Hydraulic Report on the Potential Outlet of Little McDonald Lake Via Otter Tail County Ditch 25

Prepared for

Little McDonald, Kerbs and Paul Lake Improvement District
Perham, Minnesota

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CERTIFICATION

I hereby certify that this plan, specification or 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.

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Date: August 11, 2011 Minnesota Registration No. 20378

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EXECUTIVE SUMMARY

Little McDonald, Kerbs and Paul Lakes are landlocked lakes and do not have surface outlets within the recorded range of lake levels. Since 1993, the water levels of Little McDonald, Kerbs and Paul Lakes have often exceeded their respective Ordinary High Water Levels (OHW's). Water levels in 2011 reached elevation 1360.98—over 4 ½ feet above the OHW of Little McDonald Lake. Kerbs Lake and Paul Lake are also at similarly high water levels. The lakes are now at levels never previously recorded. Extensive damages are being caused to buildings, septic systems and wells. Severe bank erosion is also occurring as a result of the high water and associated waves.

The Little McDonald, Kerbs and Paul Lake Improvement District (LMKP LID) is contemplating a project to construct an outlet to drain water from the land locked lakes. This outlet route extends southwesterly from Little McDonald Lake to Berger Lake. Water discharging from Berger Lake flows in turn through Big McDonald, Round, Star, Dead, and Walker Lakes and on to the Otter Tail River at Otter Tail Lake

A petition was submitted to Otter Tail County, as the Drainage Authority, seeking permission to outlet to the County Ditch 25 drainage system. The Drainage Authority will base their decision on the ditch capacity. The hydraulic study results show that if the ditch is repaired, 50% of the time CD 25 has a surplus capacity of 19.5 cfs.

The Little McDonald Lake outlet design flow rate has been set at 22 cfs. Actual outlet releases would be guided by an operation plan that would require outflow to reduce or cease if downstream lakes rise to certain pre-established levels. A hydraulic model was developed to determine the impacts to downstream lake levels from the outlet operation.

A Draft Operation Plan has been developed to define the periods when the outlet should and should not be in operation. The physical operating of the outlet would be conducted by the LID.

The historic lake level records indicate that in some years (e.g. 1993, 2010) Big McDonald, Star or Dead Lakes were above OHW for extended periods—when hypothetically a potential Little McDonald Lake outlet would not have been operable. The lake level records also indicate that a potential Little McDonald Lake outlet could be operated in many years—for at least part of the year (typically during the late summer and/or autumn). Operation of an outlet from Little McDonald, Kerbs and Paul Lakes would be useful to manage the levels of each lake and to limit multi-year sequences of increasing lake levels.

I. INTRODUCTION

Little McDonald, Kerbs and Paul Lakes are landlocked lakes and do not have surface outlets within the recorded range of lake levels. Since 1993, the water levels of Little McDonald, Kerbs and Paul Lakes have often exceeded their respective Ordinary High Water Levels (OHW's). From 1997 through 2001, peak levels increased about ½ foot each year for five years in a row. During this period the highest water levels were recorded in 2001—approximately 3 feet above OHW on Little McDonald Lake. Water levels receded from 2002 through 2004, but rose rapidly in 2008 through 2011. Peak water levels in May of 2011 reached elevation 1360.98—4 ½ feet above the OHW of Little McDonald Lake. Kerbs Lake and Paul Lake are also at similarly high water levels. The lakes are now at levels never previously recorded. Extensive damages are being caused to buildings, septic systems and wells. Severe bank erosion is also occurring as a result of the high water and associated waves.

The Little McDonald, Kerbs and Paul Lake Improvement District (LMKP LID) is contemplating a project to construct an outlet to drain water from the lakes. This outlet route extends southwesterly from Little McDonald Lake to Berger Lake. Water discharging from Berger Lake flows in turn through Big McDonald, Round, Star, Dead, and Walker Lakes and on to the Otter Tail River at Otter Tail Lake (**Figure I-1**).

County Ditch 25 (CD 25) provides the outlet of Big McDonald Lake and extends downstream to Round and Star Lakes. County Ditch 25 was established in accordance with Minnesota Drainage Law in the early 1900's and is administered by Otter Tail County. Since Little McDonald Lake is not included in the benefited area of the CD 25 ditch system, the LID will petition Otter Tail County for permission to use the County Ditch 25 System for an outlet. The petition process to use the County Ditch 25 drainage system as an outlet includes the following general steps:

1. Petition to Drainage Authority
2. Notice of Petition to Property Owners in CD 25 Drainage System
3. Hearing on Petition
4. Drainage Authority Decision on Petition
    a. Ditch capacity is part of the issue and the County Board as Ditch Authority can set terms and conditions on operation and/or constraints (i.e. operating plan).
    b. Viewers may be used to determine an outlet fee.

The Little McDonald, Kerbs and Paul Lake Improvement District authorized Houston Engineering to collect data and conduct an engineering study to evaluate the capacity of County Ditch 25 in order to determine whether the ditch has capacity to accept the proposed outflows from the Little McDonald Outlet Project or if not, to list the necessary repairs or improvements needed to bring the system up to capacity.

Figure I-1. Potential Outlet Route from Little McDonald Lake

II. DESIGN OUTFLOW RATES

The 2001 Little McDonald Lake Flood Damage Reduction Study identified a number of potential outlet alternatives. The design outflow rate for the outlet alternatives was 10,000 gallons per minute (gpm) which is approximately 22 cubic feet per second (cfs). A rate of 10,000 gpm is a reasonable outlet capacity for Little McDonald, Kerbs and Paul Lakes.

III. COUNTY DITCH 25 ANALYSIS

Description

County Ditch 25 (CD 25) includes approximately 3.7 miles of channel including the Main Ditch and Branch 1. The ditch was established around 1907. The Main Ditch S1 extends 7,950 feet from the NENW of Section 8, T136N, R40W (Wendt Lake) to the SENW of Section 18 (Big McDonald Lake). The Main Ditch S2 extends 3,825 feet from Big McDonald Lake in the NWNW of Section 30, T136N, R40W to Round Lake in the NWNE of Section 36, T136N, R41W. The Main Ditch S3 extends 3,969 feet from Round Lake in the NWSE of Section 36, T136N, R41W to Star Lake in the SWSW of Section 36. Branch 1 extends 1,450 feet within Section 25, T136W, R41W from Brown Lake to the Main Ditch S2.

CD 25 drains land within Edna and Dora Townships. The area drained by CD 25 is approximately 9.6 square miles at the outlet of Big McDonald Lake, 17.9 square miles at the outlet of Round Lake and 18.1 square miles at the outlet of the ditch into Star Lake. **Figure III-1** shows the alignment of CD 25 between Big McDonald and Star Lakes (Main S2 and S3).

Existing County Ditch 25 Conditions

In July 2011, Houston Engineering completed a survey of CD25 from Big McDonald Lake to Round Lake. Culverts and cross sections were measured on County Ditch 25 from Big McDonald Lake to Round Lake and also within the reach from Round Lake to Star Lake.

Table III-1 lists the location, type and size of the culverts on County Ditch 25 between Big McDonald Lake and Star Lake. Culverts on CD 25 include both Corrugated Metal Pipe (CMP) culverts and Reinforced Concrete Pipe (RCP) culverts.

A Field Crossing between Big McDonald and Round Lake near Station 89+70 was surveyed in 2004 but was found washed out during the 2011 survey. The culvert is still laying in the ditch and should be removed if the crossing is no longer needed.

The ditch is generally in fair condition due to the heavy growth of grasses, cattails and brush in the channel—particularly in the reach between Big McDonald Lake and Round Lake. A beaver dam is located downstream of Round Lake near Station 20+25. The beaver pond water level appears to be presently lower than the runout elevation of Round Lake, so its hydraulic impact is not currently extending into Round Lake. Ditch repair and maintenance to address vegetation, debris and sediment deposition is needed —particularly in the reach between Big McDonald Lake and Round Lake. The field crossing culvert at Station 119+12 appeared dented on the upstream end and steel "T" posts have been driven in near the upstream end—possibly for beaver control—but they may also be restricting the culvert capacity. The culvert capacity needs to be restored by fixing the dented inlet and removing the "T" post obstruction.

