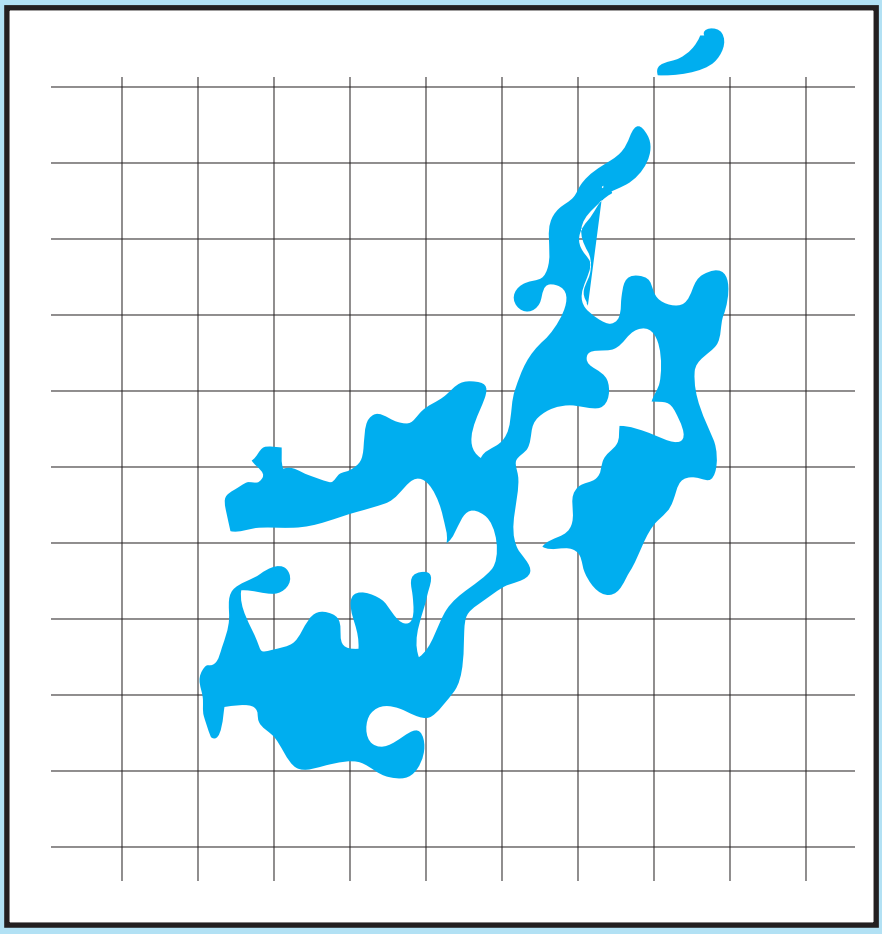


Lake St. Clair :

Report of Preliminary Findings
Hydrologic Budget Calculations
Recession Rates

DRAFT 1a* with Sensitivity Analysis

Prepared by N. Romero, Hydrogeologist, LG, LHG
Water Resources Program, Thurston County

June 18, 2012

Lake St. Clair Hydrologic Analysis

DRAFT*

Statement of the Problem

Per request from Water Resources, I have completed a brief review of the hydrology and hydrogeology of Lake St. Clair. During recent discussions, I offered the possibility of developing a predictive equation for lake levels if I could obtain field data sets and other hydrologic information.

As I understand the problem, Lake St. Clair has achieved high lake levels this past winter and current spring. I also understand that recreational activities on the lake create disturbances to existing structures and homes on the shoreline and that a regulatory elevation was set at 69.5 feet above mean sea-level (on the existing lake stage-staff plate at the bridge).

Pending the arrival of more complete datasets from the City of Olympia last week, I was able to analyze hydraulic relationships and create a hydrologic mass balance using various types 'quantified' information. I also verified these original datasets due to suspect column headings as the datalogger was set to 'depth to water' (DTW) mode versus hydraulic head (which measures feet of water above the pressure transducer).

Recent field measurements from May of 2012 were provided to me a few days ago which allowed me to run 'sensitivity tests' on the provisional predictive equation built in this exercise. In addition we completed a field visit yesterday, June 11, 2012 to Lake St. Clair with the City of Olympia.

