East Two River calcium loading study: Headwaters to Lake Vermilion

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Driven to Discover

Intro

The spread of zebra mussels across MN and their ecological impacts are a major concern for many, from state resource managers, to lake associations, lake shore owners, anglers, and fishing-dependent businesses. The Vermilion Lake Association (VLA: http://www.vermilionlakeassociation.org/) is "*committed to doing everything it can to protect the Lake Vermilion fisheries and business community by preventing all new AIS and non-AIS stressors and rolling back those already present*" (Lake Vermilion AIS [Aquatic Invasive Species] Prevention Plan- 1/31/16; see http://www.vermilionlakeassociation.org/ais-prevention/). Zebra mussels (*Dreissena polymorpha*) and spiny water fleas (*Bythotrephes longimanus*) are the top concerns for the Vermilion Lake Association as each was determined to have a high risk of introduction with potentially serious impacts to the ecology of Lake Vermilion, its fishery, and its tourist industry due to the high number of boat launchings. Unfortunately, spiny water fleas have been detected in the lake but to date no zebra mussels have been discovered.

This project is a component of the broader Lake Vermilion Zebra Mussel habitat assessment initiated by the Vermilion Lake Association (VLA), formerly known as the Sportsmen's Club of Lake Vermilion. Project goals were (1) to quantify calcium concentrations and loads seasonally from East Two River into Lake Vermilion; and (2) determine how calcium concentrations change longitudinally in the lower reaches of East Two River before it discharges into Pike Bay of Lake Vermilion. As a bivalve mollusk, zebra mussels require a certain minimum concentration of calcium for shell growth and reproduction. The USGS Fact Sheet on zebra mussels states that North American populations require at least 10 mg Ca/L to commence growth of shells and 25 mg Ca/L to continue shell growth (Benson et al, 2017). https://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=5 Revision Date: 6/26/2014). Many lakes in NE MN have calcium concentrations lower than this threshold and therefore, have a lower risk of infestation. Most locations sampled by VLA in 2015 on Lake Vermilion fell below the 10 mg Ca/L threshold, though a sample in East Two River had a calcium concentration > 25 mg Ca/L, prompting a closer look.

The strategy employed was a modification of the MPCA's Watershed Pollutant Load Monitoring sampling strategy and was designed to estimate annual loads of Ca using the FLUX32 load model (FLUX32 Load Estimation Software v4.0. https://www.pca.state.mn.us/wplmn/) and further examine seasonal loading rate variations due to high flows during snow melt and from storm event runoff, waste water discharges, and mine dewatering.

The East Two River has its origins in the Eagles Nest chain of lakes (Eagles Nest 1, Eagles Nest 2, and Eagles Nest 3) in Northeastern MN (Fig 1). It has a watershed area of 33 mi^2 (8546 ha) that is primarily undeveloped (partially within Bear Head Lake State Park) but for the last ~2.5 (4 km) miles. The impacts of note in the lower watershed include stormwater from the cities of Soudan (population 446) and Tower (population 502), mine dewatering from the Lake Vermilion-Soudan Underground Mine State Park, and the Tower-Breitung municipal wastewater treatment pond (WW) discharges (Fig 2).

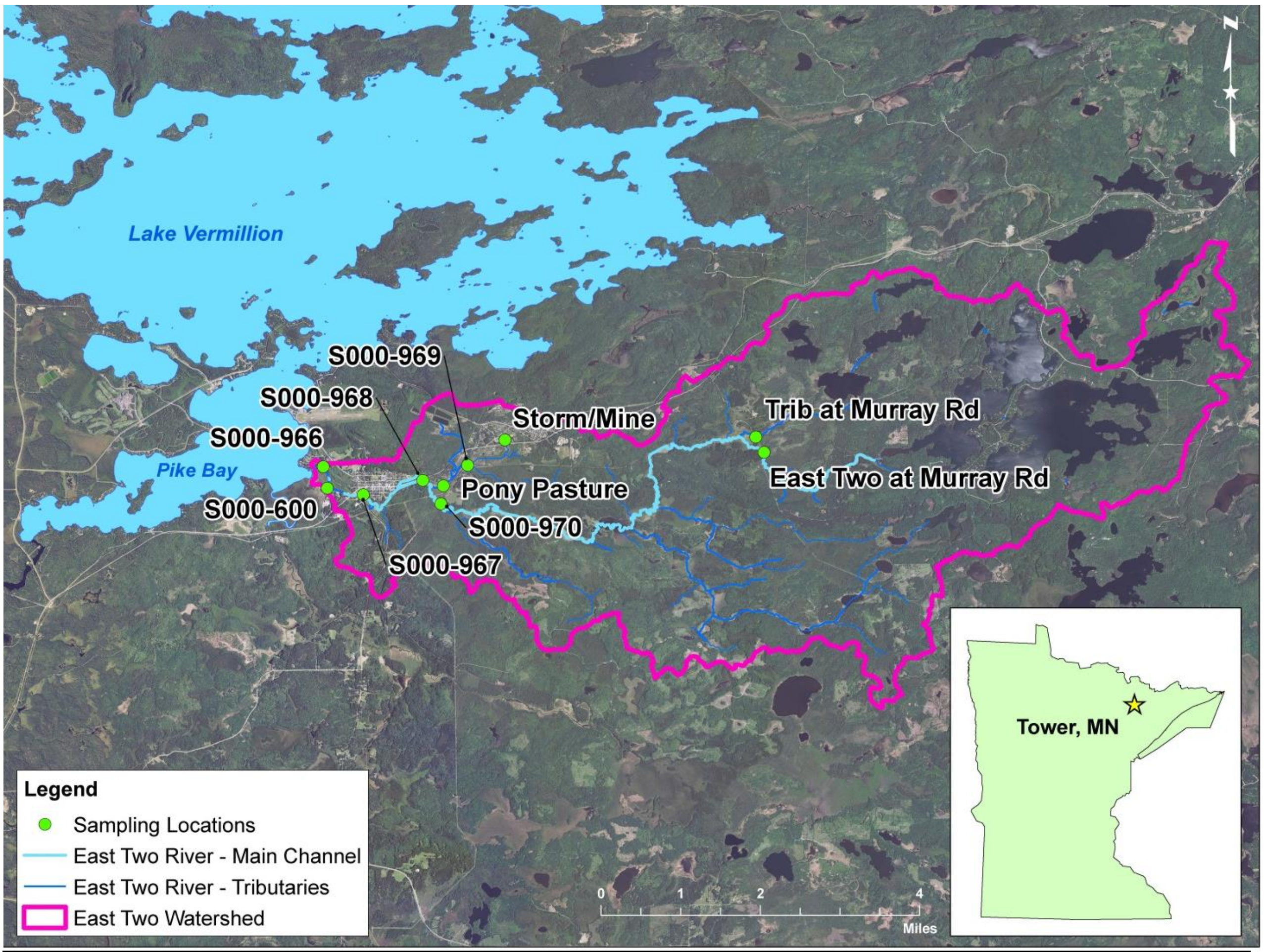

Figure 1. Overview of East Two River watershed and sampling locations.