Figure III-1 County Ditch 25 Alignment

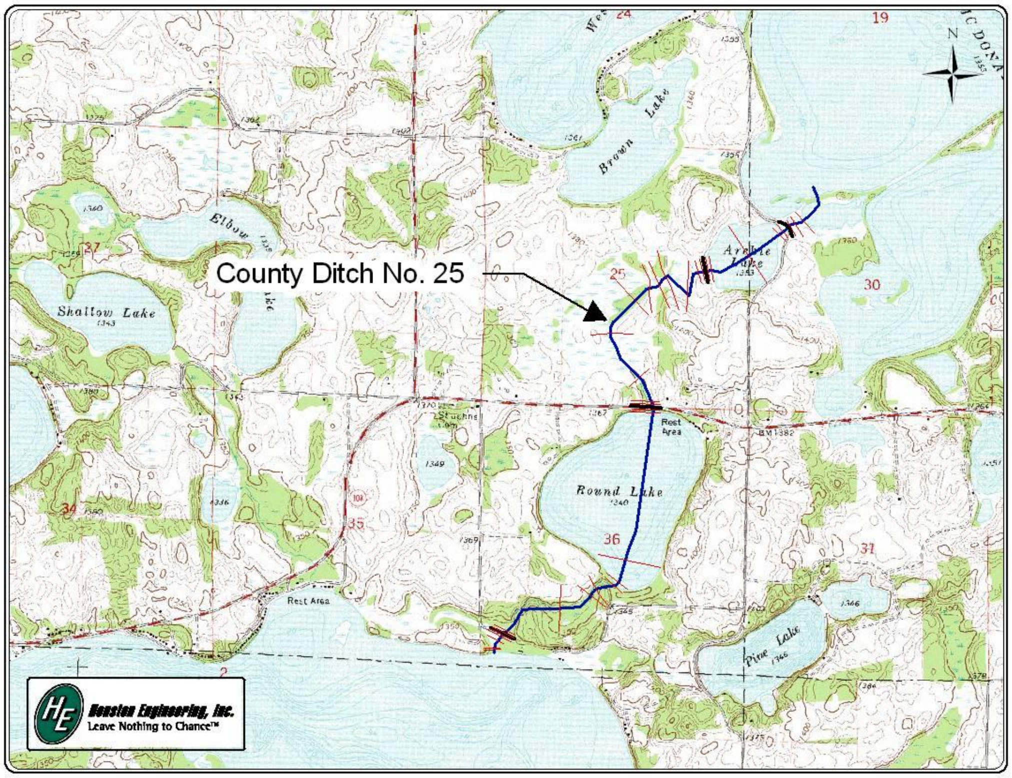


Table III-1. Culverts on County Ditch 25

Location	Station	Culvert Size	Culvert Waterway Area (sq. ft.)
Engstrom Beach Road/Big McDonald Outlet to CD25	138+18	42-inch CMP	9.6
Field Crossing at Archie Lake outlet to CD25	119+12	42-inch CMP	9.6
Field Crossing (currently washed out)	89+70	48-inch	N/A
State Highway 108	72+17	48-inch RCP	12.6
Private Driveway	10+66	48-inch CMP	12.6
Trail Crossing 425 feet above Star lake (currently washed out)	4+53	36-inch CMP	N/A

Hydraulic Model

Geometry

The information from the 2011 field survey was used to construct a hydraulic computer model of CD 25. The channel geometry dimensions and culvert details were input into a HEC-RAS model.[1] Channel cross sections collected in the field survey were supplemented by LiDAR[2] in the over bank portions of the cross sections. Topography based on LiDAR is not always accurate in areas of dense vegetation, but the data appear reasonable for this application and provide a consistent method to extend the cross section widths beyond the field survey limits. Channel roughness values that account for the frictional energy losses within the channel were based on literature values[3] estimated from the channel's visual appearance and physical condition.

Model Calibration

Water surface elevations were measured during the 2011 field survey of CD25 at a number of locations along the ditch in order to develop an observed water surface profile for use in calibrating the hydraulic model. The flow corresponding to the observed water surface profile was estimated by placing a survey rod in the flow to measure the flow depth and velocity head at several of the culvert crossings. Flow velocity was also measured by timing floats passing through culverts. Based on these measurements we estimated that 17 cfs was flowing through the Engstrom Beach Road culvert and 20 cfs was flowing through the Highway 108 culvert at the measured water surface elevations.

Figure III-2 shows the observed and simulated water surface elevations. The simulated water surface elevations varied from +0.74 to -0.95 feet from observed levels—with the average difference being -0.33 feet.

When calibrating a hydraulic model certain inputs are adjusted so the results match the observed water levels better. For this calibration, channel roughness (Manning's "n") values were raised to 0.08 in the channel. This value is higher than typically assigned to well-maintained ag drainage ditches. During the analysis we concluded that the heavily vegetated ditch bottom and banks, as well as small obstructions in the channel, were causing higher observed water levels for the estimated flow than would typically occur in a drainage ditch with normal roughness (for example with a Manning's "n" value of .04 to 05).

County Ditch 25 Capacity

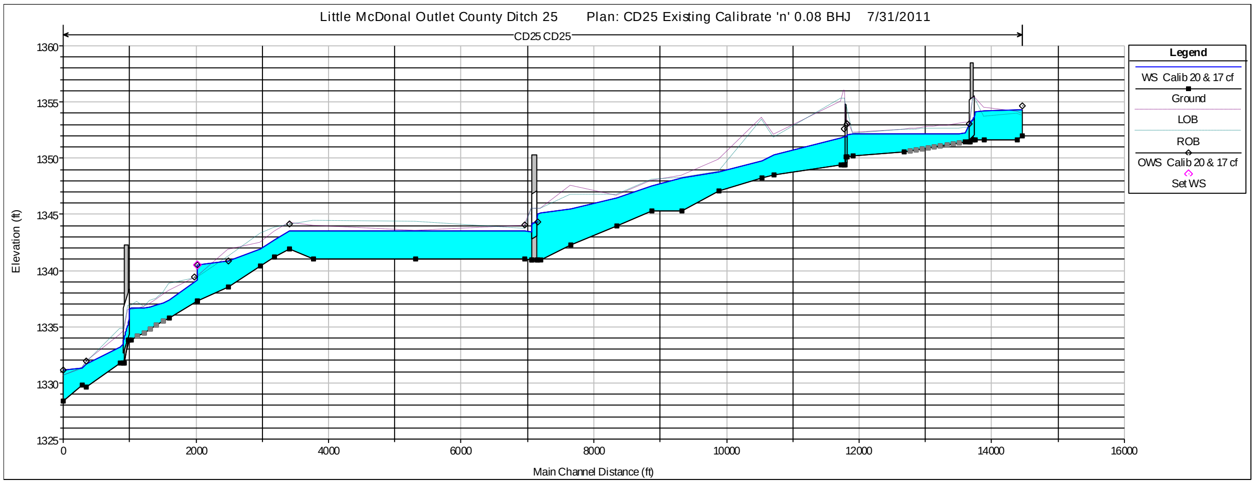
We recommend that County Ditch 25 be repaired to remove accumulated sediment and debris and to remove the dense vegetation and brush that obstructs flow. We also recommend that Otter Tail County plan to remove the beaver dam near station 20+00 if water levels begin to restrict outflow from Round Lake.

1 US Army Corps of Engineers, Hydrologic Engineering Center, HEC-RAS River Analysis System, Version 4.1.0 Davis, California May 2005

2 LiDAR (Light Detection and Ranging)from the International Water Institute Collect

3 Chow, Open Channel Hydraulics, McGraw Hill, 1959

Figure III-2 Profile of Calibrated Model with Observed Water Surface Elevations



We expect that the CD 25 channel friction will be significantly reduced once the ditch is cleaned and repaired. In order to determine the ditch capacity in a repaired condition, we have adjusted the Manning's friction factor for the channel (Sta. 70+11 to 145+72) to a value of 0.045—grass lined channels often include Mannings "n" values in the range from .04 to .05 as representing a typical ditch design value.[4]

Bankfull is a term used in open channel hydraulics to describe the flow value associated with a channel flowing full to the top of the banks without substantial overbank flow. The bankfull flow of CD 25 is approximately 20 to 25 cfs in its existing condition and is estimated to range from 30 to 35 cfs for a repaired condition. We identified the 30 cfs bankfull water surface profile to be generated by a flow of 30 cfs in the upper end of the ditch between Big McDonald Lake and the Branch 1 confluence as well as a 46.5 cfs rate in the lower reach of the ditch between Star Lake and Branch 1. The varying flow along the ditch reach in this scenario accounts for inflow from Branch 1 and other adjoining lands. The 35 cfs bankfull water surface profile was generated by a constant flow of 35 cfs within the reach from Big McDonald to Star Lake and does not vary with tributary drainage area. The bankfull flows and water surface profiles were estimated based on review of the hydraulic model results and the channel dimensions. **FIGURE III-3** is a profile drawing of CD 25 including the 30 cfs bankfull water surface profile.