Work Completed

In this analysis , I completed the following eight tasks:

1. Prepared hydrographs of dataset.
2. Prepared a draft geologic cross-section with land and lake surface elevations.
3. Downloaded agriculture station datasets for solar radiation, wind speed, dew point and temps.
4. Digitized rough estimates of lake surface area using GeoDATA maps .
5. Downloaded bathymetry and LiDAR.
6. Prepared a rough set of hydrologic mass balance calculations and analysis.

7. Examined and compared findings to other developed hydrologic records for neighboring basins.
8. Prepared this brief write-up of findings.

FINDINGS

A number of important findings emerged from this assessment. First, we were able to gain a sense of the hydraulic heads in the Lake St Clair *esker system* which are considerably deeper than other nearby lakes (*i.e., Long and Pattison Lakes*) in Thurston County. Using bathymetry and LiDAR we were surprised to find a large portion of the lake at or below 'sea-level'. Unlike lakes in other parts of the county located in 'dead ice mass deposits' or related esker terrains, lake surface elevations are around 154 feet above msl (mean sea level) versus 68 feet (GeoDATA). Furthermore, most of these lakes are relatively shallow (15 to 25 feet deep). Lake St Clair, however, is as deep as 110 feet.

Secondly, we were able to compare the hydrograph to other hydrologic basins (i.e. Woodland Creek) where we've computed stream discharge (*cfs*) to understand current high ground water elevations and base flow.

Thirdly, and most interestingly, we were able to confirm that field measurements of lake levels on sunny days match the lake evaporation calculations at .014 to .020 feet per day using our estimates of wind speed, solar radiation, dew point, and temperatures found for May of 2012 and summer of 2011.

Eaton Creek discharge contributions to the lake levels on the other hand is in constant equilibrium--surface water continuously pushes into the ground water system (and discharges out through the springs). If Lake St. Clair were a land-locked lake with no outlets or ground water discharge it would fill up at a rate of 0.084 feet per day. Instead, the lake levels come down at rates virtually equivalent to lake evaporation calculations as shown in this preliminary exercise.

Lake Evaporation Calculations

Using local wind speeds, dew point, daily average temperature and solar radiation we were able to derive lake evaporative losses for average sunny days in May of 2012 (Table 1) using a lake evaporation nomograph (Fetter, 1988). Lake evaporation in May of 2012 is estimated at 0.0133 to 0.0180 feet per day. This equates to 1.2- 1.4 million gallons per day.

Hydrograph Recession and Rise Analysis

A hydrograph was prepared from the City of Olympia datasets and compared to Eaton Creek/Lake St Clair precipitation record. In general, for every 3.5 to 4 inches of rainfall, Lake St. Clair rises .58 to .60 feet. This rise is almost double the expected hydraulic rise of the lake itself.

Recesssion rates for the City of Olympia datasets show a typical recession of 0.0140 – 0.018 feet per day (field measurements) for sunny days and the spring/summer hydrograph. Interestingly, this recession drop matches the lake evaporation calculations using wind speed, dew point, solar radiation and average daily temperature.

Provisional Equation for Estimating Lake Elevation

A rough equation was prepared using the 'recession and rise' analysis from the prepared hydrograph, precipitation and lake evaporative calculations. Refer to hydrologic tables (attached).

This equation can be used to estimate future lake level elevations, particularly number of days to recess to a given elevation. Again, this equation is *provisional only* and will need continued refining as more data comes in. Nonetheless, it serves as an excellent analytical tool/model for lake level prediction because it is based on quantified data.

I can explain this equation and development of coefficients further. The most important point here is we have a *starting place for prediction* based on a body of 'quantified' data and discerned relationships.

$$\mathbf{Z} = \mathbf{H_b} + \mathbf{K}*\mathbf{P_g} - (\mathbf{E}_{.014 - 0.020})*\mathbf{n}$$

Z = Calculated/Estimated Lake Elevation (ft > msl)
n = number of days (sunny without rain)
$\mathbf{K}_{Coeff}$ = 2.03 (to 1.85 range earlier in season)
$\mathbf{P}_g$= Precipitation Gain, range of values:
$P_{3.5''}$ = .292 ft
$P_{4''}$ = .333 ft
E = Lake Evaporation; nomograph derived
Hb= Lake Elevation on October 1st of Water Year (ft >msl) or subsequent known lake elevation just prior to a chosen rain event or period of sunny days.