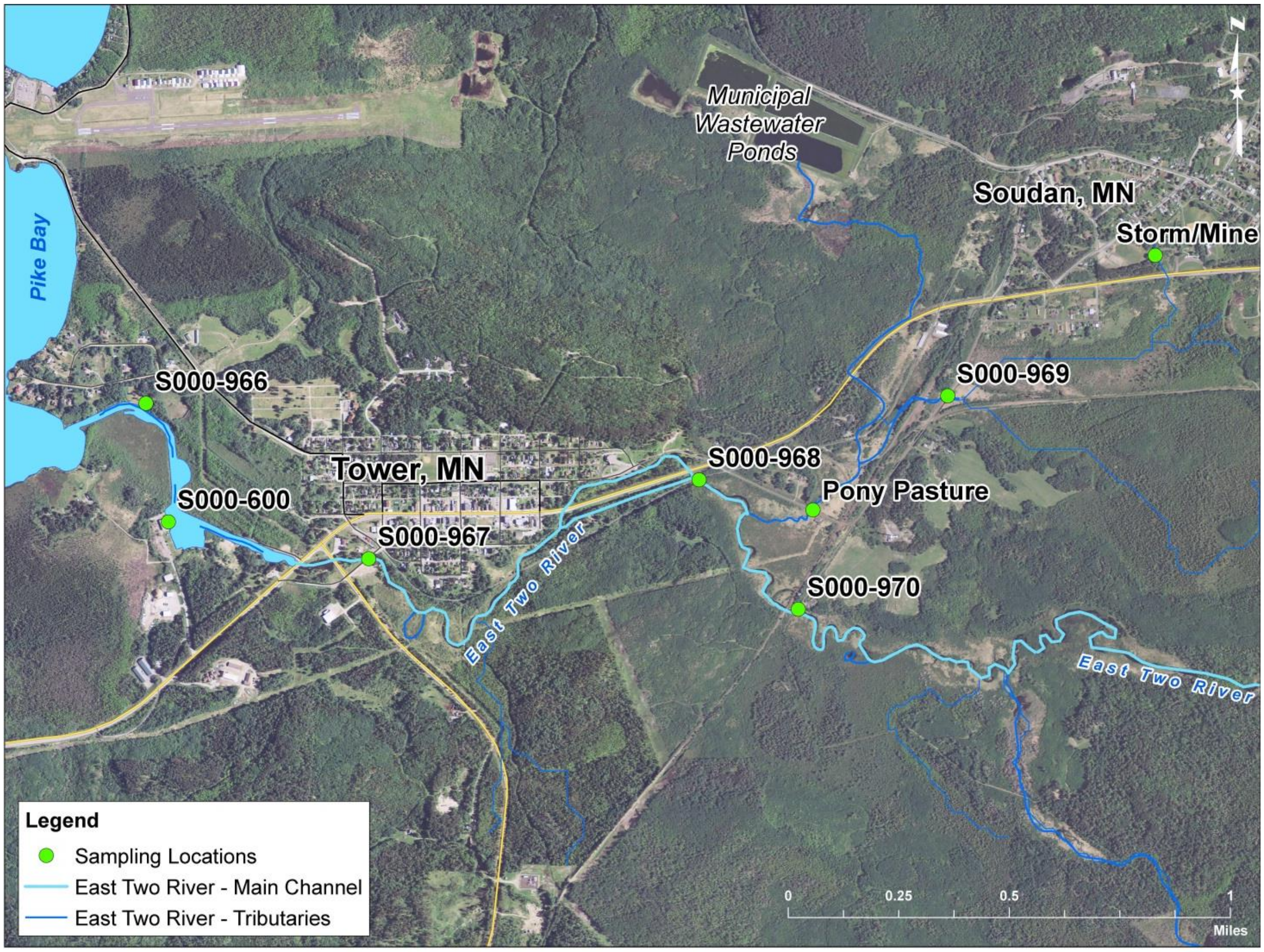

Figure 2. Detail of lower East Two River with synoptic sampling locations

Methods

The water sampling plan consisted of a load monitoring and a synoptic (broad spatial coverage) portion. Load monitoring was based on intensive sampling at the flow gauging station installed at the Pine St bridge (S000-967) (Fig 2).Water samples were collected most intensively during high flow events, snow melt and rainstorms, with less frequent sampling the remainder of the year. This tiered sampling approach optimizes sample distribution emphasizing higher flow periods which provides the best data set for the FLUX32 model. FLUX32 then calculates and sums load values based on the high frequency (datum every 15 minutes) stream flow data measured at the gauging station. This “processed” data set allows users to calculate daily, annual, individual storm-event, and snowmelt runoff loads of the parameter of interest, e.g. calcium, total suspended sediment, nutrients, etc. The synoptic sampling portion consisted of same day sampling of selected points from the headwaters to the outlet (Fig 2) with intensive sampling around the times of WW discharges, snow melt/rain events, and during base flow.

Samples were collected from ice-out to ice-up (Mar 15- Nov 15). Field measures of temperature, specific electrical conductivity (EC25), pH, dissolved oxygen and Secchi tube (water clarity) were recorded at every sampling visit. Surface water grab samples were collected, split and transported to Pace Labs Virginia, MN and the NRRI analytical labs, both of which are State of MN accredited water quality labs. All sampling and sample analysis protocols followed standardized, accepted protocols (MPCA, 2015; Ruzycki, Henneck & Axler, 2015). Water samples were analyzed for calcium (Ca^{+2}) and magnesium (Mg^{+2}), hereafter referred to as Ca and Mg respectively, and hardness (as CaCO3 mg/L). Magnesium (Mg) analyses were discontinued after the data indicated that Ca and Mg co-varied in a consistent manner (Appendix 1).

The synoptic sampling collected samples at seven locations upstream of Pine St where East Two River or its tributaries are accessible, primarily road crossings, at the Pine St gauging site, and two downstream locations (Fig 2) collected by volunteers. The timing of the synoptic samplings was to cover spring snowmelt, spring and fall WW discharge events, major rain event(s), low flow, and "normal" flow(s). The WW pond is discharged for eight consecutive days each time the pond is drained and so sample collection was spread across these periods. Synoptic samples at eight locations (Fig 1 and 2) were collected on a total of 14 separate occasions. Both of the Spring wastewater discharges and a single Fall discharge were sampled four times. Synoptic samples were also collected during snow melt, rain event, and low flow. An additional two sites downstream of Pine St were collected by volunteers Al Williams and Wayne Suoja. Sampling was coordinated with volunteers, Matt Tuchel- Tower-Breitung Water and Wastewater Supervisor, Jim Essig- Park Manager MN DNR, and Jeff Lovgren- VLA.

The load monitoring included all of the synoptic events and additional sampling to provide a more comprehensive picture of annual variability and greater modeling confidence. Stage height was measured and recorded at 15 minute intervals through installation of a pressure gauge at the Pine St Bridge (sample location S000-967). Multiple manual measurements of flow over a range of stage heights were made over the course of the year to develop a rating curve to convert stage height values to flows. Specific electrical conductivity (EC25) and temperature probes were also installed at the gauging site to log data at the same 15 minute interval. Data from the flow gauging station was downloaded in the field at regular intervals to minimize the potential loss of data should problems arise- none were encountered and a complete record of flows, temperature and specific conductance were collected from March 15 through Nov 15.

Results

The flow gauging station at Pine St was installed shortly before ice-out and began collecting depth, temperature and EC25 data on Mar 15, 2016. Load monitoring samples were taken 26 times through the year (Fig 3), spanning the range of flow conditions. Concurrent with water sampling, streamflow was directly measured seven times, again spanning the range of flows to provide the most comprehensive coverage of potential conditions.

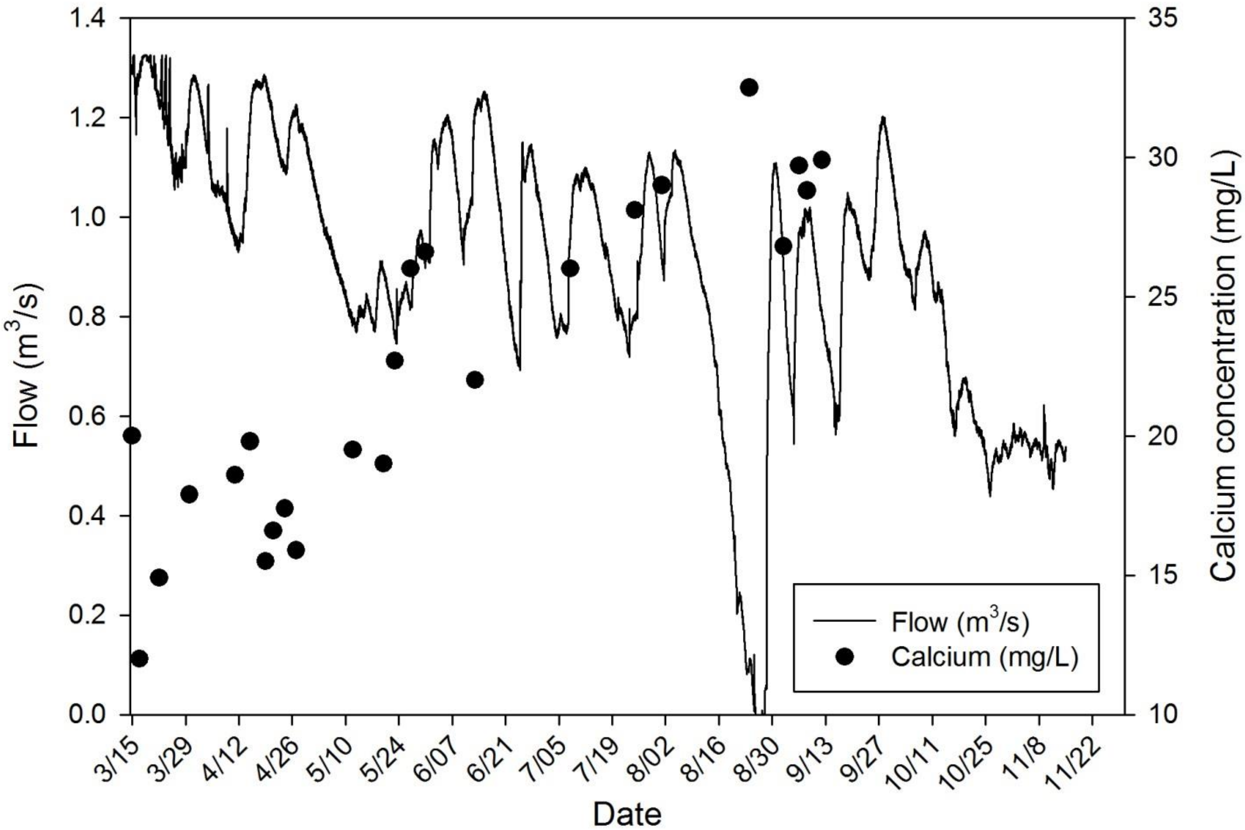

Figure 3. Flow (m^3/s) and calcium concentration (mg/L) at S000-967.

