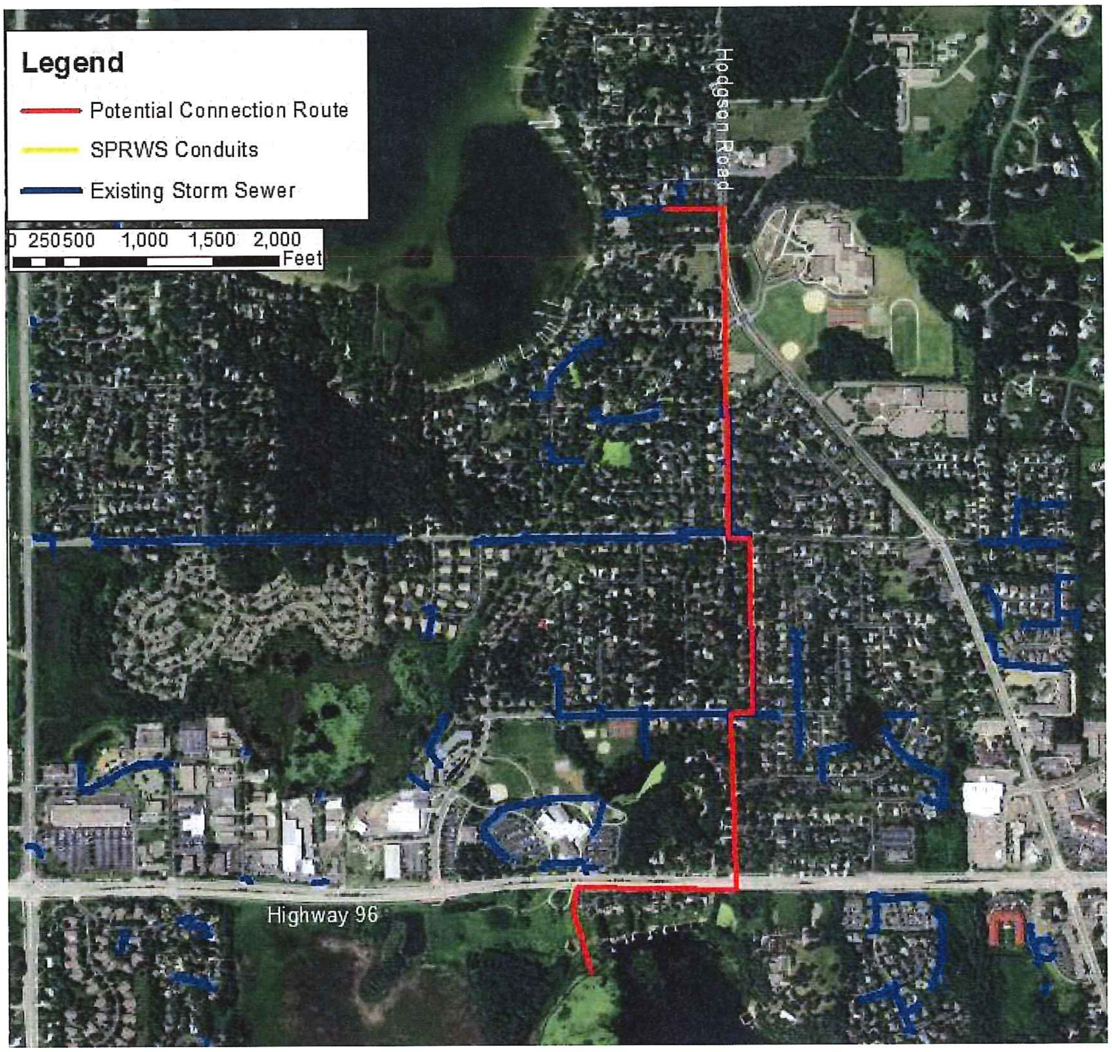
7.2.4 Snail Lake

Snail Lake is the most distant of the source water options studied, at about 1.5 miles south of Turtle Lake, though it is located within City of Shoreview. Snail Lake also has the smallest volume of the lakes for which bathymetric data was available; it is approximately 20% the volume of Turtle Lake. Snail Lake has high levels of groundwater seepage, and is currently augmented by Sucker Lake (to the east). Snail Lake's OHWL is about 9 feet below that of

Turtle Lake, resulting in a relatively large elevation head compared to other source options (MnDNR1, 2015).

A route to Turtle Lake would require about 7, 920 feet of pipe, running from the northern shore of Snail Lake, east on Highway 96, then north on residential streets until tying in with Hodgson Road, northwest on Hodgson Road, then west into the existing stormwater outfall at Turtle Lake Park. See Figure 9 illustrates this route.

Figure 9 – Snail Lake Option Route Map



This route would require about 1,200 feet of trenching and crossing of Highway 96, 4,800 feet of trenching and 3 crossings of residential streets, and 320 feet of trenching on Hodgson Road. This route would also require a 50 hp pump, Table 18 includes the costs associated with this option. The majority of this cost is attributed to roadway reconstruction.

Table 18- Snail Lake Source Alternative physical Infrastructure Cost

Major Item	Unit	Unit Cost	Estimated Quantity	Cost
Storm sewer pipe - 10"	LF	$60.00	7,920	$475,200
Roadway reconstruction	SY	$60.00	30,670	$1,840,200
Turf re-establishment	SY	$5.00	4,540	$22,700
1000 gpm pump	HP	$900.00	50	$45,000
			subtotal	**$2,383,100**

7.2.5 Summary of Pumping and Piping Infrastructure Costs

A summary of pumping and piping infrastructure costs are summarized in Table 19.

Table 19 - Summary of Pumping and Piping Infrastructure Costs

Alternative	Cost
SPRWS Conduit	$200,650
Charley Lake	$903,000
Pleasant Lake	$1,092,700
Snail Lake	$2,383,100

8.0 Water Quality

8.1 Source Water

The main water quality parameter assessed for source water options to augment Turtle Lake was phosphorus. Phosphorus is typically the limiting nutrient in freshwater ecosystems. Increased levels of phosphorus directly correlate to increases in aquatic plant growth and the frequency of algae blooms. As these conditions increase, the use of the lake is negatively impacted.

Turtle Lake has a very high level of water quality amongst regional water bodies. Table 20 below summarizes three key water quality parameters for the lake.

Table 20 - Turtle Lake 2004-2014 Average Growing Season Water Quality Parameters

Parameter	Value	NCHF Class 2B
Phosphorus, ppb	19.5	<40
Chlorophyll-a, ppb	4.9	<14
Secchi Depth, m	2.8	>1.4

Note: These standards correspond to the "cool and warm water fisheries (not protected for drinking water)" beneficial use category for the North Central Hardwood Forest Ecoregion.

Sources: 1) Minnesota Pollution Control Agency. "Lakes and Water Quality: Advanced Search Tool." Updated 11/3/2014. 2) Minnesota Pollution Control Agency. "Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List." October, 2009.

All three parameters in Table 20 are important, however, when comparing water quality between Turtle Lake and the potential source options, phosphorus was selected as the critical parameter. This is because phosphorus directly influences chlorophyll-a and Secchi depth (water clarity), which are in turn indicators of lake conditions. Table 21 provides a comparison of Turtle Lake's phosphorus levels with those of the potential source water options.

Table 21- Source Water Phosphorus Comparison

Water Body	Average P, ug/L	Period of Record
Turtle Lake	19.5	2004-2014
Snail Lake	22.0	2004-2014
Pleasant Lake	27.8	2011-2014
Charley Lake	68.4	2009-2014
SPRWS	80.2	2010-2014

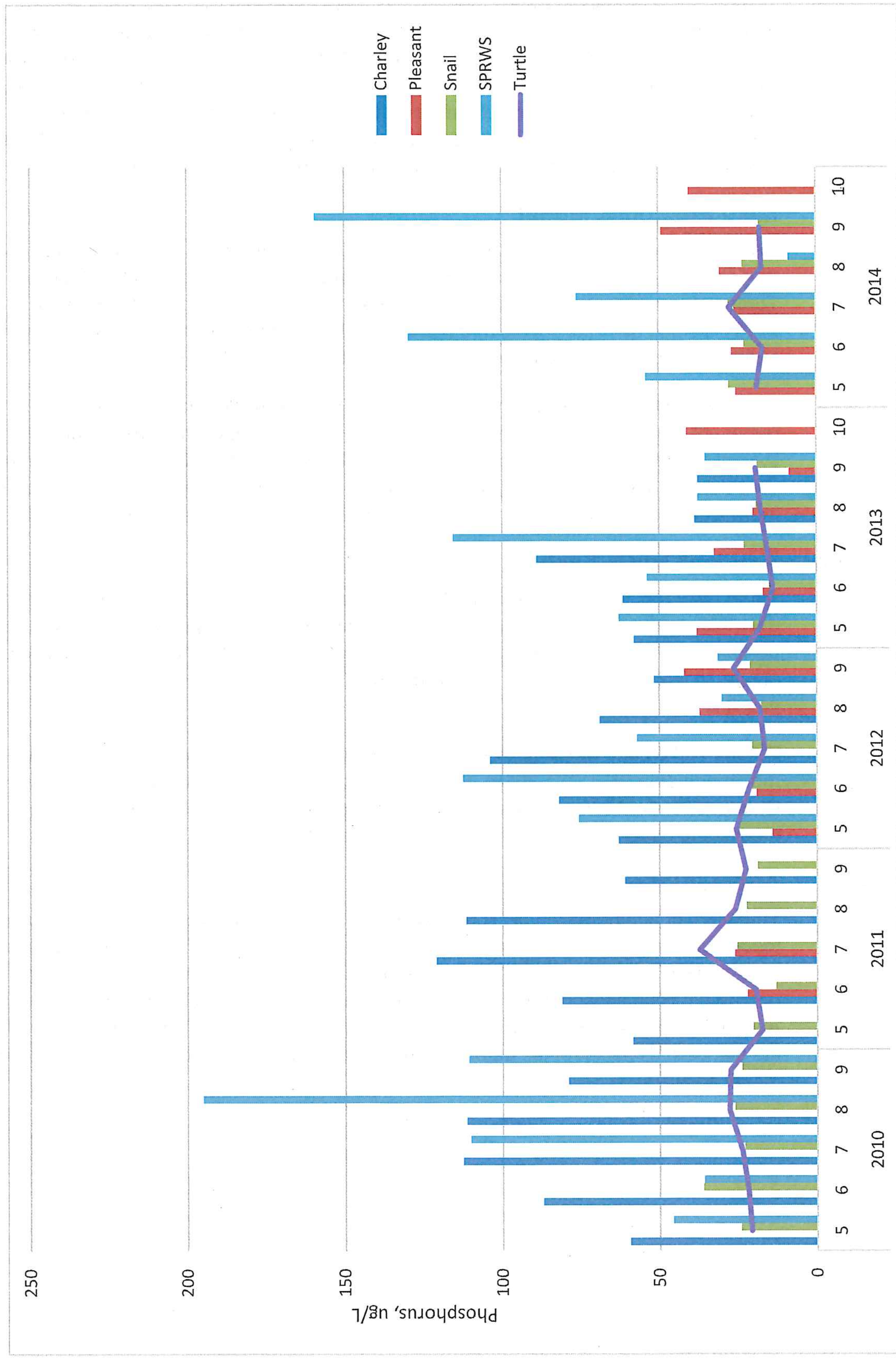
Note: Because the SPRWS water quality data was gathered at the Fridley Pumping Station before the water was dosed with ferric chloride for phosphorus flocculation, it represents Mississippi River water quality at Fridley.