Base Flow in Woodland Creek and Other Puget Sound Streams

We have computed stream flows for three other streams in Thurston County for the last 3 years of record including Woodland, Woodard and Percival Creeks. Yearly discharge has tripled since the 2008-2009 Water Year for each stream. Interestingly, discharge hydrographs for all three streams mimic each other despite variability in the precipitation record. Similarly, base flow or hydraulic head for Lake St Clair is 0.75 foot higher than the previous water year (WY 2010-2011) and almost 2 feet since WY 2009-2010.

Summary

I hope this provisional analysis and summary of findings helps frame the hydrologic budget and use of potential lake prediction tools for Lake St. Clair. This was a great exercise to delve into for Thurston County – allowing a deeper understanding of the hydrogeology and hydrology of the Lake St. Clair area, including lake recession and rise, evaporation, ground water movement (baseflow), hydrologic budgets and hydrograph comparisons. Preliminary sensitivity tests show that we may be able to predict lake levels to within .10 to .20 feet plus or minus *(+/-)* 5-7 days. This means that given a lake level of 70.04 feet (measurement taken June 11, 2012) and no further rainfall, we may see Lake St. Clair drop to 69.5 feet by July 11, 2012.

Again, this is only a preliminary exercise and I look forward to new data, when it becomes available, including any surveyed information.

Sincerely,

Nadine L. Romero, LPG, LPHG
Thurston County Hydrogeologist
Water Resources Program, RS

ATTACHMENTS

Table - Evaporation Calculations for Lake St. Clair

	Area			Nomograph Evap Rate			Eaton Creek Q		Input Lake Rise	Lake Rise	Lake Measurement (DTW)			Measured Recession	Lake Recharge		
	ft^2	Acres		Calc ("/day)	ft/day	gpd	cfs	cf/day	ft/day	in/day	7/27/2011	9/12/2011	ft diff	ft/day	in	ft	cf
Total Lake	12,305,615	282.5		0.16	0.0133	1,209,017	12	1,036,800	0.0843	1.0111	14.076	14.705	0.629	0.0140	1	0.083	1,025,468
				0.18	0.0150	1,360,144					6/11/2010	8/22/2010			3.47	0.289	3,558,374
LrgIsland	123,829	2.84		0.19	0.0158	1,435,707					14.073	15.374	1.301	0.0178	4	0.333	4,101,872
2ndLrg	59,291	1.36		0.20	0.0167	1,511,271									4.5	0.375	4,614,606
				0.21	0.0175	1,586,835											
Tot Area	12,122,495	278.3					12	1,036,800	0.0855	1.0263							

Eaton Crk/LStC Record Comparison

Eaton/LStC — **Lake Hydrograph**

Precip			Rise	
in	ft	1/14/2012	1/26/2012	diff ft
3.42	0.285	13.486	12.897	**0.589**

Lake Hydrograph

Precip			Rise	
in	ft	12/22/2011	12/31/2011	diff ft
3.47	0.2892	13.85	13.313	**0.537**