Summer saw wetter conditions than normal with 3.8” of rain more than the long-term average and each month from June to September also had more rain than average. Precipitation exceeded estimated evapotranspiration (UW Extension Ag Weather. (n.d.). Retrieved from http://agweather.cals.wisc.edu/sun_water/et_wimn) during the study period by ~4 inches with the wet month of June accounting for 3 of those inches (Fig 4). Estimated evapotranspiration exceeded precipitation only in the months of May (~1.5 inch) and July (~0.5 inch). Snow melt was mostly completed by the middle of April.

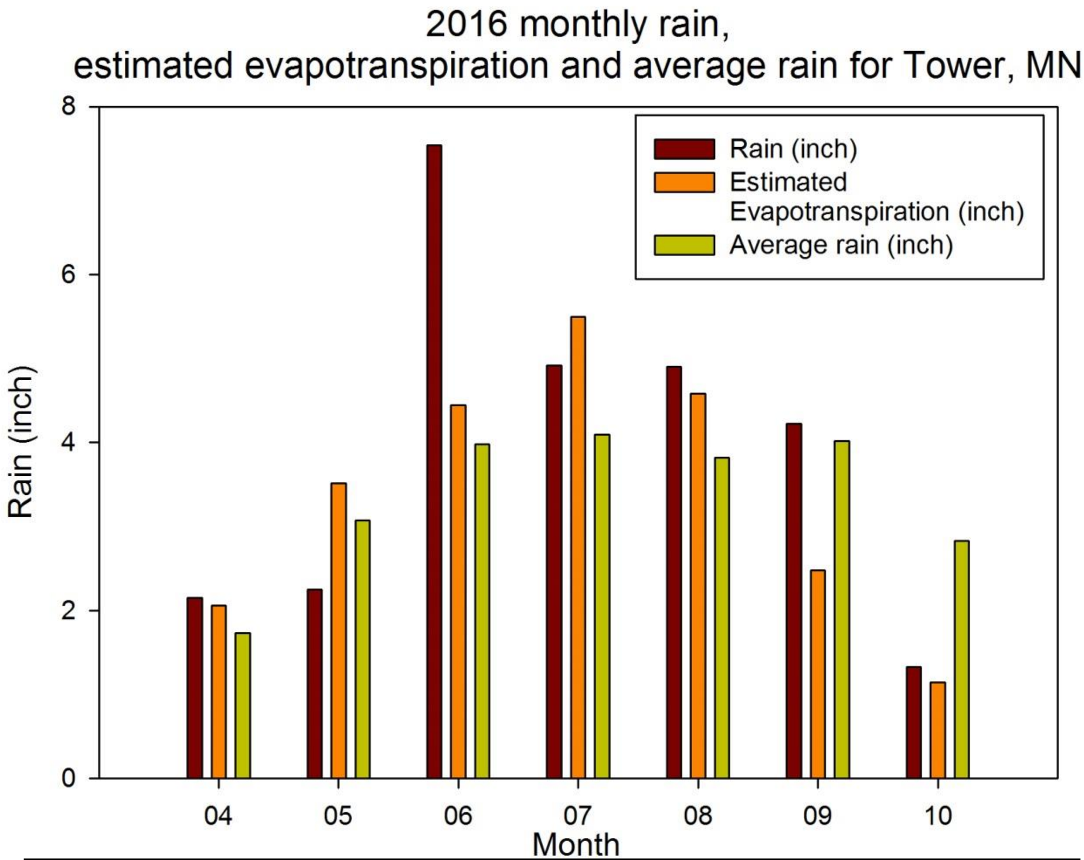

Figure 4. A monthly comparison of rain, estimated evapotranspiration, and long term rain average for Tower, MN.

As stated previously, Mg analyses were discontinued after showing a strong correlation with Ca (Appendix 1). The average East Two River Mg concentration was 2.4 mg Mg/L (n=41) and ranged from 1.5 to 3.6 mg Mg/L.

Calcium and hardness were similarly strongly correlated with an average hardness concentration of 68 mg/L as $CaCO_3$ (n=59). Hardness is a measure of polyvalent cations which in natural waters is predominantly Ca and to a lesser extent Mg. Hardness calculated from the Ca and Mg concentrations was nearly equal to the measured hardness (calculated=58.5 mg/L as $CaCO_3$ and measured = 59.5 mg/L as $CaCO_3$) indicating few other divalent ions such as iron, manganese or zinc were present and confirming Ca and Mg were the predominant cations.

Specific electrical conductivity (EC25) was measured every 15 minutes at the gauging site (S000-067) and during every synoptic site visit. (Appendix 2). The storm/mine site had the highest EC25 with several values an order of magnitude greater than those in East Two River (Fig 4). The average EC25 in East Two River was 139 µS/cm and ranged from 77 – 211 µS/cm. The average at the storm/mine site was an order of magnitude greater at 1034 µS/cm and ranged from 244-2810 µS/cm. The strong correlation between EC25 and Ca concentrations (Fig 5) further confirms calcium is the predominate cation.

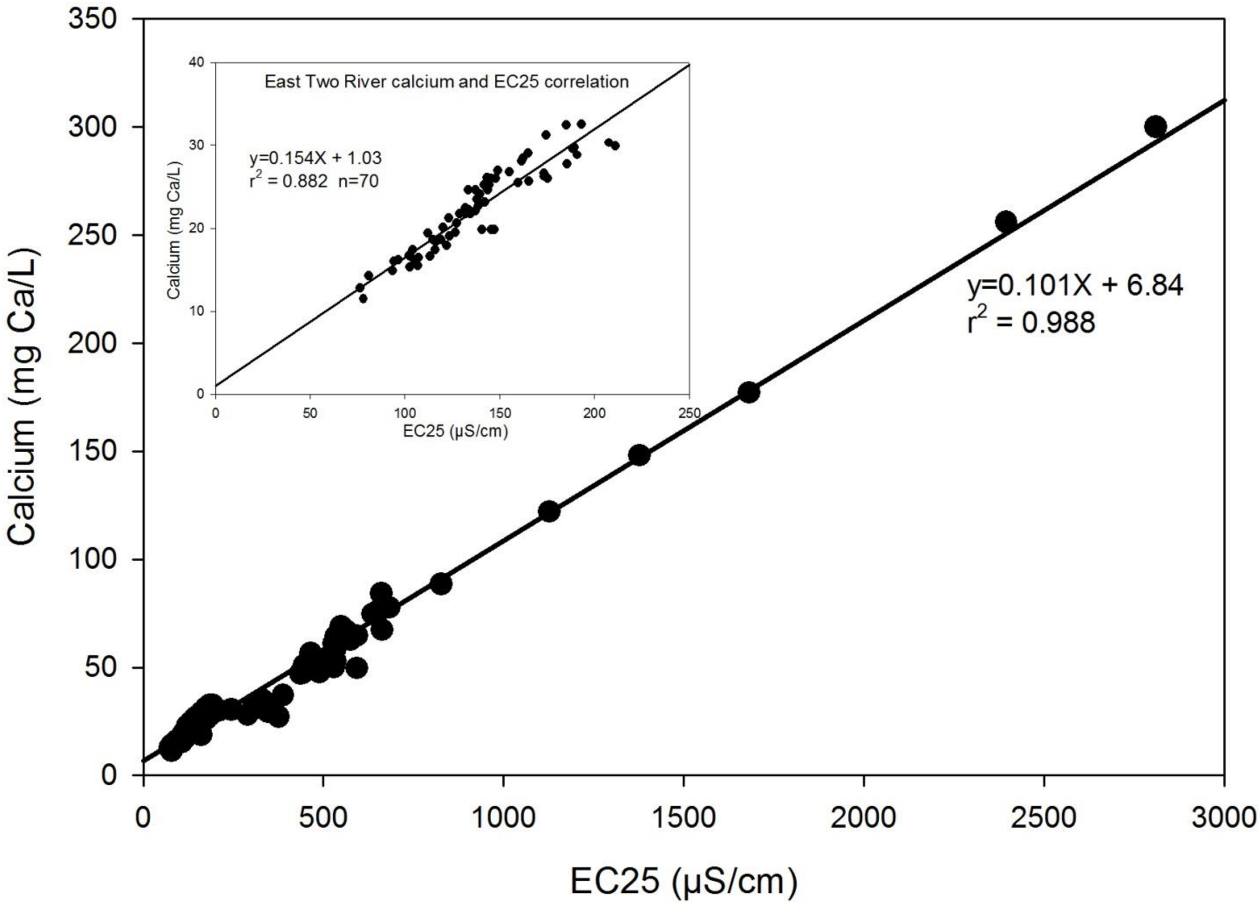

Figure 5. A strong correlation between calcium and electrical conductivity (EC25) measured at the synoptic sites (n=129). The inset plot is values form the four East Two River samples sites only (n=70)

Two semi-quantifiable loads into the East Two River are the Tower-Breitung municipal wastewater treatment pond discharge (WW) and the Lake Vermilion-Sudan Underground Mine State Park dewatering discharge, although the mine discharge combines with the City of Soudan stormwater prior to our sampling and will be referred to as storm/mine hereafter. The wastewater pond discharge volume and rate is known because the water is released by daily removal of 6" tall boards in a control structure for eight consecutive days. The monthly pumped volume from the mine dewatering operation is known although the fall pumped volumes are missing. The volumes pumped in the fall are typically less than the spring according to the Park (Jim Essig, Park Manager, pers comm). Calcium concentration data from the mine dewatering were also provided by the Park. These two inputs (WW and storm/mine) combine before entering East Two River and are sampled at Pony Pasture site (Fig 2).