4 Minnesota Drainage Guide, USDA Soil Conservation Service, St. Paul, MN P6-6

Figure III-3 Profile of Bankfull Water Surface Elevations—Repaired Condition

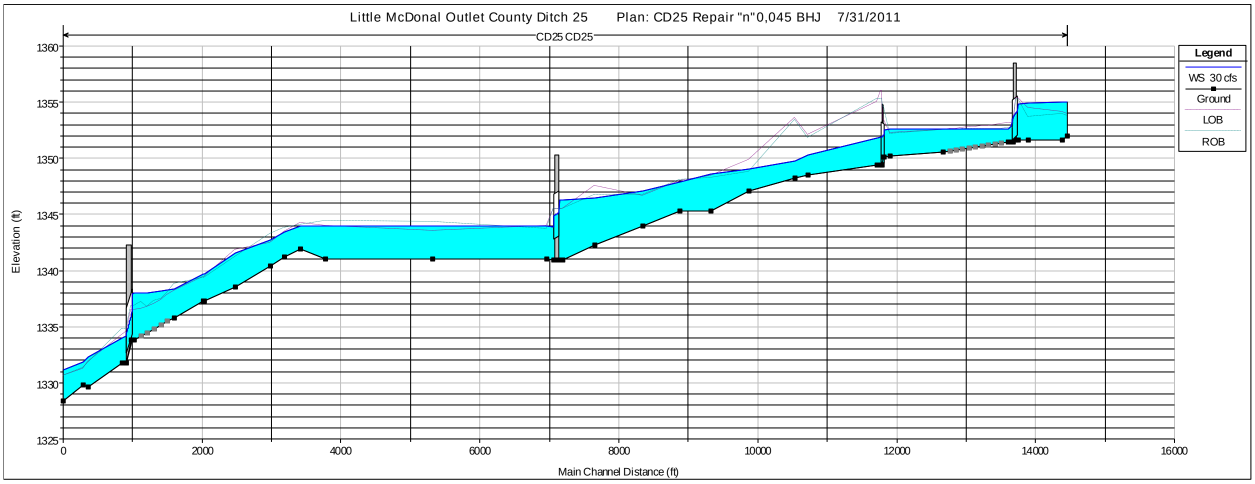
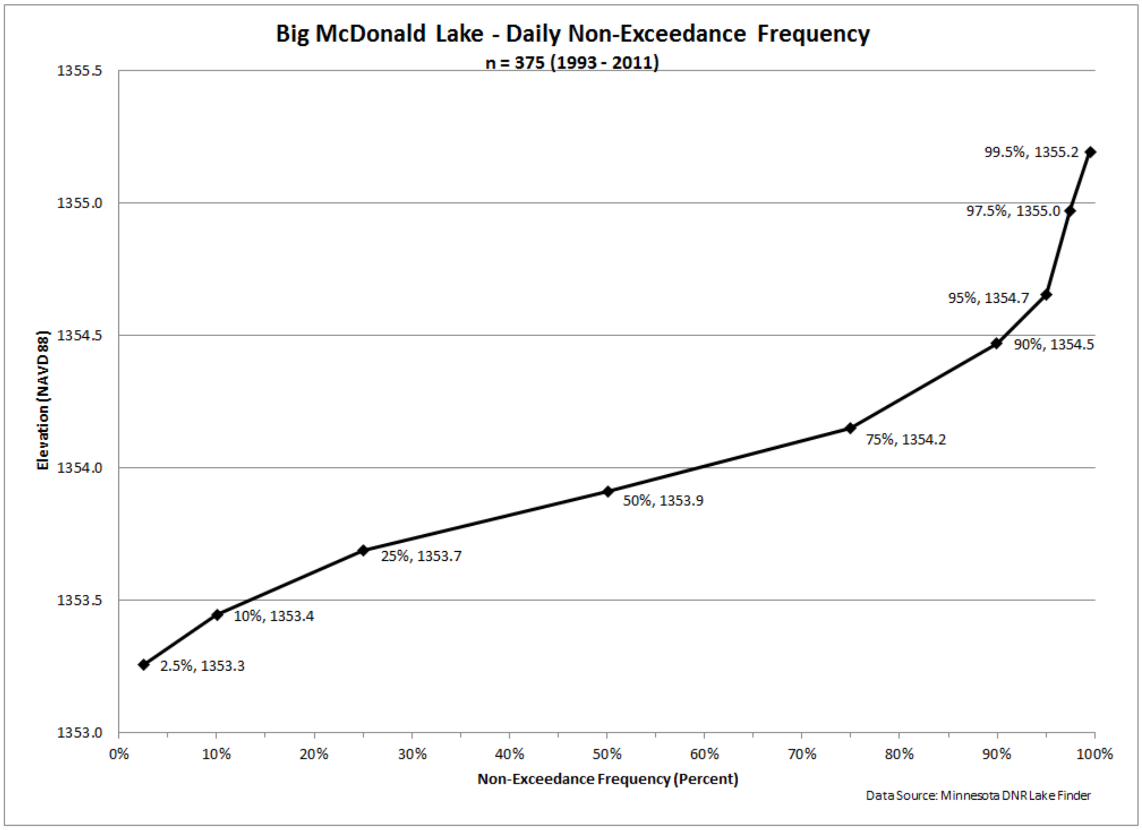


Figure III-4 is a graph showing the results of a frequency analysis of the recorded water levels of Big McDonald Lake. A rating curve of the Big McDonald Lake level versus CD 25 outflow was used to assign a frequency to the CD 25 outflow rates. **Table III-2** provides a comparison of the CD 25 outflow frequency to the bankfull capacity of the ditch, allowing a tabulation of the percent of time that CD 25 flows at or below the listed rates and the corresponding surplus capacity that could be available for the Little McDonald Lake outflows. For example, 50% of the time Big McDonald Lake is at or below elevation 1353.91 feet and outflow to CD 25 is at or below 13 cfs. Since the average bankfull capacity of CD 25 is 32.5 cfs, 50% of the time CD 25 has a surplus capacity of 19.5 cfs.

Table III-2. Comparison of CD 25 Outflow to Bankfull Capacity (Repaired Condition)

Non-exceedence Frequency (%)	Big McDonald Level (NAVD 88) n=375, source DNR-LakeFinder	CD 25 Outflow at Engstrom Beach Road for Repaired Condition with Existing Culverts (cfs)	Average CD 25 Bankfull Capacity for Repair Condition (cfs)	Surplus Capacity (cfs)
2.5	1353.26	5	32.5	27.5
10	1353.44	8	32.5	24.5
25	1353.69	10	32.5	22.5
50	1353.91	13	32.5	19.5
75	1354.15	16	32.5	16.5
90	1354.47	22	32.5	10.5
95	1354.66	24	32.5	8.5
97.5	1354.97	30	32.5	2.5
99.5	1355.20	34	32.5	0

Figure III-4 Big McDonald Lake Water Level Frequency



Existing Crossings Effect on Water Surface Profile

There are two road crossings and several additional driveway and field crossings on CD 25 between Big McDonald and Star Lakes. **Table III-3** lists the crossing locations and culvert sizes.

Table III-3. CD 25 Crossing Locations and Sizes

Location	Station	Culvert Size	Culvert Waterway Area (sq. ft.)
Engstrom Beach Road/Big McDonald Outlet to CD25	138+18	42-inch CMP	9.6
Field Crossing at Archie Lake outlet to CD25	119+12	42-inch CMP	9.6
Field Crossing (currently washed out)	89+70	48-inch	N/A
State Highway 108	72+17	48-inch RCP	12.6
Private Driveway	10+66	48-inch CMP	12.6
Trail Crossing 425 feet above Star lake (currently washed out)	4+53	36-inch CMP	N/A

Culvert Sizes and Peak Flows by USGS Regression Techniques:

In reviewing the existing culvert sizes on the CD 25, we used the US Geological Survey Stream Stats interactive website to determine watershed characteristics and computed regression equation estimates of flow based upon those basin characteristics.[5] **Table III-4** lists the ditch locations and the USGS peak flow estimate for the selected locations.