Lake Hydrograph

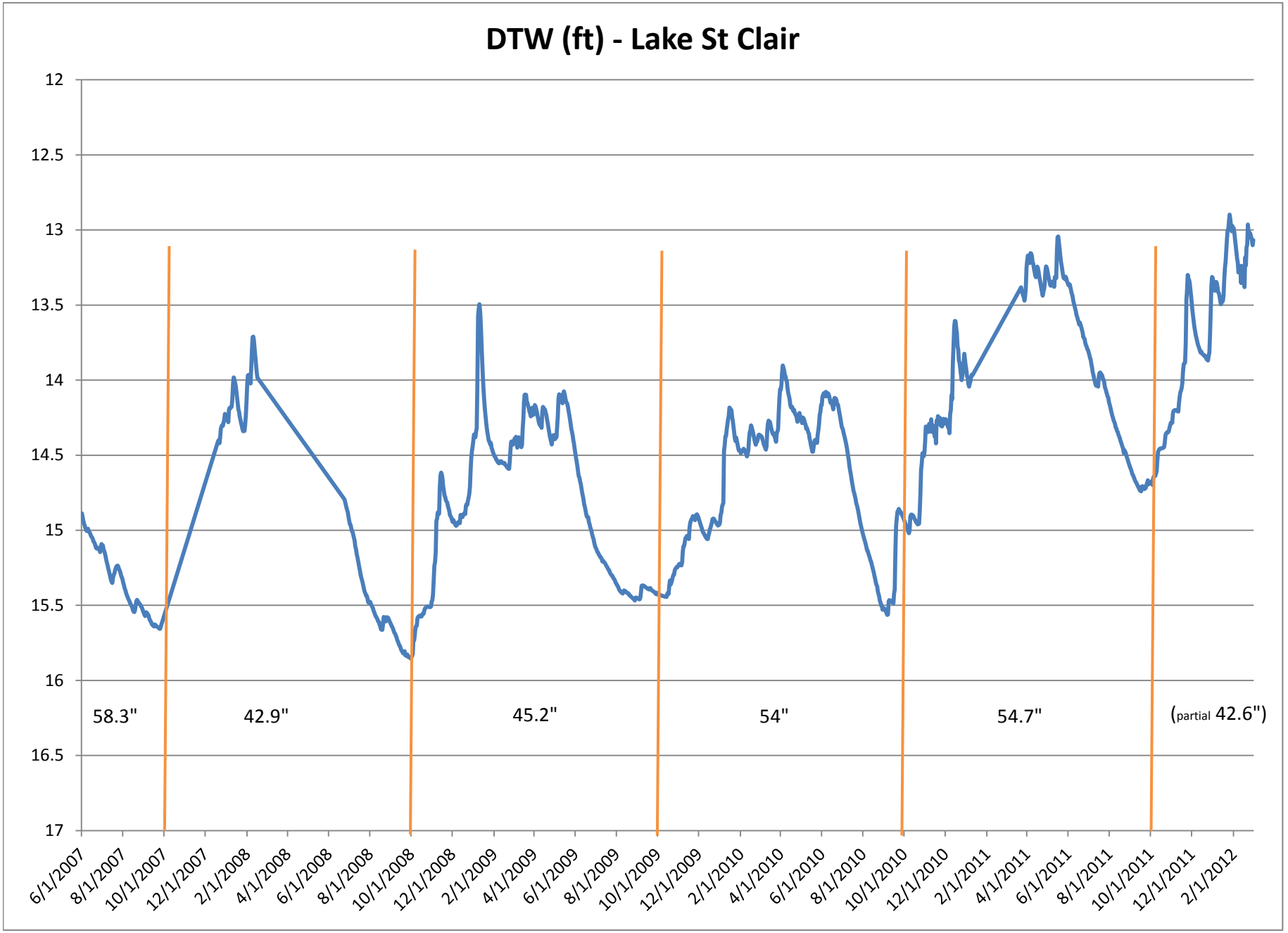
Precip			Rise	
in	ft	11/19/2011	11/25/2011	diff ft
4.68	0.39	13.894	13.30	**0.594**