Source: MPCA, 2014

Turtle Lake's low phosphorus levels, annually averaging approximately 19.5 ug/L for 2004-2014, are unmatched among the source options. The closest are Snail Lake, which averages 22.0 ug/L for this same period of record, and Pleasant Lake, which averages 27.8 ug/L since the installation of the aeration system in 2011. SPRWS and Charley Lake water have the most consistently high phosphorus levels.

Figure 10 compares monthly average phosphorus concentrations for Turtle Lake to each of the source waters from 2010 through 2014. Concentrations from the growing season, considered May through September for the purposes of this analysis, were used for comparison. This is because the growing season is the period during which phosphorus levels most impact in-lake conditions.

Figure 10 – Recent Source Water Average Phosphorus Concentrations During Growing Season



8.2 Lake Water Quality Response to Augmentation

The phosphorus loading for each option has been assessed with the objective that no degradation of Turtle Lake in-lake ambient phosphorus concentrations will be allowed. From Section 8.1, it is clear that each of the source alternatives have phosphorus concentrations in excess of Turtle Lake. However, because augmentation phosphorus loads, which are a function of concentration and volume, are much smaller than those the loading from watershed runoff and atmospheric deposition, a phosphorus concentration that exceeds the in-lake concentration can be added without increasing overall in-lake concentrations.

8.2.1 Lake Response Model

BATHTUB modelling software provided by the U.S. Army Corps of Engineers was used to model existing and proposed augmentation scenarios in Turtle Lake. A BATHTUB model of Turtle Lake existing conditions was obtained from the Rice Creek Watershed District (RCWD, 2015). Default conditions were updated to match recent monitoring data as well as the results of the Turtle Lake water budget. See Appendix D for model details.

The BATHTUB model is based on annual averages. Both lake and augmentation inputs represent average concentrations, and the resulting lake concentrations are an average of the entire year's concentrations. This aspect of the model was addressed to err on the conservative side by modelling growing season phosphorus levels in order to not introduce more algal bloom events. Additionally, all results have an associated level of variability.

8.2.2 Ambient Turtle Lake Conditions

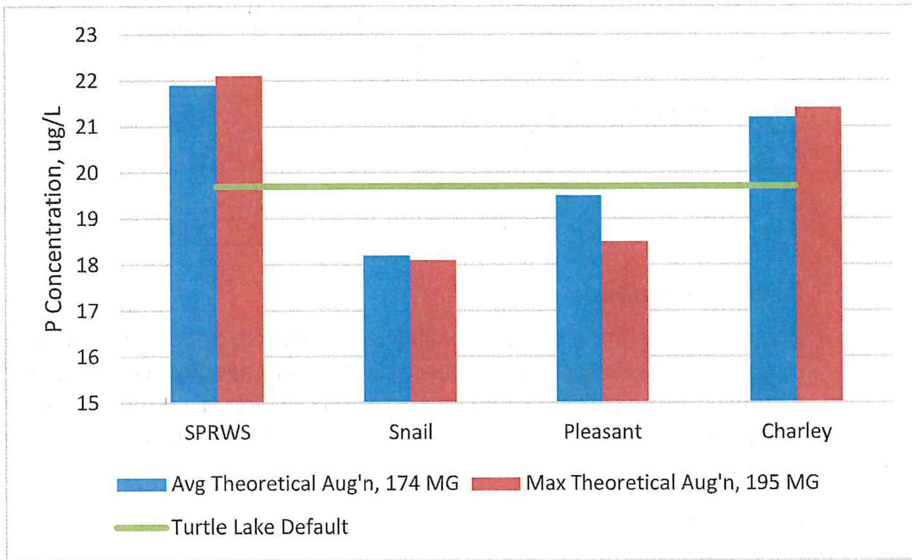
Turtle Lake monitoring data obtained from the MPCA for 2004 through 2014 was analyzed to determine water quality values for the growing season (May-September). Water quality parameters in Turtle Lake were summarized for this time period based on sampling depths above 15 feet, as it is at these shallow depths that light penetrates and algal blooms are possible.

Default Turtle Lake water quality was updated from the RCWD model based on this updated monitoring data (RCWD2, 2015). Specific updates to the default model are listed in Appendix D. In addition to these updates, the calibration factors for phosphorus and chlorophyll-a were modified to better reflect observed Turtle Lake conditions.

8.2.3 Augmentation Scenarios

The effect of augmentation on Turtle Lake phosphorus levels for average and maximum theoretical augmentation scenarios (174 MG and 195 MG – see Table 12) were assessed using the BATHTUB model. Figure 11 below illustrates the resulting effects of augmentation on Turtle Lake's phosphorus concentration for each of the potential augmentation sources. Appendix D provides full results of the model, including the coefficient of variation, which is the standard deviation of the data divided by the mean, and reflects the range of acceptable model answers.

Figure 11 – Turtle Lake Total Phosphorus Response to Augmentation



It can be seen from Figure 11 that Snail Lake or Pleasant Lake could be used as an augmentation source without increasing the in-lake phosphorus concentration of Turtle Lake. However, in order to utilize Charley Lake or the SPRWS conduit sources, phosphorus reduction will be required.

8.3 Phosphorous Reduction Requirements

The required removal of phosphorus to achieve the no degradation condition, as based on no increase in Turtle Lake phosphorus concentrations, was determined by using the "Load Response" function in BATHUB. Percentage removal required varied based on influent phosphorus concentrations and volume of augmentation water. Results of this analysis were used to calculate a load response curve, and thus determine the concentration of influent phosphorus allowed for varying volumes. Table 22 below summarizes treatment requirements based on source water and augmentation volume. Maximum allowable phosphorus concentrations for average and maximum theoretical augmentation scenarios are 43 ug/L and 42 ug/L respectively.

Table 22- Source Water Phosphorus Reduction

Source	Average, 174 MG	Max, 195 MG
Snail Lake	0%	0%
Pleasant Lake	0%	0%
Charley Lake	37.4%	38.3%
SPRWS	46.7%	47.4%

9.0 Source Water Aquatic Invasive Species Control

9.1 Overview

Several aquatic invasive species (AIS) are present in the northeast metro area. Zebra mussels, curly leaf pond weed, and eurasian milfoil are the most common of those in lakes near Turtle Lake. See Table 23 summarizes aquatic invasive species that are present in Turtle Lake and potential source waters.

Table 23 – Aquatic Invasive Species Summary

Water Body	Zebra Mussels	Eurasian Milfoil	Curly Leaf Pond Weed
Turtle Lake		x	x
Mississippi (SPRWS Conduits)	x	x	x
Pleasant Lake	x		x
Charley Lake	x		
Snail Lake		x	

9.1.1 Zebra Mussels

Zebra mussels are a nuisance invasive, non-native species that grow unchecked on aquatic surfaces, competing for food sources with native species, clogging water structures, and cutting swimmers' feet. Zebra mussel larvae, which are referred to as veligers, are from 40 to 280 micrometers in size (USACE, 1997; Lucy, 2006). All source options other than Snail Lake are listed by the MPCA as having zebra mussels.

9.1.2 Faucet Snails

While not listed in the section of the Mississippi from which the Fridley Pumping Station pulls water for the SPRWS conduits, faucet snails have been found in upstream segments of the Mississippi River near Leech Lake and Lake Winnibigoshish. This invasive, non-native species serves as a host for a type of parasite lethal to waterfowl. The lifecycle of the faucet snail includes the laying of eggs on a substrate such as rocks or leaves, the hatchlings of which are about 1.2mm in diameter (Negus, 1998).

9.2 Zebra Mussel Control Methods

9.2.1 Chemical Control

Chemical methods include chlorination, and use of ozone, potassium permanganate, and Zequanox. The concentrations needed for zebra mussel mortality using chlorination methods are also toxic to other forms of aquatic life, so this option has been crossed off (USACE, 1997). While ozone dissipates quickly from water and thus would not be toxic to other forms of aquatic life, it is an explosive chemical and must be generated on-site as it cannot be shipped (USACE, 1997). Cost and safety concerns make this option unsuitable for Turtle Lake. Potassium permanganate does not have as high a lethality rate as other chemical methods so was eliminated as an option (USACE, 1997). Zequanox is a molluscicide comprised of a zebra mussel food source that breaks down the digestive lining of the zebra mussels that consume it (MBI, 2014). It is reported to be highly selective to zebra mussels, making it safe for other aquatic species. This option is currently being investigated for use in infested lakes in Minnesota (MCWD, 2014).

Apart from environmental toxicity concerns, chemical control methods are unsatisfactory for control of zebra mussels in potential augmentation source waters because none of them have been shown to be 100% effective in all cases and are most appropriately used to address infested water bodies rather than large scale pumping from such water bodies.

9.2.2 Mechanical Control

Mechanical filtration targets veligers, which are the smallest form of zebra mussels. Screen sizes of 25 micrometers and 40 micrometers have been shown to be equally effective at removing the 40-250 micrometer veligers (USACE, 1997). In one independent trial using a 40 micrometer filter, a small amount of eggs and veligers did pass through the filter, however all of them were dead or dying- torn, compressed or deflated from passage through the filter (Lauria, 2009). In addition to zebra mussel control, such a filter would also remove the future possibility of faucet snails if they were to migrate south, as their smallest stage is 1.2 millimeters in size.

Based on these findings, filtration with a 25 micrometer screen has been selected as the preferred control method for potential source waters containing zebra mussels, consistent with similar filters for Snail Lake and Lake Gilfillan. Available technology for filtration down to 25 um includes a backwashing mechanism due to the very small pore size. Backwash from the system would be reintroduced to the source water. The filtration equipment for such a system, set up with parallel strainers to allow for constant operation during backwashing, would cost approximately $280,000 (Fluid Engineering, 2015).

10.0 Phosphorus Removal

10.1 Overview

Table 22 in Section 8.3 identifies the phosphorus removal requirements for each of the four water source alternatives reviewed as part of this study. The Sail Lake and Pleasant Lake water sources would require no phosphorus removal in order to meet the objective that no degradation of Turtle Lake in-lake ambient phosphorus concentrations will be allowed. However, both the SPRWS and Charley Lake sources require phosphorus removal to meet the objective.

Three elements in the potential treatment process were considered: mechanical screening, and sand filtration. Chemical Treatment was consider as part of mechanical and screening and sand filtration, as well as a separate treatment option.