Table III-4. USGS Peak Flow Estimates

	Big McDonald Lake Outlet at Engstrom Beach Road	Hwy. 108 at Round Lake Inlet	CD 25 Outlet to Star Lake
CD 25 Station (feet)	138+18	72+17	0+00
Existing Drainage Area (not including Little McDonald Lake) sq. miles	9.6	17.3	18.1
1.5-year Peak Flow (cfs)	11	18	18
2-year Peak Flow (cfs)	14	23	23
5-year Peak Flow (cfs)	22	36	37
10-year Peak Flow (cfs)	28	46	47
25-year Peak Flow (cfs)	37	59	61
50-year Peak Flow (cfs)	43	70	72
100-year Peak Flow (cfs)	50	81	84

A general rule of thumb for designing rural crossings of streams and ditches (in regard to backwater effects upon the drainage ditch, velocities through the culverts, and roadway overtopping) is to pass:

- the 25-year recurrence interval flow at an average velocity of 5 ft./sec., and
- the 50-year recurrence interval flow at an average velocity of 6.5 ft./sec.

The use of these design velocities corresponds to typical stage increases of ½ foot and 1 foot for the 25-year and 50-year floods, respectively. The range in hydraulic head and velocity at bridge and culvert crossings, provided by the rule of thumb, are within the ranges generally recommended by the Soil Conservation Service and the Bureau of Reclamation.

The existing culverts on CD 25 at Engstrom Beach Road, Highway 108 and the field and driveway crossings at Stations 119+12, and 10+66 generally have adequate cross sectional area to satisfy the velocity guidelines of the rule of thumb (assuming the pipes flow full). However,

5 Lorenz, D.L., Sanocki, C.A., and Kocian, M.J., 2009, Techniques for estimating the magnitude and frequency of peak flows on Small Streams in Minnesota based on data through water year 2005: U.S. Geological Survey Scientific Investigations Report 2009–5250, 54 p.

the pipes typically flow part-full at the ditch bankfull capacity. It has also been reported that one of the field crossings and the private driveway have washed out in the past. It is unknown whether the wash-outs occurred due to overtopping (which seems unlikely) or other causes such as seepage and erosion along the culvert.

Even though the culverts are generally sized to satisfy road crossing standards, we know from the survey and hydraulic modeling that the CD 25 is currently limited in capacity by the culverts installed at the road crossings—especially the 42-inch diameter culvert on Engstrom Beach Road at the outlet of Big McDonald Lake. **Figures III-5** and **Figure III-6** are profile and cross section drawings of the Engstrom Beach Road Crossing. Although the culvert size is generally acceptable from a road overtopping standpoint, the culvert shape and elevation could be improved to allow more capacity at lower stages. Presently the culvert will carry about 30 cfs with an upstream depth of 2.8 feet (leaving .7 feet of the pipe unfilled) when Big McDonald Lake is at the OHW level of 1354.89 feet.

Figure III-5 CD25 Profile at Engstrom Beach Road—Culvert is Part Full at Big Mc OHW

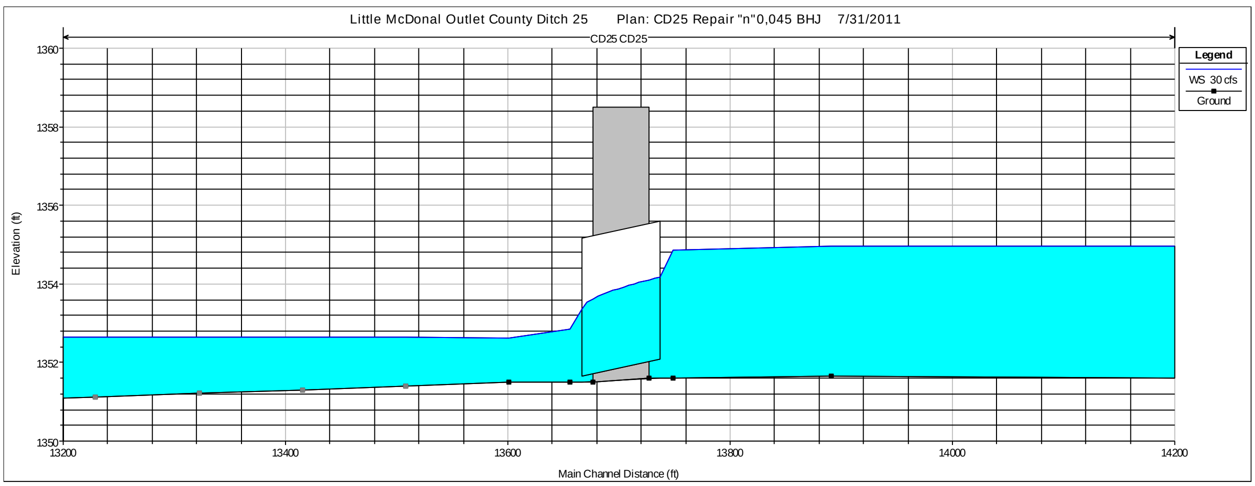
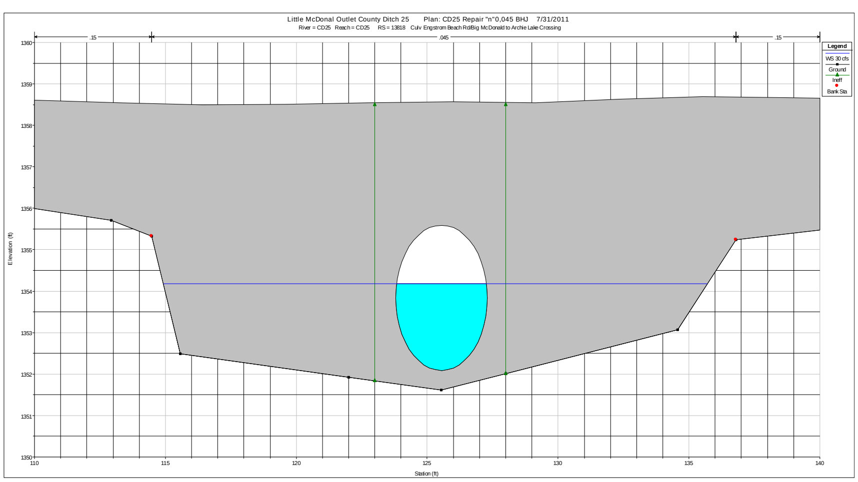


Figure III-6 CD25 Cross Section at Engstrom Beach Road—
Culvert is Part Full at Big Mc OHW



We are recommending installing additional culverts at several of the crossings listed in **Table III-5** to reduce the depth of water in the ditch for given flows and to increase the flow capacity of the ditch within the channel banks.

We recommend that the additional culvert at the outlet of Big McDonald Lake include a canal gate for use in accordance with the Little McDonald Lake Outlet operation plan. In this manner, the gate would be opened when the Little McDonald outlet is in operation in order to reduce water level fluctuations within Big McDonald, McDonald and Berger Lakes due to outflows from the Little McDonald outlet The operation of these controls will be outlined in the project operation plan.

The auxiliary culvert on CD 25 at the Big McDonald Lake outlet could also potentially provide additional water level management benefits to Big McDonald Lake, provided that the gate operations were carried out within the constraints of an approved operating plan and agreement.

Since additional culverts are recommended to be installed in the driveway and field crossings of CD 25 at Stations 10+66 and 119+12, the average bankfull capacity of the ditch will increase slightly in the channel reach just upstream from each crossing.

Table III-5. Recommended Additional Culverts at CD 25 Road Crossings

Crossing	Station		Culvert Size	Waterway Area (sq. ft.)	Total Waterway Area (sq. ft.)
Engstrom Beach Road/Big McDonald Outlet to CD25	138+18	Existing	42" CMP	9.6	14.0
		Proposed to Add	36" x 22" RCP-Arch with Gate	4.4	
Field Crossing at Archie Lake outlet to CD25	119+12	Existing	42" CMP	9.6	9.8
		Proposed to Remove Existing and Replace with 2@30-inch	2@30" CMP	9.8	
Private Driveway	10+66	Existing	48" CMP	12.6	25.1
		Proposed to Add	Add 48" CMP	12.6	

Process

It is not known whether culverts were installed as part of the ditch system when it was established in 1907. Certainly the existing culverts on County Ditch 25 were not installed 100 years ago (since metal culverts do not last for 100 years) and have been installed more recently as replacement culverts or as new crossings. The plan and profile sheets prepared by Martin Aalberg (circa 1907) do not show any bridges or culverts on County Ditch 25. It seems likely that County Ditch 25 previously had a greater flow capacity (provided by larger bridges or by open channels without crossings). Changing the size and capacity of culvert crossings could be ordered by the Ditch Authority upon review of this Hydraulic Report as a procedure to repair or restore the ditch capacity.