Sensitivity Analysis

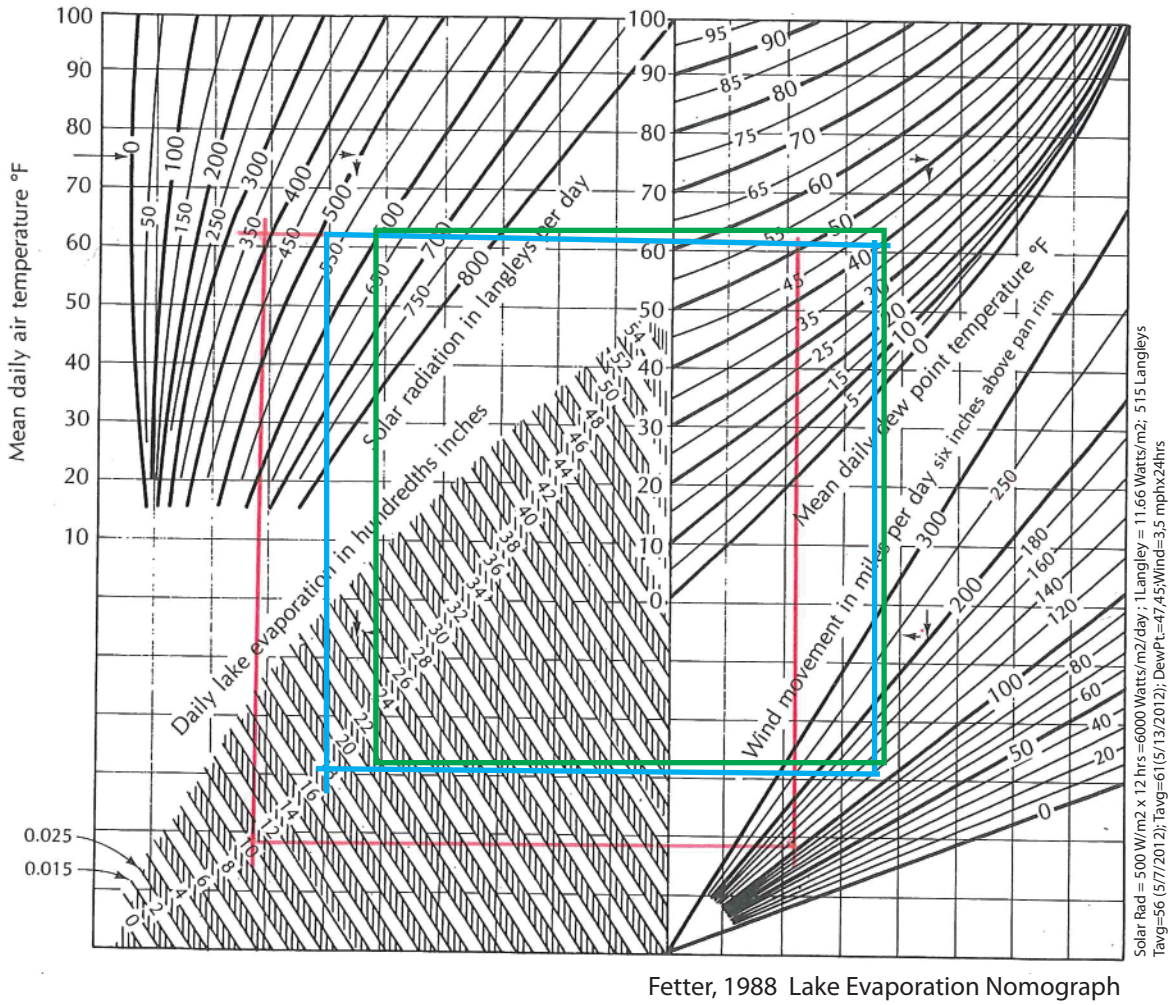
5/8/2012	**5/14/2012**	Diff	Days sun	E	Drop	**Zpredict**	**Zactual**	**Accuracy**
70.4	70.18	0.22	6	0.018	0.108	70.292	70.18	0.11
6/6/2012	**6/11/2012**	Diff	Days sun	P 0.7"estim	Gain*ratio	**Zpredict**	**Zactual**	
69.95	70.04	-0.09	4	0.06	0.1248	70.0108	70.04	-0.03

				Prediction		**Prediction**
6/11/2012	Goal	Diff	If E	Then, Days		**Date**
70.04	69.5	0.54	0.018	30		*11-Jun-12*
70.04	69.5	0.54	0.022	24.5		5-Jul-12

		Actual		**if**	**Predicted**			
6/11/2012	**6/18/2012**	Diff	Days sun	**E**	**Drop**	**Zpredict**	**Zactual**	**Accuracy**
70.04	69.90	0.14	7	**0.018**	0.126	69.91	69.90	*0.01*
70.04	69.90	0.14	7	0.015	0.105	69.99	69.90	*0.09*