10.2 Mechanical Screening

10.2.1 SPRWS Source Evaluation

Mechanical screening can be an effective way to remove phosphorus that is bound chemically in a floc to promote settling and removal. This is the case with the SPRWS augmentation source. SPRWS adds ferric chloride to Mississippi River Water at the river intake that delivers water through two 60 inch conduits to Charley Lake. Ferric chloride acts to bind up the phosphorus in the river water in a form that algae cannot rapidly assimilate. On contact with water, ferric chloride will react with phosphorus in the water and form a precipitate or floc. Because the floc is heavier than water, it eventually settles out of the water column. The floc likely remain in suspension until settling out in Charley Lake. Therefore, mechanical screening was only considered as an option for the SPRWS source.

Section 9.2.2 described the mechanical screening to be used to control zebra mussels, mimicking successful installations as part of the Snail Lake and Lake Gilfillan augmentation systems. The coarse (250 micron) and fine (25 micron) screens intended to contain zebra mussels will also retain the floc that is in suspension. On the positive side, this can potentially remove phosphorus form the source water, On the negative side, the screen will plug faster and require more frequent backwashing to prevent damage to the screens. The backwash feature of the filter is based on pressure across the filter; as the filter plugs, the pressure increases, triggering an automatic backwash. If the screens plug too fast, the system will be too inefficient due to backwash frequency, causing long pump run times and reducing the design life of the system.

10.2.2 Results

A test was performed using the screening system at Snail Lake. A source water was created to mimic the chemical conditions of the water in the SPRWS conduits. Manganese sulfite was added to the artificial source water to create the phosphorus-binding effective of the ferric chloride used by the SPRWS at the Fridley pumping station. The artificial source water was pumped through the Snail Lake screens using the SEH portable water treatment plant. The phosphorus removal was measured hourly during the test along with the backwash performance of the filters.

The results of the screen test indicates that floc in the artificial source water is in fact effectively retained on the screens, resulting in measured phosphorus removal up to 50%. The observed time to backwash for the 250 micron screen was approximately 2.5 hours, followed by a 3 minute backwash; similarly, the 20 micron screen backwashed every 3hours, for 5 minutes.

10.3 Sand Filtration

Sand filtration is a common potable water treatment technology. Untreated water is pumped through a filter media – sand – that helps to remove part small particles present in the water. With the additional of chemicals like ferric chloride, the phosphorus present in the source water can be bound into larger particles that can be removed throughout the sand filter process.

10.3.1 SPRWS Source Evaluation

For augmentation source phosphorus removal, the SEH pilot water treatment plant was used to evaluate the effectiveness and size of a sand filtration system as part of the phosphorus removal process. The study analyzed water from the SPRWS outfall at Charley Lake. The pilot plant was arranged to add a chemical coagulant to the source water to create a floc and then pumping the water through different columns for varying filter media size and depth to optimize the removal performance of the system.

The results of the sand filtration tests were disappointing at best. The sand filters were not able to achieve the necessary phosphorus removals without additional chemical addition or treatment elements that would allow greater contact time, i.e. digestion, with the coagulant (like ferric chloride) and the phosphorus. It is likely that velocities in the SPRWS conduits are two swift to allow enough contact time for a strong floc to form. Therefore the sand, which included media sizes of 350 – 550 microns is generally too coarse to achieve significant phosphorus removal. The sand filter does perform well with the removal of organics, which would reduce the backwash frequencies of the zebra mussel filters described in the previous section.

A smaller version of the initial testing was performed in the fall of 2015 to validate the initial results. However, the standard operating process for the SPRWS is to stop feeding ferric chloride during the winter months. Therefore the raw water samples analyzed were not typical of raw water that would be treated during the prime augmentation months of May through September.

10.4 Chemical Control

Chemical introduction into a treatment system will enhance the effectiveness of both mechanical screens and sand filters. The process of using a chemical coagulant to bind phosphorus in a floc that will settle from the water column has been discussed in previous sections of the report. The SPRWS adds ferric chloride at the Mississippi River pumping station. The floc does not form completely in the conduit due to the flow velocity. The floc forms completely after the water discharges into Charley Lake and can have necessary contact time. On contact with water, ferric chloride reacts with phosphorus in the water and form a precipitate or floc. The floc can be removed by mechanical screens and sand filkters to varying degrees of effectiveness.

Because the floc is heavier than water, it settles out of the water column. As the floc slowly settles out of the water column, phosphorus binds to floc and becomes, in effect, inactivated or unavailable for biological uptake by algae and phytoplankton. Once the floc settles on the bottom of the lake it becomes integrated into the sediments and subsequently reacts with phosphorus released from the sediments. However, in lakes low oxygen or anoxic conditions may occur seasonally, iron phosphate floc can release the bound phosphorus back into a soluble for in the water column. Recognizing this, the SPRWS introduced aeration to Pleasant Lake which is directly downstream off Charley Lake. In the years since the addition of aeration, the Pleasant Lake water quality has improved substantially. To the point that it could serve as augmentation water source without any phosphorus removal. However, Charley Lake still has a very high phosphorus concentration and would require significant treatment as shown in Table 22 to be considered an adequate augmentation source.

11.0 Implementation

11.1 Storm Sewer Conflicts

All proposed alternatives include a connection to one of two existing stormwater outfalls into Turtle Lake. This approach minimizes construction costs, disturbance to Turtle Lake's lakebed, and permitting requirements. However, the capacity of the stormsewer outlets to accept this flow has not been analyzed in detail. Assuming a 1000 gpm pump delivering at 72% efficiency, augmentation would use up approximately 1.6 cfs of the available storm sewer capacity. This limited capacity reduction relative to the capacity of the in place storm drains should not be an operational concern.

11.2 Permits and Approvals

No agency has a permit directly applicable to augmentation, however certain aspects of such projects do have associated regulatory requirements. The MnDNR administers three such programs.

The first of these is the public waters work permit. Any projects that involve construction "below the ordinary high water level of a water body, which alter the course, current, or cross section of public waters or public waters wetlands" may require the public waters work permit (MnDNR2, 2015). This permit would be required for the water intake structure for the three water body source options: Charley Lake, Pleasant Lake, and Snail Lake. The outfall for all four alternatives can be accomplished using existing stormwater outfall structures, and thus would not need the permit. The SPRWS conduit source water option is the only alternative not anticipated to need this permit.

A water appropriation permit is required for any withdrawals of more than 10,000 gallons per day or one million gallons per year (MnDNR, 2013). Each of the three water body source options would need to obtain this permit, while the SPRWS conduit source would not as it would be covered under the SPRWS's existing water use permit. No matter which augmentation source was used, the ability to pump water would always be contingent on the MnDNR's approval under this permit. The MnDNR has noted that the appropriation permit program's water use priorities will be reevaluated in upcoming years, and that lake augmentation will likely be a low priority (MnDNR3, 2015). With this in mind, there is potential that pumping may be restricted during drought years when lake levels are lowest.

An infested water diversion permit would be required for augmentation sources that contain aquatic invasive species. As discussed in Section 9.1.1, Turtle Lake is not listed for zebra mussels. Therefore all source options other than Snail Lake would be required to obtain an infested waters permit. This permit typically includes conditions for pumping, such as seasonal/timing restrictions, treatment of the water, and discharge/disposal requirements (MnDNR4, 2015). These conditions would be addressed with the treatment technology discussed in Section 9.2.

11.3 Construction Costs

As shown in Section 7, the costs related to the augmentation pump and transmission piping vary considerable due to the distance of the augmentation source. Table 24 summarizes the overall construction costs for each of the augmentation alternatives.

Table 24 - Construction Cost Summary by Augmentation Source

	SPRWS	Charley Lake	Pleasant Lake	Snail Lake
Augmentation Pump [1]	$13,500	$36,000	$45,000	$45,000
Augmentation Piping and Restoration [1]	$187,150	$867,000	$1,047,700	$2,338,100
Zebra Mussel Screen [3]	$255,000	$255,000	$255,000	$255,000
Screening Facility - Site Work [3]	$203,500	$203,500	$203,500	$203,500
Screening Facility - Structure [3]	$84,500	$84,500	$84,500	$84,500
Electrical HVAC, Plumbing [3]	$70,000	$70,000	$70,000	$70,000
Chemical Feed [3]	$31,000	$31,000	$0	$0
Subtotal	**$844,650**	**$1,547,000**	**$1,705,700**	**$2,996,100**
Construction Contingency	$126,698	$232,050	$255,855	$449,415
Estimated Construction Cost	**$971,348**	**$1,779,050**	**$1,961,555**	**$3,445,515**

1,2 – Tables 15, 16, 17 and 18

3 – See Appendix C

clearly illustrates the economic advantage of the SPRWS augmentation source, even with the inclusion of the proposed chemical feed system to enhance phosphorus removal across the mechanical screens. Assuming the addition of the sand filter option, and the costs change as follows:

Table 25 – Construction Costs Including Sand Filter

	SPRWS	Charley Lake	Pleasant Lake	Snail Lake
Treatment Facility –Sand Filter [3]	$471,000	$471,000	$0	$0
Treatment Facility - Structure [3]	$109,950	$109,950	$0	$0
Electrical HVAC, Plumbing [3]	$83,500	$83,500	$0	$0
Subtotal	**$664,450**	**$664,450**	**$0**	**$0**
Construction Contingency	$99,668	$99,668	$0	$0
Estimated Construction Cost	$764,118	$764,118	$0	$0
Base Project Cost (Table 24)	$971,348	$1,779,050	$1,961,555	$3,445,515
Maximum Construction Cost	**$1,735,465**	**$2,543,168**	**$1,961,555**	**$3,445,515**

11.4 Operations and Maintenance

Operations and maintenance is expected to be similar to the operation and maintenance of the Snail lake Augmentation System, with the addition of chemical and/or sand filtration to enhance phosphorous removal from the source water. It is expected that the City Public Works staff responsible for the operations and maintenance of the City's new water treatment plant will oversee the operations and maintenance of this facility. Annual operation and maintenance may be in the $25,000 - $30,000 per year, as compare to Snail Lake which is closer to $20,000 annually.

11.5 Lake Improvement District

The Snail Lake Lake Improvement District (LID) was formed in 1991/1992 to provide the legal basis to assessing the cost to construct and operate the augmentation system to the riparian property owners. It is assumed that a new LID would be formed for Turtle Lake for the same purpose. The process for LID formation is spelled out in Minnesota State Statutes 103B.501 – 103B.581 and in Minnesota Rules 6615.0900 – 6115.0980. It is interesting to note that according to the DNR, since 2004, all LID formation have been based on managing invasive aquatic plants. The Turtle Lake HOA has been spending as much as $15,000 - $20,000 per year on weed abatement. These costs could be included in the LID as well.

The City's legal counsel will take the lead in LID formation should the project proceed.