Wastewater Discharge

The wastewater treatment plant holding ponds are generally discharged twice in the spring and twice in the fall. In 2016 the WW was discharged five times (Table 1) with each discharge estimated to total 11.5 million gallons spread equally over 8 days. The WW pond was sampled for calcium concentration prior to discharge and the pond is discharged into a wetland complex before combining with the storm/mine branch and making its way to the river (Fig 2). The next site downstream from the discharge point is after it combines with the storm/mine branch (Pony Pasture).

Calcium concentrations in the discharged WW averaged 50.4 mg/L (stdev = 4.1mg Ca/L). Using the annual average daily flow at the gage station of 20.49 million gallon per day (mgd), the calculated wastewater contribution would be expected to be ~3 mg/L and comprise ~7% of daily flow during the 16 days of spring discharge and 24 days of discharge this fall. This does not include dilution of the WW from the receiving wetlands it passes through before entering East Two River.

Table 1. Tower-Breitung wastewater pond discharge dates, volumes and calcium concentrations. ND is no data.

	Discharge (million gallons/day)	Calcium (mg/L)
4/13-4/20/16	1.43	46.8 (n=1)
5/20-5/27/16	1.43	56.0(n=2)
9/2-9/9/16	1.43	48.1(n=2)
10/6-10/13/16	1.43	50.6 (n=1)
11/9-11/16/16	1.43	ND

Storm and Mine Discharge

The discharge from the mine dewatering was sampled at a point after it combined with the City of Soudan stormwater (for which we unfortunately don't have flow data) and therefore, the loads are rough estimates since the two sources cannot be estimated independently. Three locations were sampled (Fig 2) to estimate this discharge: storm/mine site, site S000-969, and Pony Pasture after it combines with the WW input. The Park provided monthly pumping volumes and Ca concentrations for the mine dewatering. To estimate the May calcium concentration conservatively (i.e. an overestimate), the June and July concentrations were averaged with the April concentration to yield an approximation of 218 mg/L for the missing May value. The mine pumping flow (avg = 179,175 gpd) was ~0.9% of the total East Two river flow, therefore the calculated average contribution from the mine discharge (assuming no dilution from stormwater and no contribution along the flow path) is ~ 1.6 mg/L in East Two River. This pumped mine discharge is diluted to nearly half by the lower calcium stormwater from an average of 196 mg Ca/L in the pumped mine discharge to 112 mg Ca/L after it has combined with the stormwater at the storm/mine site. Site S000-969 is the combined storm and mine discharge as well as any contributions from the wetlands it flows through. The combined storm/mine appears to be diluted in half again by the wetlands that it flows through, reducing the 112 mg Ca/L at the storm/mine site to ~54 mg Ca/L at site S000-969.

Table 2. Mine dewatering flow rate and estimated average calcium concentrations

Month	Volume (gallons/day)	Calcium (mg/L)
April	190,000	281
May	206,700	218 (estimated) ~218
June	186,700	123
July	133,300	162
Aug- Nov	no data	no data

Combined Storm/Mine and Wastewater Discharge

Water from site S000-969 combines downstream with the WW input in another wetland complex before being sampled at the Pony Pasture site. Assuming the WW (when discharging) and mine dewatering yield a combined discharge of 1.62 mgd, one can calculate an average flow weighted concentration of 63.4 mg Ca/L. The calculated combined calcium contribution to East Two River (using the flow from the downstream site S000-967) would therefore be about an extra ~3 mg Ca/L above the ambient concentration. This can be thought of as the estimated maximum contribution if WW was discharged every day and neither of the inputs were diluted through the wetland before entering East Two River. Our sampling location at Pony Pasture captured this combined contribution and yielded an average Ca concentration of 47.2 mg/L, which is about 25% lower than the calculated value of 63.4 mg Ca/L. This discrepancy is due to our lack of understanding the effect the wetland has on calcium levels in the tributary and our limited calcium data for the tributary.

The combined contribution can also be estimated more directly by the difference between sites S000-970 and S000-968, two sites in close proximity upstream and downstream of the combined inputs from the WW and the storm/mine (Fig 2). Sample results from upstream (S000-970) and downstream (S000-968) of the combined WW and storm/mine input showed an average increase of 2.7 mg Ca/L but a statistical analysis (t-Test:Two Sample Assuming Unequal Variances) showed that this difference was not significant ($p >> 0.05$).

Murray Rd to 970 or 967

The average calcium concentration for the Murray Road site of East Two River was 21.6 mg Ca/L (n=14), while the average at the gauge station on matched dates was 24.4 mg Ca/L (n=14), an average increase of ~2.8 mg Ca/L from the headwaters to near the outlet. The average Ca concentration of 21.6 mg Ca/L at the Murray Road site was the same as at the next site downriver, site S000-970, this even after the river is joined by several branches, suggesting uniform conditions in the majority of the upper/middle watershed. The average Ca concentration in the tributary to East Two River at Murray Rd was 19.6 mg Ca/L, slightly less than the concentration in East Two River at Murray Rd.

Seasonality

All of the synoptic sites showed a trend of increasing calcium (Table 3, Fig 5) concentrations from spring to fall. The Murray Road site showed this trend as the summer progressed from an April/May average of 19.5 mg Ca/L to an Aug/Sep average of 24.4 mg Ca/L, suggesting a dilution effect from the snow melt/spring rains and/or a concentrating effect from the summer evapotranspiration and possibly greater groundwater (with higher Ca) influence. Site

S000-970 (upstream of WW and storm/mine inputs) similarly showed an increase from Apr/May levels of ~18 mg Ca/L to 26 mg Ca/L in Aug/Sep. The seasonality was strongest at the frequently sampled gage site (S000-967) where the Apr/May and Aug/Sep levels were 19.8 mg/L (stdev = 3.8, n=11) and 29.5 mg Ca/L (stdev=1.9, n=6), respectively. A similar pattern occurred at the Pony Pasture site with levels increasing over the same period from 45 mg Ca/L to 57 mg Ca/L. Daily flow at S000-967 decreased over this period from 23 mgd down to 18 mgd. Calculating the maximum combined contribution from the WW and storm/mine using the reduced fall flow in East Two River would have further increased Ca concentrations in the river by about 0.4 mg Ca/L.

Table 3. Synoptic seasonality of calcium concentrations in East Two River. Averaged values plus or minus the standard deviation with the number of samples in parentheses.

Sites	**Apr/May**	**Aug/Sep**
Tributary to East Two@ Murray Rd	18±6 (8)	21±4 (6)
East Two@Murray Rd	19±2 (8)	24±1 (6)
S000-970	18±48	26±3(6)
Combined Stormwater runoff and Sudan Mine Dewatering	83±53 (8)	151±101 (6)
S000-969	46±17 (7)	63±10 (6)
Pony Pasture	45±9 (8)	57±8 (6)
S000-968	20±4 (8)	29±2 (6)
S000-967	20±4 (11)	29±2 (6)
Tower Harbor	20±3 (5)	27±1 (4)