Prepared by N. Romero, 6/5/2012



Fetter, 1988 Lake Evaporation Nomograph

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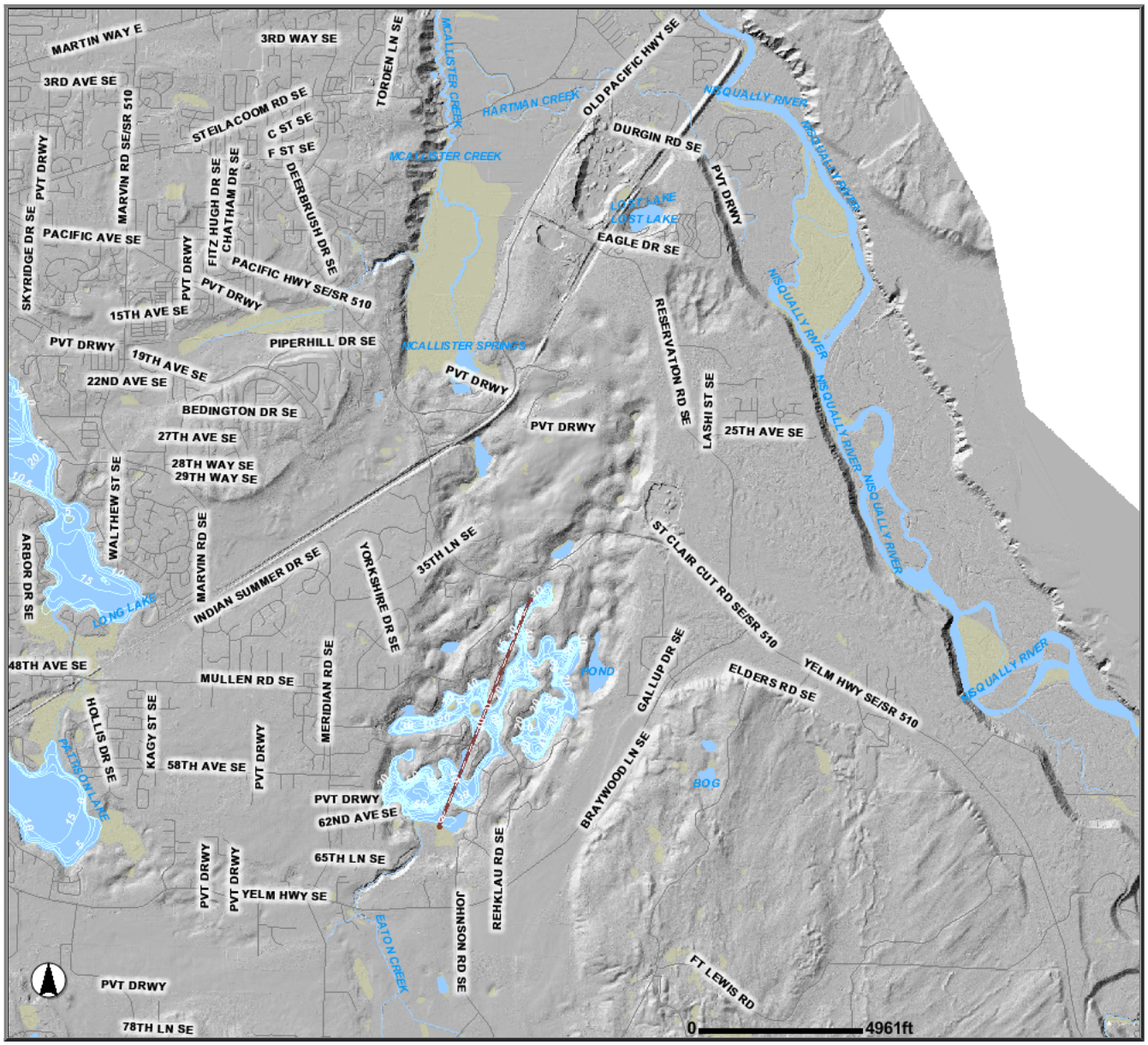
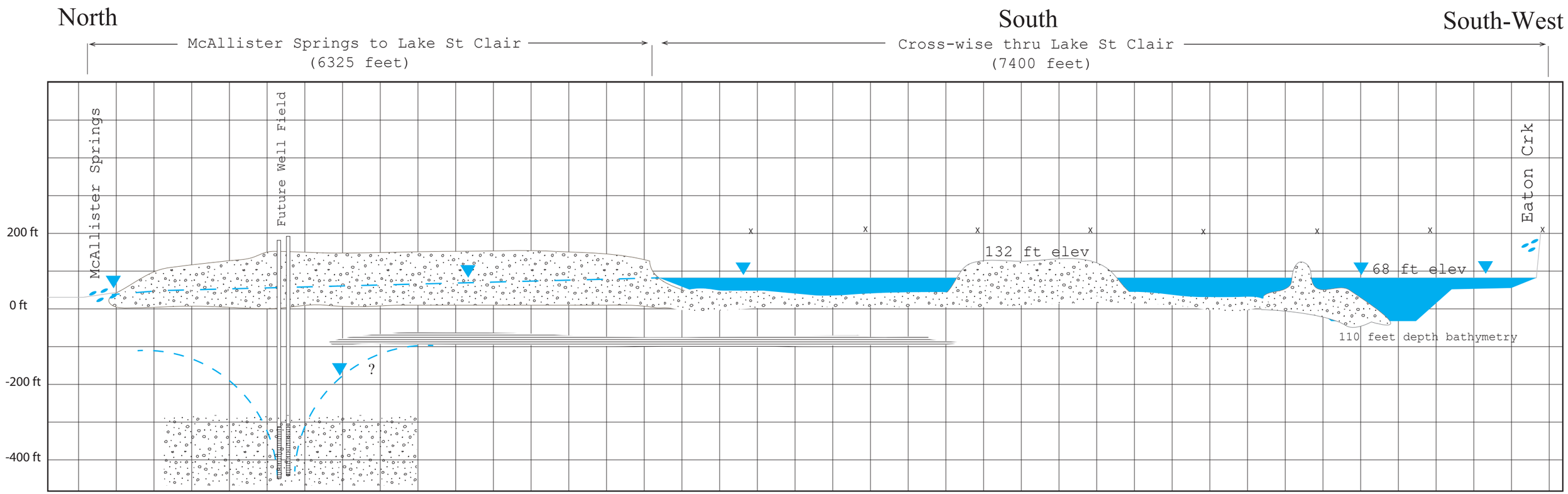
Calculations by N. Romero, 5/29/2012