11.6 Responsible Parties

The City of Shoreview is the primary responsible party regarding acceptance of the augmentation report as well as initiation of the Lake Improvement District Process. The SPRWS will be responsible for developing a water purchase agreement once the project is approved. The City will also be responsible for the design and construction of the augmentation system as well as the on-going maintenance. The review agencies including MnDNR, MPCA and the Rice Creek Watershed District will have the opportunity to continue to comment and provide feedback regarding the final implementation.

11.7 Schedule

The schedule below depicts an accelerated approval to meet an anticipated LID referendum vote. By Statute. If there is a referendum vote, it must occur in July or August.

Council Workshop:	December 14, 2015
Council Approval, Proceed with LID	January 4, 2016

Commence LID Proceedings

Pre-petition meeting	January 5, 2016
Draft Petition complete	January 14, 2016
Signed petition filed with County	February 4, 2016
Notification to DNR/MPCA	February 9, 2016
Signatures verified, County Board notified	March 4, 2015
Notice of Public Hearing published	March 15, 2016
Public Hearing	April 5, 2016
Notice of Decision Date noticed to DNR	April 19, 2016
Decision	May 3, 2016
Publish Decision – Effective July 1, 2016	May 19, 2016

Deadline for Petition for Referendum	June 30, 2016
Referendum Vote	August 30, 2016
Submit names/Parcel ID for 2017 taxes	November 30, 2016

Commence Final Design	September 1, 2016
Advertise for Bids	February 2017
Award Contract	March 20, 2017
Commence Construction	May 2017
Substantial Completion	November 30, 2017

12.0 Sources Cited and Works Reviewed

Canfield, Daniel and Bachmann, Roger. "Predication of Total Phosphorus Concentrations, Chlorophyll a , and Secchi Depths in Natural and Artificial Lakes." Canadian Journal of Fisheries and Aquatic Sciences, 1981, 38(4): 414-423.

Carlson, R.E. and J. Simpson. 1996. A Coordinator's Guide to Volunteer Lake Monitoring Methods. North American Lake Management Society. 96 pp.

CH2M Hill. "Pleasant Lake Oxygenation Overview." 9/26/2011.

City of Shoreview (COS). Email correspondence with Tom Wesolowski on 6/23/2015.

Coates, PR. "Special Report on Lake Improvement." Copyright 1926. Board of County Commissioners.

Fluid Engineering. Correspondence with Brad Kegerreis, 10/26/2015.

Freshwater Society. "What is mercury? Where does it originate?" Posted September 24, 2009. http://freshwater.org/2009/09/24/what-is-mercury-where-does-it-originate-2/

Havens, Karl. "Deep Problems in Shallow Lakes: Why Controlling Phosphorus Inputs May Not Restore Water Quality." January, 2013. Florida Sea Grant College Program, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. https://edis.ifas.ufl.edu/pdffiles/SG/SG12800.pdf

Jones, PM; Trost, JJ; Rosenberry, DO; Jackson, PR; Bode, JA; O'Grady, RM. "Groundwater and surface-water interactions near White Bear Lake, Minnesota, through 2011." Scientific Investigations Report 2013-5044. United States Geological Service. http://pubs.er.usgs.gov/publication/sir20135044

LaBaugh, James; Winter, Thomas; Rosenberry, Donald, Schuster, Paul; Reddy, Michael; Aiken, George. "Hydrological and chemical estimates of the water balance of a closed-basin lake in north central Minnesota." December, 1997. Water Resources Research, Vol. 33, No. 12, Pages 2799-2812.

Lauria, Jim. "Building a Filter Defense Against Zebra and Quagga Mussels." Water Conditioning & Purification Magazine. April, 2009.

Lucy, Frances. "Early life stages of Dreissena polymorpha (zebra mussel): the importance of long-term datasets in invasion ecology." Aquatic Invasions (2006) Volume 1, Issue 3: 171-182

Marrone Bio Innovations (MBI). "Zequanox Invasive Mussel Control." Copyright 2014. http://www.marronebioinnovations.com/lightray/site/wp-content/uploads/2012/09/BR_Zequanox_PowIndMun_2014-01_web.pdf

Minnehaha Creek Watershed District (MCWD). "USGS Zebra Mussel Zequanox Study." 11/5/2014. http://www.minnehahacreek.org/project/usgs-zebra-mussel-zequanox-study

Minnesota Climatology Working Group (MCWG1). "Precipitation Data Retrieval from a Gridded Database: county: Ramsey, township number: 30N, township name: unnamed range number: 23W, nearest community: Shoreview, section number: 11." Accessed July, 2015. http://climate.umn.edu/gridded_data/precip/monthly/monthly_gridded_precip.asp

MCWG2. "Past Climate Data for Minnesota, Station Name: VADNAIS LAKE (STA 218477)". Accessed July, 2015. Minnesota Department of Natural Resources. http://www.dnr.state.mn.us/climate/historical/acis_stn_data_table.html?sid=218477&sname=VADNAIS%20LAKE&sdate=por&edate=por

Minnesota Department of Natural Resources (MnDNR1). "LakeFinder: Lake Water Level Report." Accessed 11/1/2015. http://www.dnr.state.mn.us/lakefind/index.html

MnDNR2. "Public Waters Work Permits." Accessed 10/29/2015. http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/requirements.html

MnDNR3. Verbal communication during Agency Meeting held with SEH and City of Shoreview on July 22, 2015.

MnDNR4. "Permit Application for Appropriation, Diversion, or Transport of Infested Waters." Rev. May 2015. http://files.dnr.state.mn.us/waters/forms/infested_waters_permit_application.pdf

MnDNR5. "Monthly Pan Evaporation - U. of M. St. Paul Campus." Accessed July, 2015. http://www.dnr.state.mn.us/climate/wxsta/pan-evaporation.html

MnDNR. "Lake Bathymetric Outlines, Contours, Vegetation, and DEM." Last updated: 11/12/2014. https://gisdata.mn.gov/dataset/water-lake-bathymetry

MnDNR. "Lake Depth Maps: Pleasant Lake" Copyright 1993. http://files.dnr.state.mn.us/lakefind/data/lakemaps/c0500010.pdf

MnDNR. "Lake-Groundwater Interaction at White Bear Lake, Minnesota." June 1998. http://www.wblra.org/wp-content/uploads/2014/12/MN-DNR-Study-on-Lake-Ground-Water-Interaction-at-WBL.pdf

MnDNR. "LiDAR Elevation, Twin Cities Metro Region, Minnesota, 2011." 2011. http://www.mngeo.state.mn.us/chouse/metadata/lidar_metro2011.html

MnDNR. "Water use - Water Appropriations Permit Program." Updated 2/4/2013. http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html

Minnesota Pollution Control Agency (MPCA). "Lakes and Water Quality: Advanced Search Tool." Updated 11/3/2014. http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lakes-and-water-quality.html

MPCA. "Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List." October, 2009. http://www.pca.state.mn.us/index.php/view-document.html?gid=21257

MPCA. "Nutrients: Phosphorus, Nitrogen Sources, Impact on Water Quality- A General Overview." May, 2008. http://www.pca.state.mn.us/index.php/view-document.html?gid=7939

MPCA. "Sources of mercury pollution and the methylmercury contamination of fish in Minnesota." Feb, 2013. http://www.pca.state.mn.us/index.php/view-document.html?gid=288

Mishra, S.K.; Singh, Vijay. Soil Conservation Service Curve Number (SCS-CN) Methodology. Dordrecht : Springer Netherlands, 2003.

Natural Resources Conservation Service (NRCS1). "Using SNOTEL Data to Estimate Snow Load Amounts." Accessed 8/11/2015. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/id/snow/?cid=nrcs144p2_046673

NRCS. "What is Snow Water Equivalent?" Accessed 8/11/2015. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/or/snow/?cid=nrcs142p2_046155

NRCS. "Chapter 11 Snowmelt." National Engineering Handbook, Part 630 Hydrology. July, 2004. http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17753.wba

Negus, Michael R. "A Life Table for the fresh water mollusc Bithynia tentaculata (L.)" Published 1998. Journal of Biological Education.

Ramsey County Department of Public Works (RCDPW). Correspondence with between Terry Noonan and Dan Reid. 7/10/1991.

Rice Creek Watershed District (RCWD1). "RCWD Drainage System Information Portal." Accessed 11/1/2015. http://rcwd.houstoneng.net/ditchportal/drainagesystemportal.html

RCWD2. Bathtub modelled provided by Matt Kocian via email correspondence on 3/3/2015.

Saint Paul Regional Water Service (SPRWS). "What is St Paul Regional Water Services?" 2012. http://wblcd.org/SPRWS_PPT_Pres.pdf

Short Elliott Hendrickson. "Second Generation Surface Water Management Plan." Prepared for City of Shoreview. March, 2005.

United States Army Corps of Engineers (USACE). Zebra Mussel (Dreissena polymorpha) Control Handbook for Facility Operators, First Edition. Miscellaneous Paper EL-97-1. June 1997. http://el.erdc.usace.army.mil/elpubs/pdf/98e176.pdf

United States Environmental Protection Agency (USEPA). "5.6 Phosphorus." Last Updated 3/6/2012. http://water.epa.gov/type/rsl/monitoring/vms56.cfm

United States Geological Service (USGS). "Surficial Hydrogeology." Authors: Roman Kanivetsky and Jane Cleland. 1992.

Wisconsin Department of Natural Resources (WiDNR). "Lake Levels." Accessed 11/1/2015. http://www.wisconsinlakes.org/index.php/the-science-of-lakes/30-lake-levels

Appendix A

Area Lake Augmentation

Area Lake Augmentation

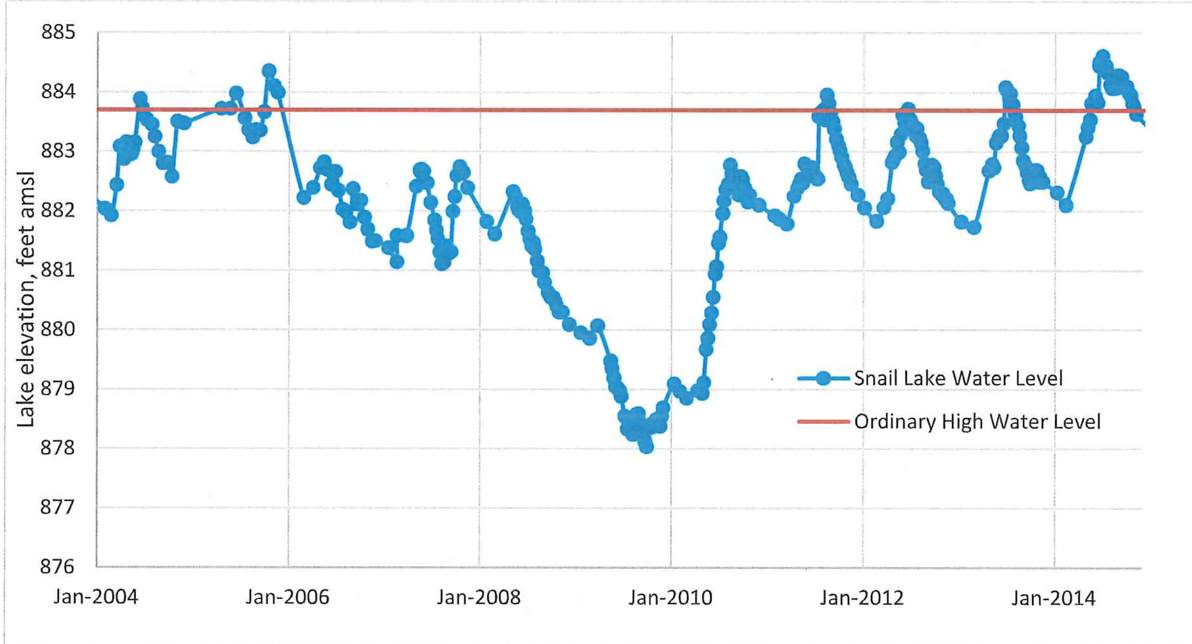
Following a 1928 report by Paul Coates recommending augmentation of northeast metro area lakes, augmentation became an extremely common practice until groundwater systems were restricted in the late 1980s. In fact, this method of lake level maintenance is still used by both public and private entities across Minnesota. The MnDNR appropriations permits database lists 37 unique permittees with water level maintenance appropriations and non-zero withdrawals for its most recent reporting year, 2011 (MnDNR, 2013).