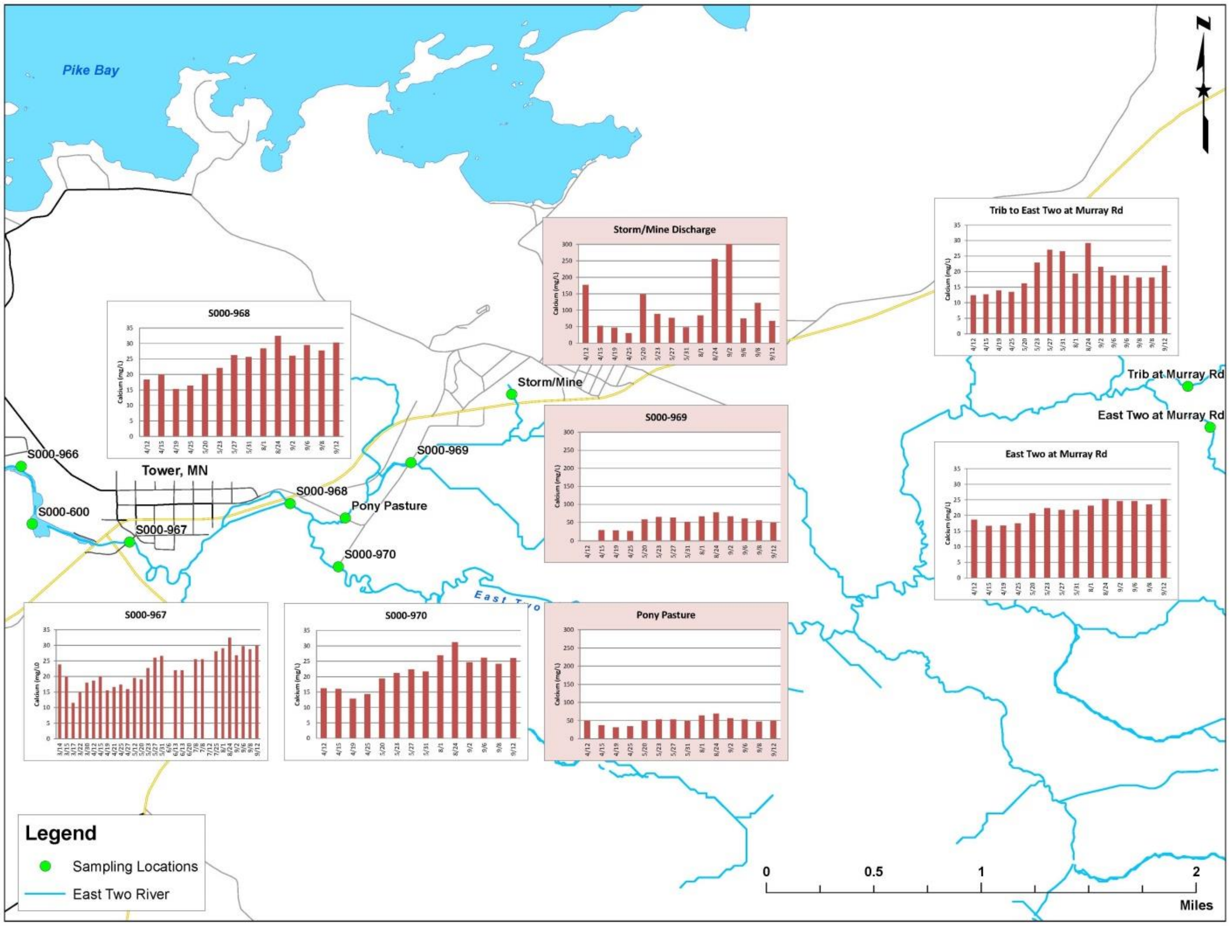

Figure 5. Measured calcium concentrations at synoptic sampling sites, note scale change on shaded plots.

Seasonality was not evident when looking at the difference between sites 970 and 968 on matched dates, Apr/May increase = 2.5 mg Ca/L and Aug/Sep increase = 2.6 mg Ca/L.

Tower Harbor showed an average Ca concentration of 23.7 mg Ca/L, not significantly different than at the nearby stream gauging station which had an average of 24.5 mg Ca/L. This site also showed the same seasonal pattern with calcium concentrations increasing from 20.0 (n=5) in Spring to 27.5 mg Ca/L (n=4) in late summer/early Fall.

<u>FLUX32 calculated loads</u>

FLUX32 was used to calculate daily and seasonal flow as well as loads of calcium and hardness. The samples were well distributed across the flow regime and covered the seasonal spread as well (Fig 6). The average daily flow was 0.898 m3/s (~31.7 cfs) and ranged from a high of 1.32m^3/s to a low of ~ 0.61 m^3/s (46.6 cfs and 21.5 cfs respectively), excluding the nearly zero flows at the end of August. The large decrease in flow in late August was likely attributable to beavers blocking the culverts on Murray Road, both East Two River and a tributary to East Two River. The beavers were removed and the culvert was unplugged allowing for “normal” flows to resume.

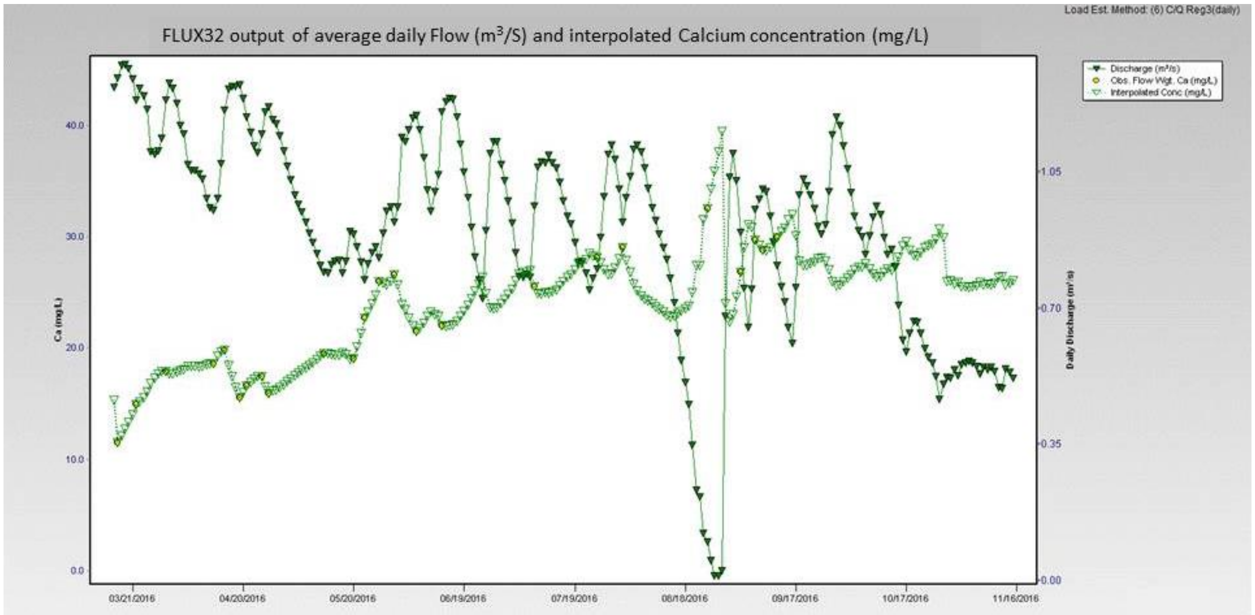

Figure 6. FLUX32 output of average daily flow (m^3/s), measured calcium concentrations and the interpolated daily calcium concentration.

Calcium was inversely related to flow, i.e., as flow decreased calcium increased. This is consistent with the seasonality discussed above as flow decreased in the fall and calcium increased. The model yielded an average flow weighted Ca concentration of 22.2 mg Ca/L, and ranged from a low of ~ 11 mg Ca/L to a high of 40 mg Ca/L. The high value may be an anomaly resulting from the inverse relationship of flow and calcium and the very low flows. The greatest measured calcium concentration was 32.5 mg Ca/L measured on 8/24/16. The average daily calcium load was 898 kg (3800 lbs).

Discussion

Special attention was paid to the first WW discharge event and the specific electrical conductivity (EC25) at station S000-967as it was expected that a conductivity spike would denote a wastewater plume passing through. Had we seen this it would have allowed us to refine the focus of the sampling plan around the timing of the spike and better estimate its impact. Unfortunately, although we scrutinized the plots of EC25 and flow during the wastewater discharge periods for evidence of a WW plume, no increase in flow, conductance, or temperature was seen before, during or after the WW discharge that could be attributed to the expected increase in conductivity of the wastewater (Fig 7). The first discharge was early in the season when the wetland that it runs through on its way to East Two River was just thawing. The lack of a conductivity spike at the gauging station was attributed, at that time, to dilution by the melting of ice and snow in the WW receiving wetland causing a dilution to below detection. The second synoptic sampling was conducted during the second discharge but again no conductivity spike was noted and none of the other parameters appeared to be influenced by the discharge. This second discharge had light rain towards the end of the discharge but all of the snow and ice had melted prior to this. The stream data during the third WW discharge event (9/2-9/9) was also scrutinized for evidence of a wastewater plume passing the gauging station. This discharge was accompanied by ~2” of rain between 9/5 and 9/9/16 but again no clearly discernible WW plume was evident. The varied conditions of the three events were such that a spike in flow or conductivity should have been detected if a plug flow assumption was valid. It appears that the flow path through the WW receiving wetland is sufficiently long and complicated to dilute the pond’s wastewater to ambient levels of major ions as indicated by EC25 and Ca concentration at the gauging station.