MARTIN WAY E
3RD WAY SE
3RD AVE SE
TORDEN LN SE
MCALLISTER CREEK
HARTMAN CREEK
OLD PACIFIC HWY SE
NISQUALLY RIVER
STEILACOOM RD SE
C ST SE
F ST SE
DURGIN RD SE
MARVIN RD SE/SR 510
PVT DRWY
DEERBRUSH DR SE
FITZ HUGH DR SE
CHATHAM DR SE
LOST LAKE
EAGLE DR SE
SKYRIDGE DR SE
PACIFIC AVE SE
PACIFIC HWY SE/SR 510
15TH AVE SE
PIPERHILL DR SE
MCALLISTER SPRINGS
RESERVATION RD SE
LASHI ST SE
25TH AVE SE
19TH AVE SE
22ND AVE SE
BEDINGTON DR SE
27TH AVE SE
28TH WAY SE
29TH WAY SE
WALTHEW ST SE
ARBOR DR SE
MARVIN RD SE
INDIAN SUMMER DR SE
YORKSHIRE DR SE
35TH LN SE
ST CLAIR CUT RD SE/SR 510
LONG LAKE
48TH AVE SE
MULLEN RD SE
MERIDIAN RD SE
POND
GALLUP DR SE
ELDERS RD SE
YELM HWY SE/SR 510
HOLLIS DR SE
KAGY ST SE
58TH AVE SE
PATTISON LAKE
BOG
BRAYWOOD LN SE
62ND AVE SE
65TH LN SE
REHKLAU RD SE
YELM HWY SE
JOHNSON RD SE
EATON CREEK
FT LEWIS RD
78TH LN SE
0
4961ft

Lake St. Clair Esker System - Geologic X-Section



Prepared by N. Romero, 5/29/2012

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Notes - Hydrogeologic Analyses by Nadine Romero
(See other sheets for calculations)