Locally, augmentation systems were installed at two lakes in close proximity to Turtle Lake- Lake Gilfillan and Snail Lake. Since 1993 a 2000 gpm augmentation system has pumped water from Sucker Lake to Snail Lake. This system was shut down in 2007 due to the discovery of zebra mussels in Sucker Lake. In 2009 the system was updated with a zebra mussel filtration system. The system consisted of two 25 micrometer filtration screens running in parallel to remove zebra mussels, in conjunction with a 250 micrometer prefiltration screen to remove organics and prevent clogging of the 25 micrometer screen. For the two years that pumping has been utilized since installation, volumes have been 212 MG (2010) and 142 MG (2012) (COS, 2015). Since 2009 water monitoring has revealed slight improvements in the water quality of Snail Lake with regard to chlorophyll a concentrations, Secchi depth, and turbidity; however, slight increases were also observed in phosphorus and orthophosphorus levels during this time (see Table A-1 below). Lake levels had dropped to almost six feet below Snail Lake's ordinary high water level when the original system was shut off in 2007, but quickly rebounded and have fluctuated within a two foot range since augmentation was restarted in 2010 (see Figure A-1 below).

Table A-1 – Phosphorus & Orthophosphorus Levels

Date Range	2004-2009	2011-2014	Change
Chlorophyll a, corrected for pheophytin	4.0	3.4	-16%
Depth, Secchi disk depth	3.08	3.26	6%
Orthophosphate as P	0.010	0.010	2%
Phosphorus as P	0.020	0.023	13%
Turbidity	1.7	1.3	-26%

Figure A-1 - Snail Lake Historical Water Levels



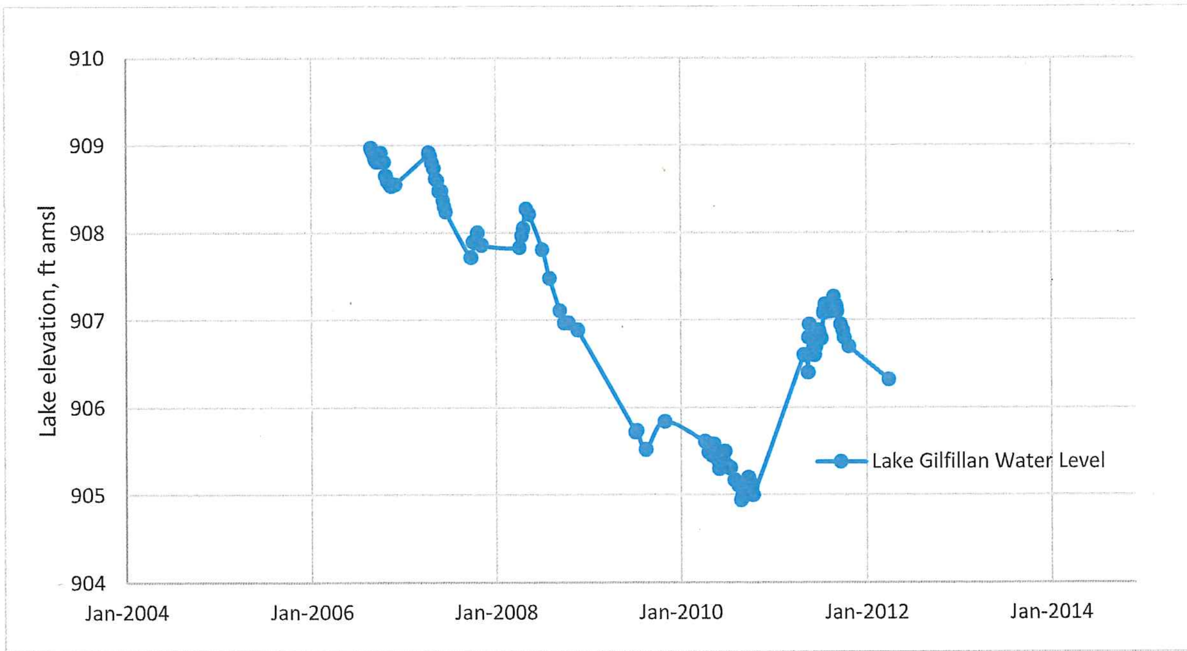
Note: Lake levels rebounded quickly with the addition of 212 MG of augmentation water during 2010.

In 2009 Lake Gillfillan was experiencing water levels approximately four feet below 2006 levels. The lake had no pre-existing augmentation system, rather a 1000 gpm system was installed in 2011 to pull water from the SPRWS conduit between Pleasant Lake and Sucker Lake and route it into an existing stormwater outfall at the south end of Lake Gilfillan. A zebra mussel filtration system similar to that described for Snail Lake was also implemented. In-lake water quality experienced substantial improvements following augmentation, see Table A-2 below. Limited water level data was available (see Figure A-2 below), and no data following augmentation was available.

Table A-2 -Water Level Data

Date Range	2008-2010	2012-2014	change
Chlorophyll a, corrected for pheophytin	37	15	-60%
Depth, Secchi disk depth	0.5	1.5	209%
Phosphorus as P	0.145	0.049	-66%

Figure A-2 - Lake Gilfillan Historical Lake Levels



Appendix B

Water Budget Methods of Analysis

Data Collection

Data gathered for each of the water budget parameters and associated calculations for incorporation into the water budget are described below.

Direct Precipitation

Monthly gridded rainfall data was obtained from the State Climatology Office. Within this system, data gaps are filled by an interpolation algorithm called Kriging, which creates an evenly spaced data grid of monthly precipitation across all of Minnesota based on weather station recordings within the grid. This data was entered directly into the 30 year water budget without any processing.

Snowfall data was obtained from the MnDNR's "Past Climate Data" webpage on a daily basis, and many daily values were reported as missing. The amount of missing data was calculated by assigning all numeric, "T" (trace), "-A" (aggregate value), and "S" (preceding aggregate values) values an ID of "0" and all "M" (missing) values an ID of 1. A pivot table was used to summarize the ID=1 entries on both a monthly and yearly basis. Missing data averaged 27% per year, with the time period between 1984 and 1990 averaging 90% per year.

All missing and non-numerical data entries were initially replaced with "0" for data processing purposes. In order to correct for missing data, daily snowfall values were summed on a monthly basis and compared to the number of missing daily values on a monthly basis. When a month had a snowfall value of zero, had ten or more missing snowfall days, and fell between November and March, it was assigned an average value of the preceding and succeeding years' values for that month. Monthly values were averaged into daily values for that month, which were used in the daily snowmelt analysis.

The Degree-Day Method was used to determine the amount of snowmelt on a daily basis. A degree-day coefficient of 0.06 in/degree-day F was selected based on unknown melting rate conditions (NRCS, 2004). A snowfall density of ten inches of snow to one inch of meltwater was assumed for all new snow that fell (NRCS1, 2015). Daily snowmelt values were summed on a monthly basis and incorporated into the 30 year water budget.

Runoff

As gridded precipitation data was only available on a monthly basis, non-gridded daily data was used in the rainfall runoff analysis. Rainfall data was obtained from the MnDNR's "Past Climate Data" webpage on a daily basis, and many daily values were reported as missing. The amount of missing data was calculated by assigning all numeric, "T" (trace), "-A" (aggregate value), and "S" (preceding aggregate values) values an ID of "0" and all "M" (missing) values an ID of 1. A pivot table was used to summarize the ID=1 entries on both a monthly and yearly basis. Missing data within the daily precipitation data set averaged 8% per year, with a maximum of 43% in 1986.

All missing and non-numerical data entries were initially replaced with "0" for data processing purposes. In order to correct for missing data, daily rainfall values were summed on a monthly basis and compared to the number of missing daily values on a monthly basis. When a month had a sum precipitation value of zero and had ten or more missing precipitation days, it was assigned an average value of the preceding and succeeding years' values for that month. This value was then divided by the number of days in the month to obtain daily precipitation values.

The SCS Method was applied to daily rainfall values. Area and percent impervious for each of the four Turtle Lake tributary areas were obtained from a 2005 Surface Water Management Plan for Turtle Lake (SEH, 2005). A curve number of 60 was applied to all pervious area, and 98 was used for impervious. Impervious areas were assumed to be directly connected to Turtle Lake with stormsewer. Runoff volumes were calculated for pervious and impervious areas within each tributary area, then all tributary area volume contributions were summed on a monthly basis.

Similar to rainfall runoff, the SCS Method was applied to daily snowmelt values from the direct snowmelt analysis. Snowmelt was assumed to be uniform over the entire Turtle Lake watershed. Area and percent impervious for each of the four Turtle Lake tributary areas were obtained from a 2005 Surface Water Management Plan for Turtle Lake (SEH, 2005). A curve number of 60 was applied to all pervious area, and 98 was used for impervious. Impervious areas were assumed to be directly connected to Turtle Lake with stormsewer. Runoff volumes were calculated for pervious and impervious areas within each tributary area, then all tributary area volume contributions were summed on a monthly basis.

In reality several factors confound the calculation of snowmelt runoff, including the fact that snow is typically removed from impervious area (roads, parking lots) and stored on pervious area, stormsewer is frequently obstructed with ice, and soils vary between frozen and degrees of saturation. The method used likely overestimates snowmelt runoff from impervious areas, however this parameter is of much smaller magnitude than rainfall and evaporation and overestimation is not expected to significantly impact the findings of the water budget.

Evaporation

Monthly pan evaporation rates were adjusted by a pan coefficient of 0.75 based on Jones et al's value for nearby White Bear Lake, then entered directly into the 30 year water budget. Evaporation data availability limits the water balance to the time period between 1984 and 2013.