County Ditch 25 Summary

The ditch is generally in fair condition due to the heavy growth of grasses, cattails and brush in the channel—particularly in the reach between Big McDonald Lake and Round Lake. Ditch repair and maintenance to address vegetation, debris and sediment deposition is needed.

- It is recommended that County Ditch 25 be repaired to remove accumulated sediment and debris and to remove the dense vegetation and brush that obstructs flow—particularly between Big McDonald Lake and Round Lake.
- We are recommending installing additional culverts at the crossings listed in **Table III-5** to reduce the depth of water in the ditch for given flows and to increase the flow capacity of the ditch within the channel banks near each crossing.
- It is also recommended that the operation of the Little McDonald outlet be gate-controlled and guided as set forth in the draft operation plan. The proposed auxiliary culvert at the outlet of Big McDonald Lake should also include a canal gate for use in accordance with the Little McDonald Lake Outlet operation plan.

The hydraulic study results show that if the ditch is repaired, 50% of the time CD 25 has a surplus capacity of 19.5 cfs.

IV. DRAFT OPERATION PLAN

Downstream hydraulic constraints will at times limit the allowable discharge rate from the proposed Little McDonald Lake outlet. An operating plan will need to be prepared to guide the outlet structure operation and lay out the conditions when the outlet should be fully opened, partially opened or closed.

The Little McDonald, Kerbs and Paul Lakes Improvement District will be responsible for the operation and maintenance of the outlet project. The District will prepare a plan to guide the operation of the outlet structure and will assign the operation duties to authorized personell. The following paragraphs are the draft operation plan for the Little McDonald Lake outlet project.

In general, the Little McDonald Lake outlet will be closed when floods are occurring or imminent downstream. If water levels in Little McDonald Lake exceed trigger elevations, and downstream conditions permit, water will be released through the gates of the outlet. The outflow rate will be set to maximize the outflow without causing or contributing to significant flooding problems downstream. The water levels in Little McDonald Lake will be drawn down to the target elevations as quickly as practicable.

Draft Operational Trigger Points:
Water level measurements will be used to guide the operation of the outlet project. Gaging locations and trigger points will be defined within the project operation plan. Gage sites need to be readily accessible in all weather and may be established on highways or public accesses. Gage locations have not yet been selected, but would likely include about three to five existing DNR Lake gages. Gages will be needed on Little McDonald Lake and Paul Lake as well as downstream along the potential outlet route on Berger, Big McDonald, Star, and Dead Lakes (**Table IV-1**).

Table IV-1. Potential Gaging Sites

Potential Gaging Sites	Gaging Station Type
Little McDonald Lake	Water Level Staff Gage
Paul Lake	Water Level Staff Gage
Berger Lake	Water Level Staff Gage
Big McDonald Lake	Water Level Staff Gage
Star Lake	Water Level Staff Gage
Dead Lake	Water Level Staff Gage

<u>Draft Operation Plan</u>

- A Draft Operation Plan has been developed to define the periods when the outlet should and should not be in operation. The operation of the outlet will be conducted by the LID.
- If the Little McDonald Lake level is below the OHW Level (i.e. at or below elevation 1356.5 NAVD88), the project gates will be closed and no water will be discharged through the outlet.
- If the Little McDonald Lake level is above elevation 1356.5, water will be discharged through the outlet if downstream conditions allow:
    - If Berger, Star and Dead Lakes are ½ foot or more below their OHW Levels and Big McDonald is at or below elevation 1354.14 (NAVD88) : Little McDonald Lake outlet allowable outflow range is from 0 to 22.3 cfs.
    - If Berger, Star and/or Dead Lakes are between 0 and ½ feet below their OHW Levels and Big McDonald is between elevations 1354.14 and 1354.39: Little McDonald Lake outlet allowable outflow range is from 0 to 11.2 cfs.
    - If Berger, Star and/or Dead Lakes are above their OHW Levels or Big McDonald is above elevation 1354.39: Little McDonald Lake outlet shall be closed (i.e. outflow = 0 cfs).

Paul Lake
A pipe connection will be installed to allow flow from Paul Lake to Little McDonald. A 24-inch diameter outlet pipe will be installed through Otter Tail County Road 34. This pipe will include a riser structure and gate controls to allow management of water levels and discharge rates. The

operation of these controls will be outlined in the project operation plan. The expected operation will be to set discharge rates from Paul Lake to generally match the resulting drawdown rate of Little McDonald and Kerbs Lakes when the outlet to Berger Lake is operating.

Berger Lake

Berger Lake flows southerly into East McDonald Lake. The outlet is an open channel extending through a narrow point of land separating the two lakes. The channel has a bottom width of 6 to 8 feet. In order to reduce water level fluctuations within Berger Lake during operation of the Little McDonald outlet, a 48-inch diameter culvert will be installed parallel to the channel. This pipe will include a manhole structure and gate controls to allow management of water levels and discharge rates. The operation of these controls will be outlined in the project operation plan. The expected operation will be for the gates on the Berger Lake auxiliary outlet to be opened to correspond with the outflow from Little McDonald Lake.

Big McDonald Lake

The additional culvert at the outlet of Big McDonald Lake will include a canal gate for use in accordance with the Little McDonald Lake Outlet operation plan. In this manner, the gate would be opened when the Little McDonald outlet is in operation in order to reduce water level fluctuations within Big McDonald, McDonald and Berger Lakes due to outflows from the Little McDonald outlet. The operation of these controls will be outlined in the project operation plan. The expected operation will be for the gates on the Big McDonald Lake auxiliary outlet to be opened to correspond with the outflow from Little McDonald Lake.

Operation Plan Summary

Lake level records indicate that in some years (e.g. 1993, 2010) Big McDonald, Star or Dead Lakes have been above the OHW level for extended periods—when the operating plan would not have allowed discharge from Little McDonald Lake. Further detail on the lake level records and the DNR established OHW can be found in **Appendix A**. The lake level records also indicate that a potential Little McDonald Lake outlet could be operated in many years—for at least part of the year (typically during the late summer and/or autumn). Operation of an outlet from Little McDonald, Kerbs and Paul Lakes would be useful to reduce the levels of each lake and to limit multi-year sequences of increasing lake levels. The outlet project could be operated to make use of the capacity of County Ditch 25—when available—with the understanding that if downstream conditions do not allow for outflow from the project, the water levels in Little McDonald, Kerbs and Paul Lakes will fluctuate naturally.

V. IMPACTS TO DOWNSTREAM LAKE LEVELS

The Little McDonald Lake outlet design flow rate has been set at 22 cfs. Actual outlet releases would be guided by an operation plan that would require outflow to reduce or cease if downstream lakes rise to certain pre-established levels. An unsteady HEC-RAS model was developed to determine the impacts to downstream lake levels from the outlet operation. During project operations, some of the flow released from Little McDonald Lake will go into temporary storage within the downstream lakes as the lake levels rise. The rate at which they rise is a function of their respective outlet characteristics and lake size. The unsteady HEC-RAS model, like the HEC-1 model done in previous analysis of the system, allows for an understanding of how much and how quickly lake levels will rise or fall.

The model requires inputs for the lake storage volumes, surface area and the outlet relationship between lake elevation and outflow. Volumes and surface areas were computed using DNR lake bathymetric data. The lake elevation and outflow relationship was established for Big McDonald Lake during the hydraulic analysis for CD 25 between Big McDonald and Star Lake discussed in Section III. Star and Dead Lake outlet HEC-RAS models were completed during the previous analysis of the outlet in 2007, but the Star Creek model was slightly revised to more closely match the water levels and flow observed in July 2011. Under the proposed outlet plan a 48-inch pipe will be installed to increase the flow between Berger Lake and McDonald Lake along with the existing channel. The additional pipe is included in this analysis as well as the low lying sandbar area between McDonald and Big McDonald Lakes.

In order to simulate typical lake levels during the time of expected Little McDonald Lake Outlet operation (July through Freeze-up), we used the available lake level data plotted by month and day, and performed a best fit parabolic curve regression. We used the regression curves for McDonald, Big McDonald, Star and Dead Lake to define typical lake level trajectories for the period of June through December. These typical lake level hydrographs were input into an unsteady HEC-RAS hydraulic models of each lake to determine typical outflow hydrographs for each lake corresponding to the water level stage hydrograph. Net inflow was determined for each day of the simulation period based on a water budget (inflow-outflow = change in storage/time). All of the lakes were next assembled into a single HEC-RAS model. Starting lake levels were based on the typical lake level trajectories and the simulation date. The net inflow for each of the individual lake models were added and then the combined model was run as a base condition. The base condition model has no Little McDonald Lake outlet water released to establish a base condition for comparisons. Starting water levels for the downstream lakes were entered based on their respective typical level from the regressions of the available period of record lake level readings. Finally, Little McDonald Lake outlet flow was added to Berger Lake and the model was used to simulate the inflow, outflow and stage in Berger, McDonald, Big McDonald, Star and Dead Lakes throughout the simulation period.