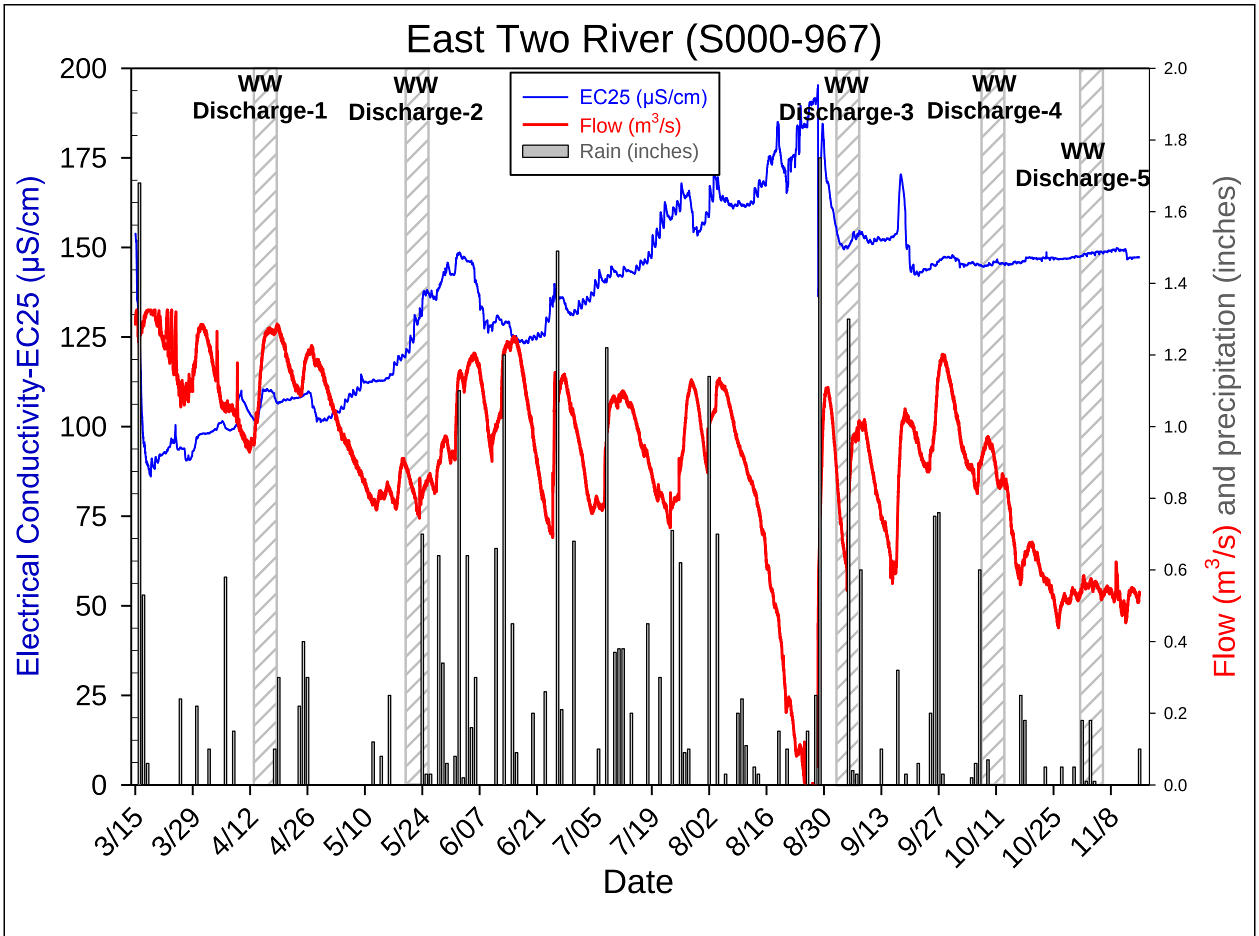

Figure 7. Wastewater discharges had no discernible impacts on flow and EC25.

The mine dewatering effluent clearly had the highest concentration of Ca (avg ~200 mg Ca/L) but also had the lowest volume (~0.18 mgd). If this had been discharged directly into East Two River it would have increased the Ca concentration by ~1.6 mg Ca/L. This relatively small volume and the dilution from stormwater and the receiving wetland reduced the concentration to ~54 mg Ca/L prior to combining with the WW branch.

The strong seasonality of the Ca concentration was apparent in the mainstem of East Two River from the headwaters to the terminus despite slightly higher than average rainfall in August and September suggesting a groundwater component high in Ca (see Figure 3). The precipitous drop in flow in the middle/end of August was likely the result of beaver activity in the culverts of Murray Road. While it is desirable to have as few outside influences as possible in a study like this, some information can be gleaned from the flow reduction resulting from beaver activity. For the flow to drop to near zero from the beaver activity shows that the majority of the flow in the

Fall is coming from the Eagles Nest chain of lakes. As the Ca concentration continued to rise during the lowest flow, it suggests an input of greater Ca concentration water (groundwater?) between the headwaters and gauging station or a concentrating of the river water from evapotranspiration, or most likely a combination of both.

Summary

The spring rains and snowmelt are assumed to have diluted the more concentrated groundwater which maintained calcium concentrations in East Two River to near 20 mg/L in March through most of May. The calcium concentration then increased to nearly 30 mg/L in late summer, presumably as a result of increased proportion of groundwater, increased concentration from evapotranspiration, and decreased dilution from snow melt. The wastewater and mine dewatering discharges contributed to the overall load of calcium, both calculated and measured loads were similar in indicating a combined increase of approximately 2.5 – 3.1 mg Ca/L. The strong correlation between calcium concentration and EC25 should allow calcium concentrations in East Two River to be tracked reasonably well through frequent and inexpensive EC25 measurements with less frequent analysis of calcium.

Acknowledgements

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Appendix-1

Location	Date	Calcium (mg/L)	Hardness (mg/L CaCO3)	Magnesium (mg/L)
Trib @ Murray Rd	04/12/2016 14:10	12.4	40.3	1.3
Trib @ Murray Rd	04/15/2016 13:00	12.7	51.6	1.3
Trib @ Murray Rd	04/19/2016 15:00	13.9	39.0	1.5
Trib @ Murray Rd	04/24/2016 12:45	13.5	39.0	1.4
Trib @ Murray Rd	05/20/2016 12:05	16.2	46.7	1.6
Trib @ Murray Rd	05/23/2016 11:40	22.9	70.1	2.2
Trib @ Murray Rd	05/27/2016 14:15	27.0	114.3	2.5
Trib @ Murray Rd	05/31/2016 13:30	26.5	65.6	2.5
Trib @ Murray Rd	08/01/2016 12:45	19.3	51.7	
Trib @ Murray Rd	08/24/2016 13:30	29.2	81.3	
Trib @ Murray Rd	09/02/2016 11:20	21.5	59.3	
Trib @ Murray Rd	09/06/2016 11:30	18.7	50.6	
Trib @ Murray Rd	09/08/2016 14:45	18.1	54.3	
Trib @ Murray Rd	09/12/2016 12:55	21.9		
E2 - Murray Road	04/12/2016 14:00	18.6	77.2	2.4
E2 - Murray Road	04/15/2016 12:45	16.6	38.8	2.2
E2 - Murray Road	04/19/2016 14:45	16.7	49.8	2.2
E2 - Murray Road	04/24/2016 12:30	17.4	50.8	2.2
E2 - Murray Road	05/20/2016 11:50	20.6	60.6	2.5
E2 - Murray Road	05/23/2016 11:45	22.3	67.4	2.6
E2 - Murray Road	05/27/2016 14:25	21.7	88.1	2.5
E2 - Murray Road	05/31/2016 13:40	21.7	87.5	2.5
E2 - Murray Road	08/01/2016 12:35	23.1	71.3	
E2 - Murray Road	08/24/2016 13:20	25.2	68.4	
E2 - Murray Road	09/02/2016 11:45	24.6	69.7	
E2 - Murray Road	09/06/2016 11:00	24.6	75.2	
E2 - Murray Road	09/08/2016 12:30	23.5	74.9	
E2 - Murray Road	09/12/2016 12:45	25.2		
Pony Pasture	04/12/2016 12:25	50.8	166	10
Pony Pasture	04/15/2016 11:20	37.2		7.1
Pony Pasture	04/19/2016 13:45	31.1	103	5.8
Pony Pasture	04/24/2016 13:30	34.8	111	6.4
Pony Pasture	05/20/2016 10:55	50.1	168	9.0
Pony Pasture	05/23/2016 11:00	52.9	177	9.5
Pony Pasture	05/27/2016 13:10	53.0	178	9.3
Pony Pasture	05/31/2016 12:35	49.1	164	8.6
Pony Pasture	08/01/2016 11:45	64.1	153	
Pony Pasture	08/24/2016 11:45	68.7	214	
Pony Pasture	09/02/2016 12:35	56.5	175	

Location	Date	Calcium (mg/L)	Hardness (mg/L CaCO3)	Magnesium (mg/L)
Pony Pasture	09/06/2016 12:30	53.2	171	
Pony Pasture	09/08/2016 13:30	47.4	159	
Pony Pasture	09/12/2016 11:45	50.2		
S000-967 E2 - Pine Street	03/14/2016 10:45	23.9	61.4	3.6
S000-967 E2 - Pine Street	03/15/2016 12:20	19.8		3.0
S000-967 E2 - Pine Street	03/17/2016 12:00	11.5	35.2	1.7
S000-967 E2 - Pine Street	03/22/2016 14:33	14.9	45.6	2.0
S000-967 E2 - Pine Street	03/30/2016 12:30	17.9	54.7	2.5
S000-967 E2 - Pine Street	04/11/2016 11:30	18.6	57.8	2.5
S000-967 E2 - Pine Street	04/15/2016 10:20	19.8	63.5	2.9
S000-967 E2 - Pine Street	04/19/2016 13:00	15.5	47.3	2.1
S000-967 E2 - Pine Street	04/21/2016 13:40	16.6		2.2
S000-967 E2 - Pine Street	04/24/2016 14:15	17.4	47.5	2.3
S000-967 E2 - Pine Street	04/27/2016 13:45	15.9		2.1
S000-967 E2 - Pine Street	05/12/2016 11:00	19.5		2.3
S000-967 E2 - Pine Street	05/20/2016 12:25	19.0	60.5	2.2
S000-967 E2 - Pine Street	05/23/2016 10:30	22.7	74.3	2.7
S000-967 E2 - Pine Street	05/27/2016 12:20	26.0	30.4	3.2
S000-967 E2 - Pine Street	05/31/2016 11:55	26.6	78.3	3.2
S000-967 E2 - Pine Street	06/06/2016 13:45	21.5		
S000-967 E2 - Pine Street	06/13/2016 11:50	22.0		
S000-967 E2 - Pine Street	07/08/2016 12:00	25.5	74.9	
S000-967 E2 - Pine Street	07/25/2016 11:20	28.1	85.5	3.0
S000-967 E2 - Pine Street	08/01/2016 11:15	29.0	117	
S000-967 E2 - Pine Street	08/24/2016 11:00	32.5	95.9	
S000-967 E2 - Pine Street	09/02/2016 10:15	26.8	78.5	
S000-967 E2 - Pine Street	09/06/2016 12:50	29.7	84.8	
S000-967 E2 - Pine Street	09/08/2016 14:10	28.8	92.6	
S000-967 E2 - Pine Street	09/12/2016 11:15	29.9		
S000-968 E2 - Snow Bridge @ Hwy 1	04/12/2016 13:15	18.3	57.2	2.4
S000-968 E2 - Snow Bridge @ Hwy 1	04/15/2016 11:00	19.8	59.4	2.8
S000-968 E2 - Snow Bridge @ Hwy 1	04/19/2016 13:20	15.3	45.4	2.1
S000-968 E2 - Snow Bridge @ Hwy 1	04/24/2016 13:15	16.4	48.2	2.2
S000-968 E2 - Snow Bridge @ Hwy 1	05/20/2016 10:40	20.1	56.7	2.4
S000-968 E2 - Snow Bridge @ Hwy 1	05/23/2016 10:50	22.1	71.7	2.6
S000-968 E2 - Snow Bridge @ Hwy 1	05/27/2016 13:00	26.2	79.1	3.3
S000-968 E2 - Snow Bridge @ Hwy 1	05/31/2016 12:15	25.6	80.3	3.1
S000-968 E2 - Snow Bridge @ Hwy 1	08/01/2016 11:30	28.4		
S000-968 E2 - Snow Bridge @ Hwy 1	08/24/2016 11:25	32.4	96.2	