Augmentation

Augmentation data is provided on an annual basis, along with the number of days it occurred within the year. Historical augmentation occurred within the water budget date range for 1988 and 1989, which was incorporated into the water balance on a monthly basis by assuming augmentation started in June, was pumped at a constant rate, and didn't turn off until all the days of augmentation recorded had passed. A depth over Turtle Lake was assigned to the volume calculated for each month based on the stage-storage relationship determined from bathymetric data.

Overflow

An outlet swale and culvert exist at the northwest shore of Turtle Lake at a private residence. According to available contour data (lidar coverage), a small berm exists between the culvert's inlet, which lies in the swale, and the lakeshore. This berm is estimated at an elevation of 892.5' based on lidar contours. Available information from the Rice Creek Watershed District Ditchviewer indicated that the culvert's inverts are both at 891.15', the diameter is 24", and that the culvert is metal. A rating curve was developed for the culvert assuming that no flow would occur until 892.5', and thus the inverts were set to this elevation for calculation purposes. The rating curve provided an outflow flowrate for each headwater (lake level) value. These flowrates were converted into volume per month, which was then converted to inches over Turtle Lake per month.

While the available data indicates that the outlet culvert has a slope of 0%, this design is unlikely in reality. The effect of adding a minimal slope of 0.2% to the culvert was found to have a significant effect on overflow rates, doubling and quintupling monthly outflow volumes in some instances. This culvert, the inlet of which lies on a private residence, should be surveyed if a final design for the augmentation system is pursued. Overall, overflow accounts for a very small percentage of the water budget.

Groundwater

For each month, Turtle Lake inputs (direct precipitation, runoff, augmentation) and outputs (evaporation, outflow) were summed in a column called "residual". A "delta lake level" was also calculated for each month, which was the current month's lake level minus the preceding month's level. A "groundwater flux" column was calculated as the difference between the delta lake level and the residual for each month.

Because the calculation described above includes not only the groundwater flux but also any errors in the other water budget parameters, monthly groundwater values were averaged on a 10 year basis, for date ranges 1984-1993, 1994-2003, and 2004-2013. These values were referenced back into the water budget in the "10 yr average monthly groundwater flux" column for the appropriate years. As groundwater movement typically balances out on the scale of years to decades, this method is expected to take into account long term groundwater trends.

Bathymetric Data
GIS depth contour data for Turtle Lake was exported to Excel. Stage-storage and stage-area relationships were determined based on linear regressions. As lake levels never dropped below 5 feet of the surface contour, a linear regression between the 5' depth contour and the surface contour was adequate for all calculations.

Lake Levels
The water budget uses a time step of one month because evaporation data is available in one month increments. While evaporation and precipitation can be summed on a monthly basis, lake levels were not regularly available on the first of each month. Instead, whichever lake level reading date was closest to the first of the month was selected. When a reading was not available close to the first of the month an average of previous and subsequent month values was used.

Analysis

The water budget was created for with a monthly time step for the 30 year period between 1984 and 2013, and was compared to recorded monthly lake water levels to observe how closely measurable data reflects historical lake trends. To do this, Turtle Lake's elevation on January 1st, 1984 was used as a starting point, and to this was added the water budget parameters for each subsequent month. The resulting difference between the predicted level and the actual lake level was accounted to groundwater flux. This flux was calculated for each month from 1984-2013, then averaged on a monthly basis for the same time period and added into the water budget as the GWex parameter. This resulted in predicted lake levels rather closely approximating historic levels. Levels were further adjusted by setting the surface outlet outflow elevation at 892.5 feet amsl, resulting in a maximum lake level of 892.5 feet with all water predicted above that elevation lost to outflow.

Major deviations from recorded lake levels indicated groundwater contributions and/or errors in the water budget parameter data. An attempt was made to address groundwater contributions by averaging these monthly deviations over 10 year periods and incorporating them back into the water budget as a groundwater parameter

Assumptions and Caveats

General assumptions include that the location of measurement for each water budget parameter was representative of Turtle Lake and its watershed, and that the magnitude of each water budget parameter was distributed equally over Turtle Lake and its watershed.

Two types of rainfall data were obtained for analysis. Monthly data for direct rainfall (that falling directly onto Turtle Lake) was obtained from a gridded database. The gridded database creates synthetic, regularly spaced "nodes" for which precipitation data is interpolated based on its distance from nearby precipitation monitoring locations. It is assumed that these interpolated values are representative of rainfall over Turtle Lake.

Daily precipitation data used in calculating runoff was obtained for Station 218477, which lies approximately 3.5 miles southeast of Turtle Lake's watershed. Weather patterns may vary across Turtle Lake's watershed and undoubtedly vary across the 3.5 mile distance to the Station 218477, which introduces a degree of error into the water budget. This station also has missing daily precipitation records. These data gaps may be due to several reasons, including occasional interruptions of automatic stations, instrument malfunctions, network reorganizations, etc (MCWG1, 2015). Missing data has been replaced with averaged data as described in individual sections below. It is assumed that the data from this station and the averaged replacement values for its missing data are representative of Turtle Lake's watershed.

Pumped augmentation was reported on an annual rather than monthly basis, so an assumption was made that pumping occurred starting in June consecutively until the number of days recorded had expired.

The length Turtle Lake's outlet culvert was not available, so it was estimated based on an aerial view of the area which showed a downstream swale. While invert elevation was available for the culvert, it reported that the inlet and outlet elevations were the same. This is an unlikely design, and calls into the question the veracity of the data. When overflow calculations were done assuming a 0.5 foot drop in elevation of the culvert between the inlet and outlet, overflow rates were 2 to 5 times higher for varying lake elevations. If a final design is pursued a permission should be obtained from the homeowner on whose property it lies, and a survey of invert elevations and length should be conducted.

As previously discussed, the method used to calculate groundwater is purely theoretical and includes any error in the other parameters' data.

Appendix C

Detailed Cost Analysis

Turtle Lake Augmentation
Cost Estimate

Updated: 11-29-15

Item:	Unit	QTY	Unit Price	Total Price	Subtotal
Zebra Mussel Mechanical Screen Equipment					
Allowance: Skid-Mounted Screening Equipment, incl. backwash	LS	1	225,000.00	$225,000.00	
Skid-Mounted Screening Equipment Installation	LS	1	30,000.00	$30,000.00	
Subtotal					**$255,000**
Sitework					
Mobilization	LS	1	35,000.00	$35,000.00	
Permits	LS	1	3,000.00	$3,000.00	
Easements & Property Acquisition	SF	6500	15.00	$97,500.00	
Traffic Control: Barricades and Lights	LS	1	6,000.00	$6,000.00	
Silt Fence	LF	1000	5.00	$5,000.00	
Tree Removal	LS	1	3,500.00	$3,500.00	
Excavation	CY	300	50.00	$15,000.00	
Dewatering (Wells/Well Points)	LS	3	3,000.00	$9,000.00	
Trucking to Waste	CY	50	25.00	$1,250.00	
Site Grading	SY	325	5.00	$1,625.00	
CLSM Backfill	CY	10	125.00	$1,250.00	
Select Fill	CY	20	25.00	$500.00	
Granular Foundation Material	CY	200	25.00	$5,000.00	
3" Crushed Rock & Fabric	CY	75	60.00	$4,500.00	
Asphalt Driveway	CY	50	55.00	$2,750.00	
Precast Utility Vault	LS	2	2,500.00	$5,000.00	
Top Soil	CY	40	75.00	$3,000.00	
Turf Establishment (Sod)	SY	600	5.00	$3,000.00	
Guard Posts & Chain	LS	1	1,625.00	$1,625.00	
Subtotal					**$203,500**
Screening Facility Structure - 500 SF					
Framing, Siding & Roof	LS	1	10,000.00	$10,000.00	
Cast in Place Concrete (Walls, Base Slab, Footings)	CY	20	650.00	$13,000.00	
Reinforcing	TON	20	200.00	$4,000.00	
Interior Finish - Masonry, Metals, Woods, Plastics, Insulation	LS	1	30,000.00	$30,000.00	
Openings - Doors, Windows, Access Hatches	EA	1	17,000.00	$17,000.00	
Monorail Support System (Hoist & Trolley)	LS	1	7,500.00	$7,500.00	
Painting and Coatings	LS	1	3,000.00	$3,000.00	
Subtotal					**$84,500**

Screening Facility Electrical, HVAC, Plumbing					
Electrical Service Feed	LF	100	50.00	$5,000.00	
Miscellaneous Electrical	LS	1	15,000.00	$15,000.00	
Lighting	LS	1	5,000.00	$5,000.00	
Controls & SCADA	LS	1	25,000.00	$25,000.00	
Plumbing	LS	1	20,000.00	$20,000.00	
HVAC Equipment and Controls	LS	0	36,500.00	$0.00	
Subtotal					**$70,000**

Treatment Facility Chemical Feed					
Chemical Feed Equipment	LS	1	15,500.00	$31,000.00	
Subtotal					**$31,000**

Treatment Facility Structure Addition - 800 SF					
Framing, Siding & Roof	LS	1	17,000.00	$17,000.00	
Cast in Place Concrete (Walls, Base Slab, Footings)	CY	35	650.00	$22,750.00	
Reinforcing	TON	35	200.00	$7,000.00	
Interior Finish - Masonry, Metals, Woods, Plastics, Insulation	LS	1	50,000.00	$50,000.00	
Openings - Doors, Windows, Access Hatches	EA	1	10,000.00	$10,000.00	
Painting and Coatings	LS	1	3,000.00	$3,000.00	
Subtotal					**$109,750**

Treatment Facility Equipment - Sand Filter					
Process Piping and Valves	LS	1	80,000.00	$80,000.00	
Flow Meters	EA	2	5,000.00	$10,000.00	
Pressure Filter Equipment, including media	LS	1	350,000.00	$350,000.00	
Chemical Feed Equipment	LS	1	15,000.00	$15,000.00	
Process Equipment Installation	LS	1	16,500.00	$16,500.00	
Subtotal					**$471,500**

Treatment Facility Electrical, HVAC, Plumbing					
Miscellaneous Electrical	LS	1	15,000.00	$15,000.00	
Lighting	LS	1	2,000.00	$2,000.00	
Controls & SCADA	LS	1	10,000.00	$10,000.00	
Plumbing	LS	1	20,000.00	$20,000.00	
HVAC Equipment and Controls	LS	1	36,500.00	$36,500.00	
Subtotal					**$83,500**