Modeled Scenario Following Operating Plan with Typical Lake Levels

A scenario was simulated that followed the Operating Plan described in Section IV. The simulated outlet was opened on August 1st at ½ capacity, since Star Lake was within 0.5 feet of its OHW of 1530.4. The Operating Plan requires that the gates on the auxiliary Big McDonald outlet and the 48-inch pipe at Berger Lake be opened to correspond with their identified half-capacity flow rates. For four months Star Lake remained with 0.5 feet of its OHW, until December 1st when the Little McDonald Outlet was run at full capacity of 22 cfs. Full capacity outflow was simulated for 2 weeks. The Big McDonald and Berger Lake outlet pipes were also opened to their full heights during this period. The results of this modeling scenario are summarized in the **Table V-1** and Graphs of the Existing Condition and the described scenario with typical lake levels following the Operating Plan are shown in **Appendix __**. In this simulation, the Little McDonald outlet discharged approximately 3000 acre-feet during the 4 ½ month simulation period—about .8 feet from the lakes and aquifers adjoining Little McDonald Lake.

Table V-1 – Summary of Downstream Lake Level Impacts

	Existing Max Elevation (feet)	Max Elevation with Operation (feet)	Max Increase (feet)	Date of Max Increase	Difference at End of Simulation Period
Berger Lake	1354.02	1354.02	0.06	Sept 27	-0.08
McDonald Lake	1354.02	1354.02	0.16	Nov 10	-0.01
Big McDonald Lake	1354.02	1354.02	0.24	Nov 30	0.16
Star Lake	1330.38	1330.38	0.27	Dec 19	0.23
Dead Lake	1327.97	1327.97	0.08	Dec 27	0.08

VI. SUMMARY

The Little McDonald, Kerbs and Paul Lake Improvement District (LMKP LID) is contemplating a project to construct an outlet to drain water from the land locked lakes. This outlet route extends southwesterly from Little McDonald Lake to Berger Lake. Water discharging from Berger Lake flows in turn through Big McDonald, Round, Star, Dead, and Walker Lakes and on to the Otter Tail River at Otter Tail Lake

A petition was submitted to Otter Tail County, as the Drainage Authority, seeking permission to outlet to the County Ditch 25 drainage system. The Drainage Authority will base their decision on the ditch capacity. The hydraulic study results show that, in the scenario where the ditch is repaired, 50% of the time CD 25 has a surplus capacity of 19.5 cfs.

The Little McDonald Lake outlet design flow rate has been set at 22 cfs. Actual outlet releases would be guided by an operation plan that would require outflow to reduce or cease if downstream lakes rise to certain pre-established levels. A hydraulic model was developed to determine the impacts to downstream lake levels from the outlet operation.

A Draft Operation Plan has been developed to define the periods when the outlet should and should not be in operation. The physical operating of the outlet would be conducted by the LID.

The historic lake level records indicate that in some years (e.g. 1993, 2010) Big McDonald, Star or Dead Lakes were above OHW for extended periods—when hypothetically a potential Little McDonald Lake outlet would not have been operable. The lake level records also indicate that a potential Little McDonald Lake outlet could be operated in many years—for at least part of the year (typically during the late summer and/or autumn). Operation of an outlet from Little McDonald, Kerbs and Paul Lakes would be useful to manage the levels of each lake and to limit multi-year sequences of increasing lake levels.

APPENDIX A

Ordinary High Water (OHW) and Lake Level Records

Ordinary High Water Levels:

The Minnesota DNR has established Ordinary High Water (OHW) Levels for most of the lakes in the project area. **Table A-1** lists the established OHW levels and the corresponding sea level datum as well as the OHW converted to a common sea level datum North American Vertical Datum of 1988 (NAVD 88).

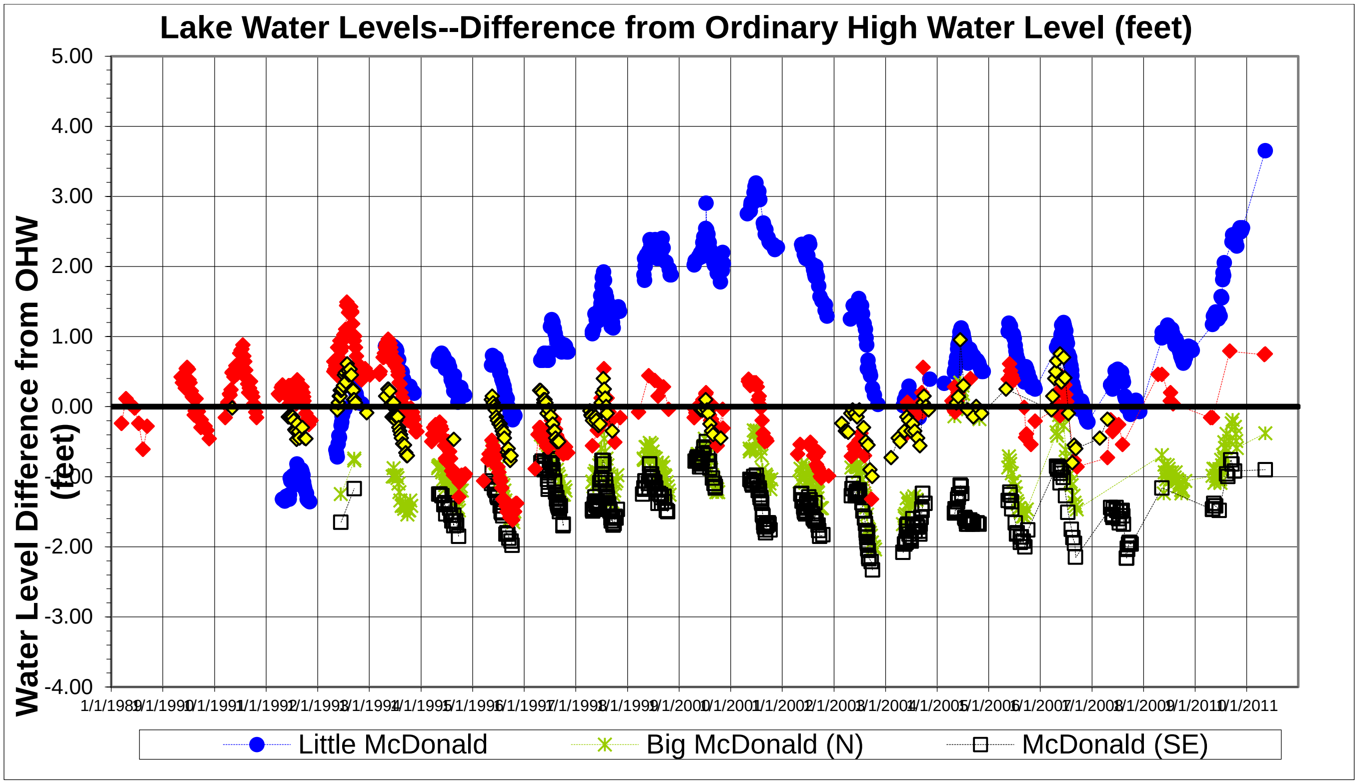
Table A-1. Ordinary High Water Levels

Lake	Lake ID	Established DNR OHW	OHW Datum	Datum Conversion to NAVD 88	OHW in NAVD 88
Little McDonald	56032800	1355.6	1929	+0.90	1356.5
Big McDonald	56038601	1354.0	1929	+0.90	1354.9
McDonald	56038600	1354.4	1929	+0.90	1355.3
Star	56038500	1329.5	1929	+0.90	1330.4
Dead	56038300	1327.8	1912	+0.23	1328.03

Figure A-1 is a graph of recorded lake water levels over the period of 1989 to 2006. The water level records for Little McDonald, Big McDonald, Star and Dead Lakes were obtained from the Minnesota DNR.[6]. The water level of each lake in **Figure A-1** was normalized in relation to the respective Ordinary High Water Level (OHW), so the plot indicates the magnitude that each water level record was above or below the OHW.