Location	Date	Calcium (mg/L)	Hardness (mg/L CaCO3)	Magnesium (mg/L)
S000-968 E2 - Snow Bridge @ Hwy 1	09/02/2016 10:45	26.0	74.0	
S000-968 E2 - Snow Bridge @ Hwy 1	09/06/2016 12:35	29.5	84.3	
S000-968 E2 - Snow Bridge @ Hwy 1	09/08/2016 13:15	27.7	87.3	
S000-968 E2 - Snow Bridge @ Hwy 1	09/12/2016 11:30	30.3		
S000-969	04/15/2016 11:55	29.5	112	5.5
S000-969	04/19/2016 14:15	28.2	95.0	5.3
S000-969	04/24/2016 14:00	27.2	86.4	5.0
S000-969	05/20/2016 11:30	58.4	191	10.9
S000-969	05/23/2016 11:15	64.6	208	11.8
S000-969	05/27/2016 13:35	62.8	220	11.2
S000-969	05/31/2016 12:55	51.0	129	9.2
S000-969	08/01/2016 12:05	66.9		
S000-969	08/24/2016 12:25	77.6	262	
S000-969	09/02/2016 12:10	66.5	202	
S000-969	09/06/2016 12:05	61.0	187	
S000-969	09/08/2016 13:45	55.4	191	
S000-969	09/12/2016 12:15	49.6		
S000-970 E2 - Snow Trail @ Junction Rd	04/12/2016 12:35	16.2	50.8	2.0
S000-970 E2 - Snow Trail @ Junction Rd	04/15/2016 11:35	16.0	48.0	1.9
S000-970 E2 - Snow Trail @ Junction Rd	04/19/2016 14:00	12.8	37.0	1.5
S000-970 E2 - Snow Trail @ Junction Rd	04/24/2016 13:45	14.3	39.4	1.7
S000-970 E2 - Snow Trail @ Junction Rd	05/20/2016 11:10	19.4	57.5	2.2
S000-970 E2 - Snow Trail @ Junction Rd	05/23/2016 11:10	21.2	75.6	2.4
S000-970 E2 - Snow Trail @ Junction Rd	05/27/2016 13:25	22.4	66.7	2.5
S000-970 E2 - Snow Trail @ Junction Rd	05/31/2016 12:45	21.7	67.3	2.4
S000-970 E2 - Snow Trail @ Junction Rd	08/01/2016 11:55	26.9	103	
S000-970 E2 - Snow Trail @ Junction Rd	08/24/2016 12:05	31.2	94.9	
S000-970 E2 - Snow Trail @ Junction Rd	09/02/2016 12:25	24.6	72.3	
S000-970 E2 - Snow Trail @ Junction Rd	09/06/2016 12:20	26.1	71.2	
S000-970 E2 - Snow Trail @ Junction Rd	09/08/2016 13:40	24.1	74.6	
S000-970 E2 - Snow Trail @ Junction Rd	09/12/2016 12:00	26.0		
Storm/mine drainage	04/12/2016 13:25	177	600	32.9
Storm/mine drainage	04/15/2016 12:20	52.5	202	16
Storm/mine drainage	04/19/2016 14:30	47.1	184	15.6
Storm/mine drainage	04/24/2016 13:00	30.5	98	6.1
Storm/mine drainage	05/20/2016 10:15	148	478	31
Storm/mine drainage	05/23/2016 11:25	88.4	361	24.7
Storm/mine drainage	05/27/2016 13:50	75.9	261	19.3
Storm/mine drainage	05/31/2016 13:10	47.8	67	9.6

Location	Date	Calcium (mg/L)	Hardness (mg/L CaCO3)	Magnesium (mg/L)
Storm/mine drainage	08/01/2016 12:20	84.1	273	
Storm/mine drainage	08/24/2016 12:50	256	875	
Storm/mine drainage	09/02/2016 11:00	300	955	
Storm/mine drainage	09/06/2016 11:55	74.6	247	
Storm/mine drainage	09/08/2016 13:00	122	425	
Storm/mine drainage	09/12/2016 12:30	67.3		
WW pond	04/13/2016 10:54	23.1		
WW pond	04/18/2016 07:35	46.8		
WW pond	05/20/2016 10:03	56.1		
WW pond	05/23/2016 07:30	50.0		
WW pond	05/24/2016 13:00	55.8		
WW pond	09/06/2016 12:05	48.9		
WW pond	09/08/2016 12:05	47.2		
WW pond	10/06/2016 11:55	50.6		
Tower Harbor	03/29/2016 14:00	18.6		
Tower Harbor	04/18/2016 11:30	16.0		
Tower Harbor	05/12/2016 09:00	20.5		
Tower Harbor	05/20/2016 17:05	20.5		
Tower Harbor	05/23/2016 06:05	22.9		
Tower Harbor	07/27/2016 11:15	28.1		
Tower Harbor	08/02/2016 11:30	26.9		
Tower Harbor	09/02/2016 08:30	26.2		
Tower Harbor	09/06/2016 09:00	29.5		
Tower Harbor	10/21/2016 08:00	27.3		

Appendix-2

Sample Site	Date Sampled	Time	Water Temp (°C)	Spec Cond (µS/cm)	LDO % Sat	LDO (mg/L)	pH	STube (cm)
E2 - Murray Road	12-Apr-16		2.9	115	91.3	11.90	6.81	100
E2 - Murray Road	15-Apr-16	12:45	6.3	103	84.7	10.13	6.98	100
E2 - Murray Road	19-Apr-16	14:45	7.2	102	82.2	9.59	6.52	
E2 - Murray Road	25-Apr-16	12:30	4.0	104	77.0	9.55	6.66	
E2 - Murray Road	20-May-16	11:50	15.4	128	66.7	6.39	6.52	100
E2 - Murray Road	23-May-16	11:45	18.2	133	61.7	5.53	6.89	100
E2 - Murray Road	27-May-16	14:25	17.2	132	58.1	5.32	6.83	100
E2 - Murray Road	31-May-16	13:40	15.5	135	56.1	5.32	6.92	100
E2 - Murray Road	01-Aug-16	12:35	22.3	142	61.3	5.13	6.79	100
E2 - Murray Road	24-Aug-16	13:30	19.4	142	36.5	3.21	6.24	42
E2 - Murray Road	02-Sep-16	11:45	16.2	137	83.7	7.90	6.86	100
E2 - Murray Road	06-Sep-16	11:00	17.1	144	63.1	5.79	6.62	100
E2 - Murray Road	08-Sep-16	12:30	16.9	138	73.7	6.81	7.08	100
E2 - Murray Road	12-Sep-16	12:45	15.7	145	78.4	7.36	6.99	100
Pony Pasture	12-Apr-16		0.7	446	49.9	6.92	6.31	100
Pony Pasture	15-Apr-16	11:20	3.3	388	60.4	7.78	6.80	100
Pony Pasture	19-Apr-16	13:45	6.9	307	87.5	10.30	6.70	
Pony Pasture	25-Apr-16	13:30	3.7	331	74.9	9.36	6.92	
Pony Pasture	20-May-16	10:55	11.8	453	42.5	4.40	6.68	100
Pony Pasture	23-May-16	11:00	15.5	461	41.1	3.89	6.79	100
Pony Pasture	27-May-16	13:10	15.8	534	29.8	2.80	6.88	100
Pony Pasture	31-May-16	12:35	14.5	474	26.3	2.55	6.77	100
Pony Pasture	01-Aug-16	11:45	18.7	535	5.0	0.45	6.67	100
Pony Pasture	24-Aug-16	11:45	18.1	549	1.9	0.17	6.57	49
Pony Pasture	02-Sep-16	12:35	15.9	465	8.5	0.81	6.62	100
Pony Pasture	06-Sep-16	12:30	17.3	474	12.7	1.16	6.51	100
Pony Pasture	08-Sep-16	13:30	17.0	443	19.3	1.75	6.92	100
Pony Pasture	12-Sep-16	11:45	15.7	529	12.2	1.14	6.69	100
S000-967	14-Mar-16	10:45						100
S000-967	15-Mar-16	11:30	0.1	147	77.2	10.62	6.45	100
S000-967	17-Mar-16	12:00	0.0	78	67.3	9.27	6.01	
S000-967	22-Mar-16	14:35	0.3	94	80.9	11.10	6.06	100
S000-967	30-Mar-16	12:30	1.8	122	78.9	10.52	6.36	100
S000-967	12-Apr-16		1.0	119	86.3	11.83	6.65	100
S000-967	15-Apr-16	10:20	5.7	146	75.1	9.13	6.67	61
S000-967	19-Apr-16	13:00	7.3	107	75.9	8.84	6.52	
S000-967	21-Apr-16	13:35	8.4	113	70.3	7.97	6.56	100
S000-967	25-Apr-16	14:15	4.5	116	79.5	9.73	6.82	
S000-967	27-Apr-16	13:45	7.9	105	84.7	9.54	6.61	100