Appendix D

BATHTUB Model Updates

Table D-1 – BATHTUB Model Updates

BATHTUB Parameter	*RCWD Value*	*Updated Value*	*Note*
Lake surface area, ac	447	450	Determined from LIDAR contours (MnDNR, 2011)
Precipitation, m/yr	0.66	0.521	Average of 2004-2013 precipitation data (MCWG1, 2015; MCWG2, 2015)
Evaporation, m/yr	0.66	-0.629	Average of 2004-2013 evaporation data (MnDNR5, 2015)
Watershed Runoff, hm3/yr	0.111	0.075	Average of 2004-2013 precipitation data and watershed characteristics (MCWG2; SEH, 2005)
Storage, hm3/yr	0	0.032	Determined from 2004 and 2013 lake level data (MnDNR1, 2015)
Groundwater Outflow, hm3/yr	0	-0.648	Determined from Turtle Lake water budget analysis.
In-lake Phosphorus, ppb	21	19.7	Average of 2004-2014 Turtle Lake water quality data (MPCA, 2014)
In-lake Chlorophyll-a, ppb	5.01	4.86	Average of 2004-2014 Turtle Lake water quality data (MPCA, 2014)
In-lake Secchi Depth, m	2.4	2.80	Average of 2004-2014 Turtle Lake water quality data (MPCA, 2014)
In-lake Total Nitrogen, ppb	912	1144	Average of 2004-2014 Turtle Lake water quality data (MPCA, 2014)
In-lake Organic Nitrogen, ppb	0	997.1	Average of 2004-2014 Turtle Lake water quality data (MPCA, 2014)
In-lake Orthophosphorus, ppb	0	10.2	Average of 2004-2014 Turtle Lake water quality data (MPCA, 2014)

Turtle Lake Aug'n

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Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.521	0.0
Evaporation (m)	0.629	0.0
Storage Increase (m)	0.351	0.0

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	9	CANF& BACH, GENERAL
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	4	P, LINEAR
S		
ecchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	0	TEXT BOX

Atmos. Loads (kg/km²-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Segment Morphometry

nternal Loads (mg/m2-day)

Seg	Name	Outflow Segment	Group	Area km^2	Depth m	Length km	Mixed Depth (m) Mean	Mixed Depth (m) CV	Hypol Depth Mean	Hypol Depth CV	Non-Algal Turb (m^{-1}) Mean	Non-Algal Turb (m^{-1}) CV
1	Turtle	0	1	1.82	3.21	2.04	3.2	0.12	0	0	0.25	0.35

	Conserv. Mean	Conserv. CV	Total P Mean	Total P CV	Total N Mean	Total N CV
	0	0	0	0	0	0

Segment Observed Water Quality

Seg	Conserv Mean	Conserv CV	Total P (ppb) Mean	Total P (ppb) CV	Total N (ppb) Mean	Total N (ppb) CV	Chl-a (ppb) Mean	Chl-a (ppb) CV	Secchi (m) Mean	Secchi (m) CV	Organic N (ppb) Mean	Organic N (ppb) CV	TP - Ortho P (ppb) Mean	TP - Ortho P (ppb) CV	HOD (ppb/day) Mean	MOD (ppb/day)
1	0	0	19.5	0.39	1144	0.14	4.86	0.55	2.8	0.34	997.1	0.51	9.3			

Segment Calibration Factors

Seg	Dispersion Rate Mean	Dispersion Rate CV	Total P (ppb) Mean	Total P (ppb) CV	Total N (ppb) Mean	Total N (ppb) CV	Chl-a (ppb) Mean	Chl-a (ppb) CV	Secchi (m) Mean	Secchi (m) CV	Organic N (ppb) Mean	Organic N (ppb) CV	TP - Ortho P (ppb) Mean	HOD (ppb/day)	MOD (ppb/day)
1	1	0	1	0	1	0	1	0	1	0	1	0	1		

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	Flow CV	Conserv. Mean	Conserv. CV	Total P (ppb) Mean	Total P (ppb) CV	Total N (ppb) Mean	Total N (ppb) CV	C
1	Watershed	1	3	1.165	0.049	0	0	0	345	0	1	0	
2	SPRWS	1	3	0	0.66	0	0	0	80.2	0.71	0	0	
3	Groundwater Outflow	0	4	0	0.65	0	0	0	19.7	0.39	1144	0.14	
4	Snail	0	3	0	0.39	0	0	0	22	0.34	0	0	
5	Pleasant	0	3	0	0.39	0	0	0	27.8	0.48	0	0	
6	Charley	0	3	0	0.39	0	0	0	68.4	0.39	0	0	
7	Max Conc, Avg Flow	0	3	0	0.432	0	0	0	50	0	0	0	

8	Max Conc, Max Flow	0	3	0	0.719	0	0	0	46	0	0	0	0	0	0	0

Model Coefficients	**Mean**	**CV**
Dispersion Rate	1.000	0.70
Total Phosphorus	1.280	0.45
Total Nitrogen Chl-	1.000	0.55
a Model Secchi	0.890	0.26
Model Organic N	1.050	0.10
Model TP-OP	1.000	0.12
Model HODv Model	1.000	0.15
MODv Model	1.000	0.15
Secchi/Chla Slope (m^2/mg)	1.000	0.22
Minimum Qs (m/yr) Chl-a	0.025	0.00
Flushing Term Chl-a	0.100	0.00
Temporal CV	1.000	0.00
Avail. Factor - Total P	0.620	0
Avail. Factor - Ortho P	0.330	0
Avail. Factor - Total N	1.930	0
Avail. Factor - Inorganic N	0.590	0
	0.790	0

Turtle Lake Aug'n
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Segment & Tributary Network

--------Segment:	1	Turtle	
Outflow Segment:	0	Out of Reservoir	
Tributary:	1	Watershed	Type: Point Source
Tributary:	2	SPRWS	Type: Point Source

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Hydraulic & Dispersion Parameters

Seg	Name	Outflow Seg	Net Inflow ~~hm³/yr~~	Resid Time years	Overflow Rate m/yr	Velocity km/yr	Dispersion-------> Estimated ~~km²/yr~~	Numeric ~~km²/yr~~	Exchange ~~hm³/yr~~
1	Turtle	0	0.5	11.4007	0.3	1.0	29.9	0.2	0.0

Morphometry

Seg	Name	Area ~~km²~~	Zmean m	Zmix m	Length km	Volume ~~hm³~~	Width km	L/W -
1	Turtle	1.8	3.2	3.2	2.0	5.8	0.9	2.3
Totals		1.8	3.2			5.8		

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Overall Water & Nutrient Balances

Overall Water Balance — Averaging Period = 1.00 years

Trb	Type	Seg	Name	Area km²	Flow hm³/yr	Variance (hm3/yr)²	CV -	Runoff m/yr
1	3	1	Watershed	1.2	0.0	0.00E+00	0.00	0.04
2	3	1	SPRWS		0.7	0.00E+00	0.00	
3	4	0	Groundwater Outflow		0.6	0.00E+00	0.00	
4	3	0	Snail		0.4	0.00E+00	0.00	
5	3	0	Pleasant		0.4	0.00E+00	0.00	
6	3	0	Charley		0.4	0.00E+00	0.00	
7	3	0	Max Conc, Avg Flow		0.4	0.00E+00	0.00	
8	3	0	Max Conc, Max Flow		0.7	0.00E+00	0.00	
PRECIPITATION				1.8	0.9	0.00E+00	0.00	0.52
POINT-SOURCE INFLOW				1.2	0.7	0.00E+00	0.00	0.61
***TOTALINFLOW				3.0	1.7	0.00E+00	0.00	0.56
ADVECTIVE OUTFLOW				3.0	-0.1	0.00E+00	0.00	
***TOTAL OUTFLOW				3.0	-0.1	0.00E+00	0.00	
***EVAPORATION					1.1	0.00E+00	0.00	
***STORAGE INCREASE					0.6	0.00E+00	0.00	

Overall Mass Balance Based Upon Component: Predicted TOTAL P — **Outflow & Reservoir Concentrations**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)²	%Total	CV	Conc mg/m³	Export kg/km²/yr
1	3	1	Watershed	16.9	13.6%	0.00E+00		0.00	345.0	14.5
2	3	1	SPRWS	52.9	42.5%	1.41E+03	65.5%	0.71	80.2	
PRECIPITATION				54.6	43.9%	7.45E+02	34.5%	0.50	57.6	30.0
POINT-SOURCE INFLOW				69.8	56.1%	1.41E+03	65.5%	0.54	98.5	59.9
***TOTALINFLOW				124.4	100.0%	2.16E+03	100.0%	0.37	75.1	41.7
ADVECTIVE OUTFLOW				-2.8		1.48E+00		0.44	21.9	
***TOTAL OUTFLOW				-2.8		1.48E+00		0.44	21.9	
***STORAGE INCREASE				12.5	10.0%	2.36E+01		0.39	19.5	
***RETENTION				114.7	92.2%	2.23E+03		0.41		

Overflow Rate (m/yr)	0.3	Nutrient Resid. Time (yrs)	1.0278
Hydraulic Resid. Time (yrs)	11.4007	Turnover Ratio	1.0
Reservoir Conc (mg/m3)	22	Retention Coef.	0.922

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Segment Mass Balance Based Upon Predicted Concentrations

Component: TOTAL P Segment: 1 Turtle

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	3	Watershed	0.0	3.0%	16.9	13.6%	345
2	3	SPRWS	0.7	39.8%	52.9	42.5%	80
PRECIPITATION			0.9	57.2%	54.6	43.9%	58
POINT-SOURCE INFLOW			0.7	42.8%	69.8	56.1%	99
***TOTAL INFLOW			1.7	100.0%	124.4	100.0%	75
ADVECTIVE OUTFLOW			-0.1	-7.6%	-2.8	-2.2%	22
***TOTAL OUTFLOW			-0.1	-7.6%	-2.8	-2.2%	22
***EVAPORATION			1.1	69.1%	0.0	0.0%	
***STORAGE INCREASE			0.6	38.5%	14.0	11.2%	22
***RETENTION			0.0	0.0%	113.2	91.0%	

Hyd. Residence Time = 11.4007 yrs
Overflow Rate = 0.3 m/yr
Mean Depth = 3.2 m

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Water Balance Terms (hm3/yr) Averaging Period = 1.00 Years

			Inflows		Storage	Outflows------>		Downstr
Seq	Name	External	Precip	Advect	Increase	Advect	Disch.	Exchange
1	Turtle	1	1	0	1	0	0	0
Net		1	1	0	1	0	0	0

Mass Balance Terms (kg/yr) Based Upon Predicted Reservoir & Outflow Concentrations Component: TOTAL P

	Inflows-->			Storage			Outflows-----	
>		Net	Net Seg	Name External	Atmos	Advect		
Increase	Advect	Disch.		Exchange			Retention	1
Turtle	70	55	0	14	-3	0	0	
	113							
Net	70	55	0	14	-3	0	0	113