6 Minnesota DNR, Lakefinder Website: http://www.dnr.state.mn.us/waters/ accessed February 2007.

Figure A-1 Recorded Lake Water Levels for the Period of 1989 to 2006



The lake level graph can be used to evaluate how a constructed project would have been operated during the period from 1989 to 2011. **Table A-2** lists the dates all recorded lake levels are below their OHW levels. The lake level records indicate that in some years (e.g. 1993) Big McDonald, Star or Dead Lakes were above OHW for extended periods—when hypothetically a potential Little McDonald Lake outlet would not have been operable. The lake level records also indicate that the outlet would have been operable during many periods—particularly in the autumn.

The lake level records indicate that a potential Little McDonald Lake outlet could be operated in many years—for at least part of the year (typically during the late summer and/or autumn). Operation of an outlet from Little McDonald, Kerbs and Paul Lakes would be useful to reduce the levels of each lake and to limit multi-year sequences of increasing lake levels. The outlet project could be operated to make use of the capacity of the County Ditches—when available—with the understanding that if downstream conditions do not allow for outflow from the project, the water levels in Little McDonald, Kerbs and Paul Lakes will fluctuate naturally.

Table A-2. Dates Lake Levels Are Below OHW

Year	Beginning Dates Water Levels Below OHW	Comments
1989	15-Jun	Dead Lake has no data
1990	11-Aug	Dead Lake has no data
1991	20-Oct	Dead Lake has only one data point
1992	11-Oct	
1993	Never	
1994	11-Sep	
1995	all year	Star Lake data from 3/19-11/21, Dead Lake has only one data point
1996	4-Jun	
1997	11-Jun	
1998	25-Aug	
1999	21-Oct	Dead Lake has no data
2000	23-Jul	
2001	4-Aug	Dead Lake has no data
2002	all year	Dead Lake has no data
2003	all year	
2004	Never	
2005	Never	Star Lake has only one data point after 5/29
2006	11-Sep	Dead Lake has only one data point
2007	15-Jul	
2008	All year	Dead Lake has only two spring data points
2009	Inconclusive	Dead Lake-no data, Star only data thru July
2010	Never	

APPENDIX B

Downstream Lake Level Charts

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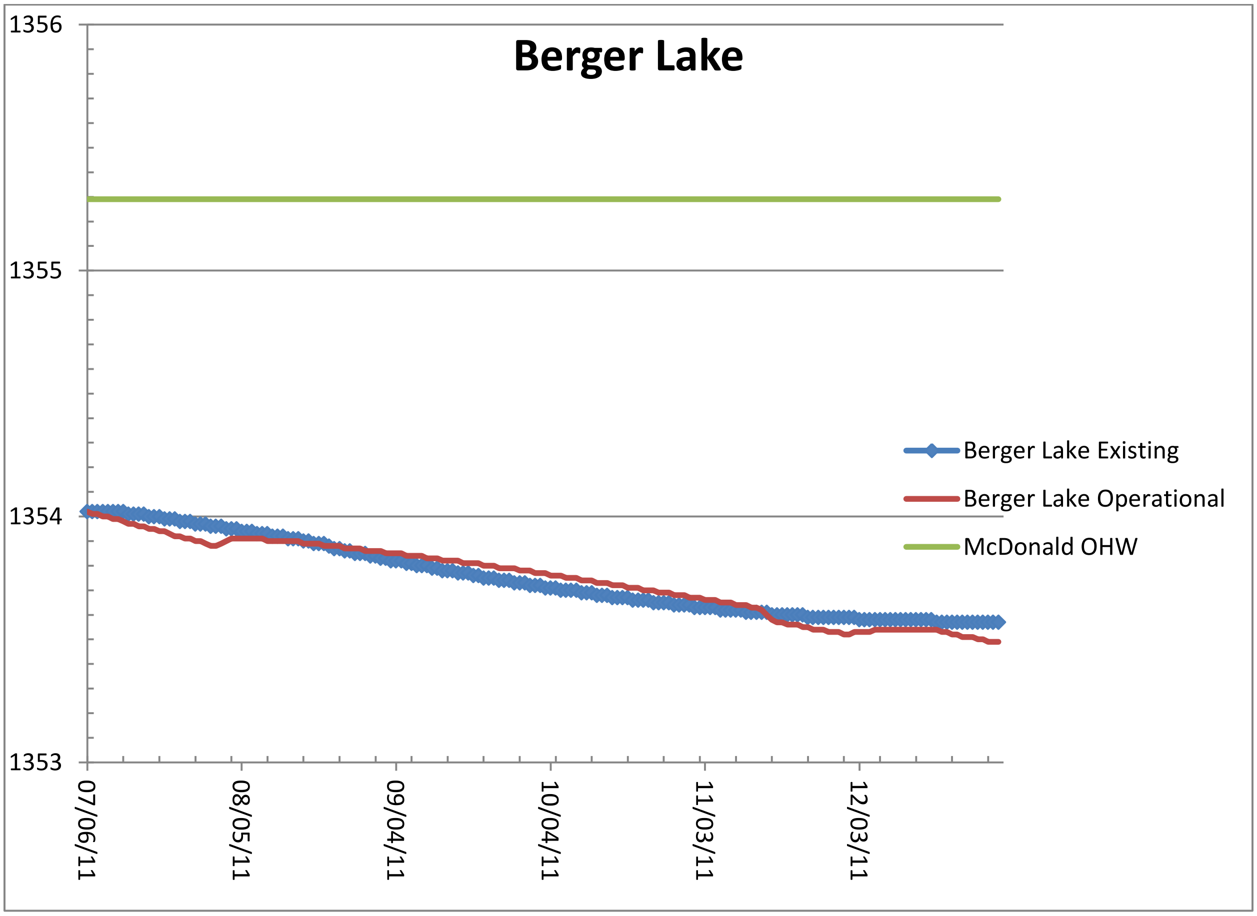
Downstream Lake Level Charts



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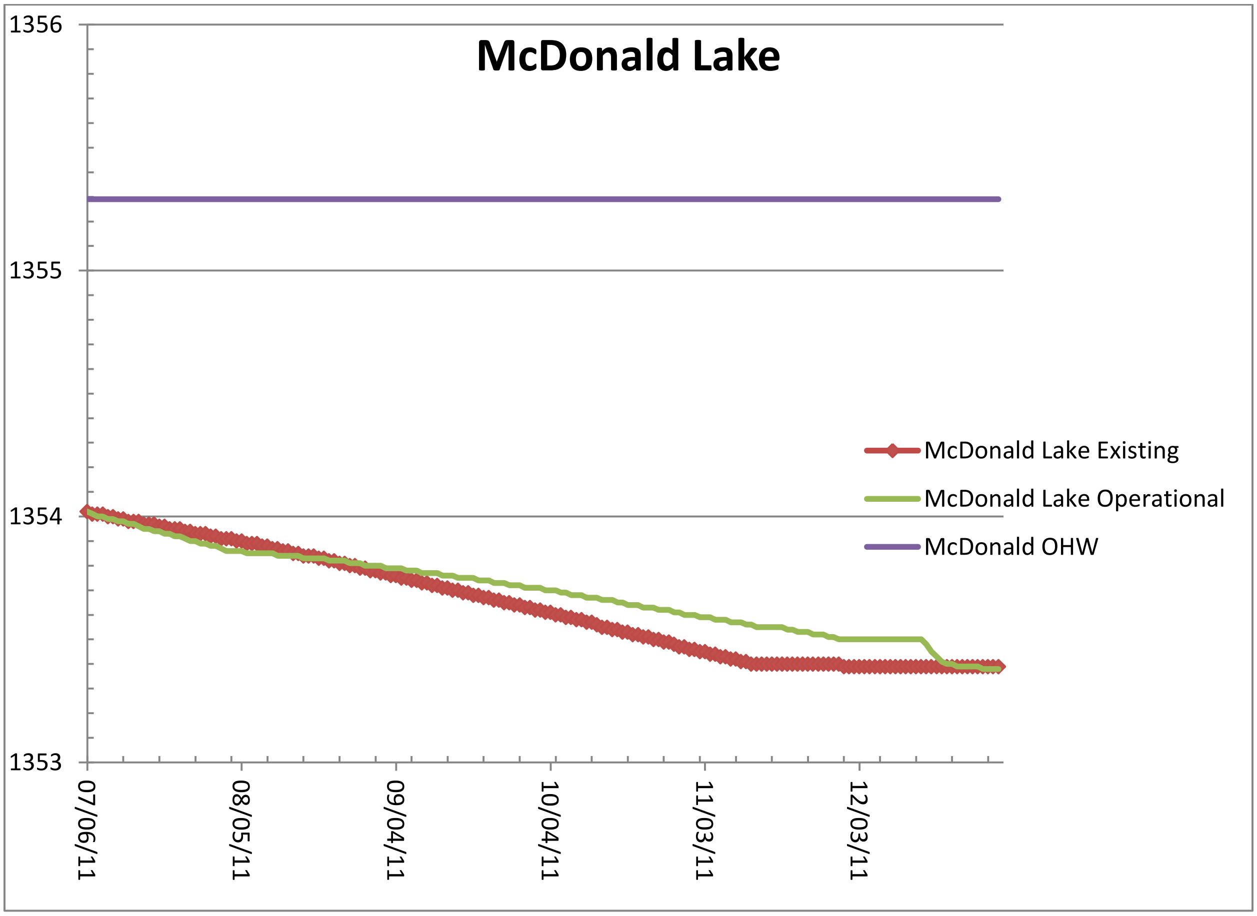

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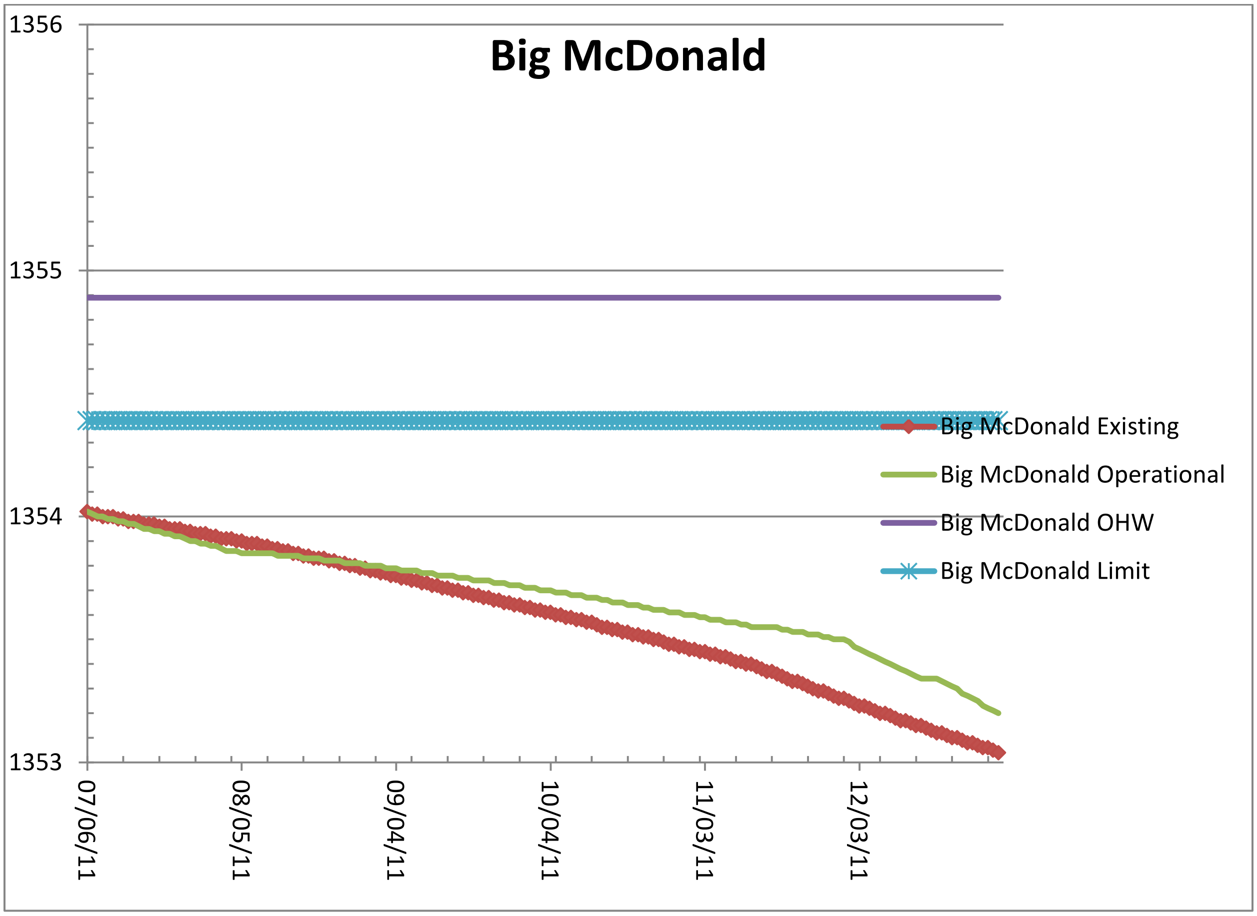

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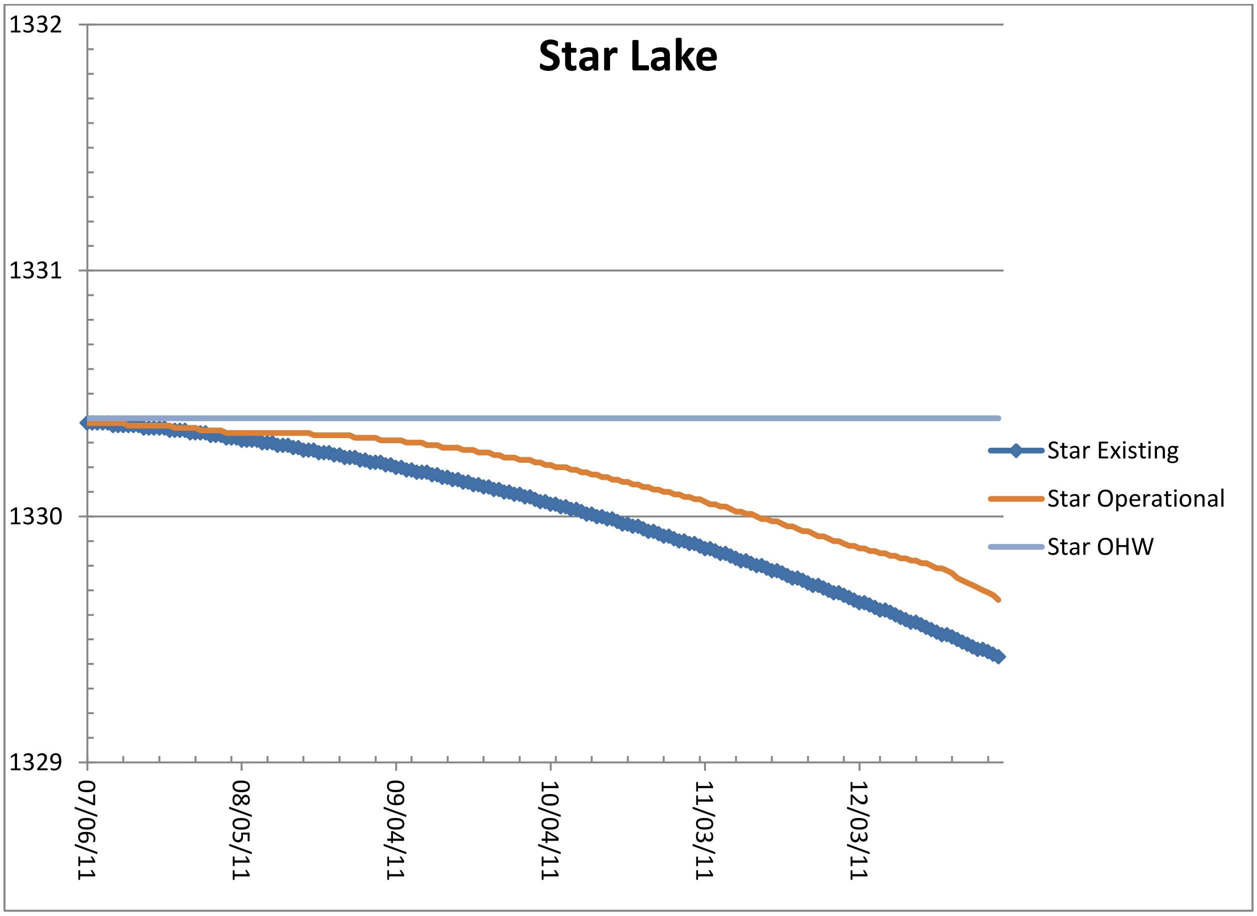

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