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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	1	Turtle				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	21.9	0.44	19.2%	19.5	0.39	15.9%
TOTAL N MG/M3	1144.0	0.14	58.2%	1144.0	0.14	58.2%
C.NUTRIENT MG/M3	21.2	0.41	25.7%	19.0	0.34	21.5%
CHL-A MG/M3	5.5	0.51	24.0%	4.9	0.55	19.6%
SECCHI M	2.7	0.30	88.8%	2.8	0.34	89.5%
ORGANIC N MG/M3	300.2	0.24	18.5%	997.1	0.51	92.8%
TP-ORTHO-P MG/M3	11.5	0.49	15.7%	9.3	0.30	10.9%
ANTILOG PC-1	73.2	0.67	17.8%	97.8	0.43	24.2%
ANTILOG PC-2	8.5	0.26	70.4%	10.0	0.45	79.8%
(N - 150) / P	45.4	0.48	92.5%	51.0	0.41	94.7%
INORGANIC N / P	81.5	0.71	84.5%	14.4	3.71	23.3%
TURBIDITY 1/M	0.3	0.35	15.6%	0.3	0.35	15.6%
ZMIX * TURBIDITY	0.8	0.37	3.9%	0.8	0.37	3.9%
ZMIX / SECCHI	1.2	0.33	0.8%	1.1	0.35	0.7%
CHL-A * SECCHI	14.8	0.41	70.1%	13.6	0.65	65.8%
CHL-A / TOTAL P	0.2	0.26	64.7%	0.2	0.67	64.7%
FREQ(CHL-a>10) %	9.9	1.44	24.0%	7.0	1.73	19.6%
FREQ(CHL-a>20) %	0.8	2.23	24.0%	0.5	2.70	19.6%
FREQ(CHL-a>30) %	0.1	2.71	24.0%	0.1	3.31	19.6%
FREQ(CHL-a>40) %	0.0	3.06	24.0%	0.0	3.77	19.6%
FREQ(CHL-a>50) %	0.0	3.33	24.0%	0.0	4.13	19.6%
FREQ(CHL-a>60) %	0.0	3.56	24.0%	0.0	4.43	19.6%
CARLSON TSI-P	48.7	0.13	19.2%	47.0	0.12	15.9%
CARLSON TSI-CHLA	47.2	0.11	24.0%	46.1	0.12	19.6%
CARLSON TSI-SEC	45.6	0.10	11.2%	45.2	0.11	10.5%

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T Statistics Compare Observed and Predicted Means Using the Following Error Terms:
1 = Observed Water Quality Error Only
2 = Error Typical of Model Development Dataset
3 = Observed & Predicted Error

Segment:	1	Turtle						
	Observed		Predicted		Obs/Pred	T-Statistics ---->		
Variable	Mean	CV	Mean	CV	Ratio	T1	T2	T3
TOTAL P MG/M3	19.5	0.39	21.9	0.44	0.89	-0.30	-0.43	-0.20
TOTAL N MG/M3	1144.0	0.14	1144.0	0.14	1.00			
C.NUTRIENT MG/M3	19.0	0.34	21.2	0.41	0.90	-0.32	-0.54	-0.20
CHL-A MG/M3	4.9	0.55	5.5	0.51	0.89	-0.21	-0.33	-0.15
SECCHI M	2.8	0.34	2.7	0.30	1.03	0.09	0.11	0.07
ORGANIC N MG/M3	997.1	0.51	300.2	0.24	3.32	2.35	4.80	2.12
TP-ORTHO-P MG/M3	9.3	0.30	11.5	0.49	0.81	-0.72	-0.59	-0.38
ANTILOG PC-1	97.8	0.43	73.2	0.67	1.34	0.67	0.82	0.36
ANTILOG PC-2	10.0	0.45	8.5	0.26	1.17	0.35	0.51	0.30
(N - 150) / P	51.0	0.41	45.4	0.48	1.12	0.28	0.36	0.18

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Variable = TOTAL P MG/M3 R^2 = 1.00
Global Calibration Factor = 1.28 (= 0.45

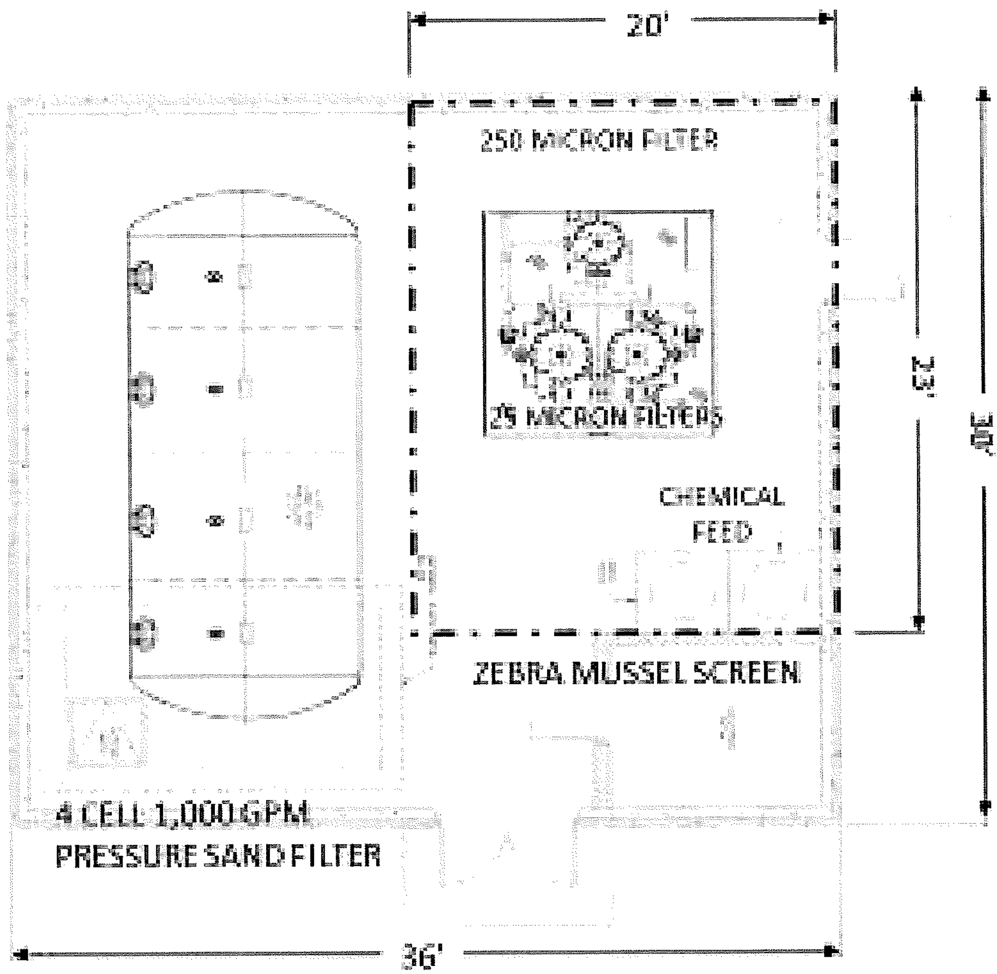
Seg	Group	Name	Calibration Factor Mean	CV	Predicted Mean	CV	Observed Mean	CV	Log (Obs/Pred) Mean	SE	t
1	1	Turtle	1.00	0.00	21.9	0.44	19.5	0.39	-0.12	0.59	-0.20

Variable = CHL-A MG/M3 R^2 = 1.00
Global Calibration Factor = 0.89 (= 0.26

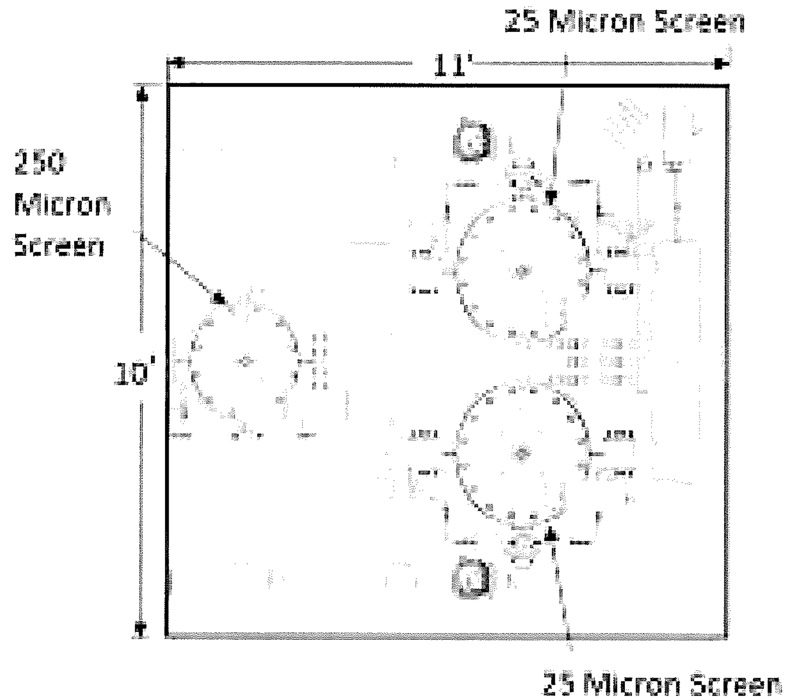
Seg	Group	Name	Calibration Factor Mean	CV	Predicted Mean	CV	Observed Mean	CV	Log (Obs/Pred) Mean	SE	t
1	1	Turtle	1.00	0.00	5.5	0.51	4.9	0.55	-0.12	0.75	-0.15

Appendix E

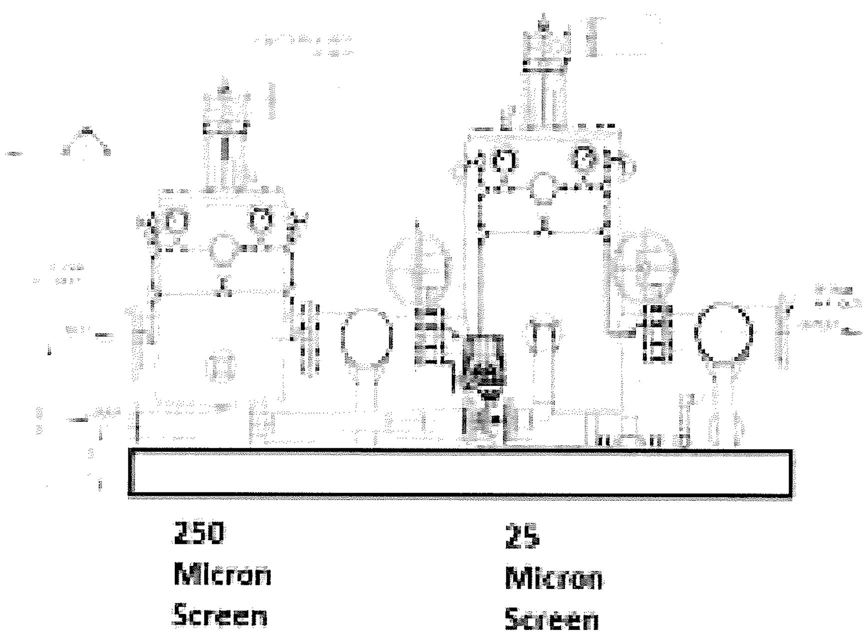
Screening and Treatment Facility



TREATMENT AND SCREENING FACITLITY – PLAN VIEW



ZEBRA MUSSEL SCREEN – PLAN VIEW



ZEBRA MUSSEL SCREEN – SECTION VIEW