Sample Site	Date Sampled	Time	Water Temp (°C)	Spec Cond (µS/cm)	LDO % Sat	LDO (mg/L)	pH	STube (cm)
S000-967	12-May-16	11:00	12.5	127	80.8	8.21	6.62	100
S000-967	20-May-16	12:25	15.2	123	80.7	7.70	6.85	100
S000-967	23-May-16	10:30	18.3	139	70.0	6.27	6.78	100
S000-967	27-May-16	12:20	17.9	175	65.0	5.85	6.86	100
S000-967	31-May-16	11:55	16.2	173	62.2	5.58	6.80	100
S000-967	06-Jun-16	13:45	15.4	138	63.0	5.94	6.64	100
S000-967	13-Jun-16	11:50						100
S000-967	13-Jun-16	11:50						100
S000-967	20-Jun-16	15:00	21.6	137	69.8	5.96	6.59	100
S000-967	08-Jul-16	12:00	19.7	160	62.4	5.40	6.72	100
S000-967	08-Jul-16	12:00	19.7	160	62.4	5.40	6.72	100
S000-967	12-Jul-16	15:15	22.0	147	72.1	5.90	7.02	100
S000-967	25-Jul-16	11:20	22.2	162	76.8	5.94	7.04	100
S000-967	01-Aug-16	11:15	21.6	165	61.6	5.20	6.82	100
S000-967	24-Aug-16	11:00	22.3	193	51.1	4.20	6.92	100
S000-967	02-Sep-16	10:15	17.1	155	60.5	5.60	6.54	100
S000-967	06-Sep-16	12:50	18.9	189	51.6	4.57	6.64	100
S000-967	08-Sep-16	14:10	18.2	191	56.2	5.05	6.76	100
S000-967	12-Sep-16	11:15	16.8	211	57.9	5.31	6.81	100
S000-967	21-Sep-16	14:35	13.7	145	72.7	7.15	6.70	100
S000-967	12-Oct-16	12:20	9.9	189	75.1	8.13	6.68	100
S000-968	12-Apr-16		1.8	116	83.8	11.26	6.56	100
S000-968	15-Apr-16	11:00	6.0	141	73.8	8.88	6.64	100
S000-968	19-Apr-16	13:20	7.6	103	75.5	8.74	6.39	
S000-968	25-Apr-16	13:15	4.5	107	76.9	9.42	6.69	
S000-968	20-May-16	10:40	14.0	120	63.1	6.23	6.79	100
S000-968	23-May-16	10:50	18.2	137	56.9	5.10	6.65	100
S000-968	27-May-16	13:00	17.6	173	49.9	4.52	6.75	100
S000-968	31-May-16	12:15	15.9	165	49.4	4.64	6.67	100
S000-968	01-Aug-16	11:30	21.4	162	42.3	3.59	6.67	100
S000-968	24-Aug-16	11:25	21.6	185	43.8	3.64	6.77	100
S000-968	02-Sep-16	10:45	17.1	148	51.3	4.74	6.53	100
S000-968	06-Sep-16	12:35	18.7	189	40.2	3.56	6.54	100
S000-968	08-Sep-16	13:15	18.2	186	44.8	4.02	6.80	100
S000-968	12-Sep-16	11:30	16.9	208	46.0	4.21	6.71	100
S000-969	12-Apr-16							
S000-969	15-Apr-16	11:55	2.4	347	63.4	8.34	6.49	100
S000-969	19-Apr-16	14:15	4.8	290	64.1	7.95	6.39	
S000-969	25-Apr-16	14:00	3.1	376	64.2	8.16	6.63	

Sample Site	Date Sampled	Time	Water Temp (°C)	Spec Cond (µS/cm)	LDO % Sat	LDO (mg/L)	pH	STube (cm)
S000-969	20-May-16	11:30	13.1	534	20.9	2.11	6.52	100
S000-969	23-May-16	11:15	16.3	594	14.1	1.33	6.54	100
S000-969	27-May-16	13:00	15.6	574	16.7	1.57	6.64	100
S000-969	31-May-16	12:55	13.9	478	23.0	2.24	6.65	100
S000-969	01-Aug-16	12:05	19.0	564	2.3	0.21	6.55	100
S000-969	24-Aug-16	12:25	19.0	682	0.0	0.00	6.54	
S000-969	02-Sep-16	12:10	15.7	558	5.4	0.52	6.70	100
S000-969	06-Sep-16	12:05	17.6	528	9.3	0.85	6.56	100
S000-969	08-Sep-16	13:45	17.2	522	11.6	1.06	7.02	100
S000-969	12-Sep-16	12:15	15.5	594	1.2	0.11	6.70	100
S000-970	12-Apr-16		1.4	96	84.2	11.45	6.43	100
S000-970	15-Apr-16	11:35	7.1	94	79.4	9.35	6.67	100
S000-970	19-Apr-16	14:00	8.0	77	79.1	9.06	6.45	
S000-970	25-Apr-16	13:45	4.6	81	79.1	9.66	6.73	
S000-970	20-May-16	11:10	14.2	112	61.1	6.00	6.70	100
S000-970	23-May-16	11:10	18.1	123	49.3	4.44	6.69	100
S000-970	27-May-16	13:25	17.6	132	47.9	4.35	6.68	100
S000-970	31-May-16	12:45	15.9	129	48.0	4.51	6.71	100
S000-970	01-Aug-16	11:55	21.4	149	36.9	3.13	6.60	100
S000-970	24-Aug-16	12:05	22.1	174	26.8	2.21	6.71	100
S000-970	02-Sep-16	12:25	17.5	133	46.1	4.23	6.57	100
S000-970	06-Sep-16	12:20	18.8	143	35.8	3.17	6.45	100
S000-970	08-Sep-16	13:40	18.2	140	43.6	3.92	6.98	100
S000-970	12-Sep-16	12:00	17.0	145	41.3	3.77	6.70	100
Storm/mine drainage	12-Apr-16		6.8	1682	99.7	11.68	7.23	100
Storm/mine drainage	15-Apr-16	12:20	8.3	482	103.5	11.74	7.32	100
Storm/mine drainage	19-Apr-16	14:30	8.2	437	102.7	11.69	7.18	
Storm/mine drainage	25-Apr-16	13:00	4.9	244	93.0	11.26	6.92	
Storm/mine drainage	20-May-16	10:15	10.2	1377	108.3	11.64	7.49	100
Storm/mine drainage	23-May-16	11:25	10.1	827	105.5	11.30	7.43	100
Storm/mine drainage	27-May-16	13:50	10.3	651	97.3	9.39	7.34	100
Storm/mine drainage	31-May-16	13:10	12.7	488	92.7	9.34	7.04	100
Storm/mine drainage	01-Aug-16	12:20	15.1	662	90.0	8.69	7.51	30
Storm/mine drainage	24-Aug-16	12:50	13.3	2395	107.3	10.52	7.00	37
Storm/mine drainage	02-Sep-16	11:00	10.4	2810	109.7	11.67	7.18	100
Storm/mine drainage	06-Sep-16	11:55	15.5	637	90.0	8.52	7.03	100
Storm/mine drainage	08-Sep-16	13:00	14.1	1127	90.5	8.85	7.43	100
Storm/mine drainage	12-Sep-16	12:30	9.6	663	105.0	11.27	7.14	100
Trib @ Murray Rd	12-Apr-16		3.0	74	73.2	9.54	6.31	100

Sample Site	Date Sampled	Time	Water Temp (°C)	Spec Cond (µS/cm)	LDO % Sat	LDO (mg/L)	pH	STube (cm)
Trib @ Murray Rd	15-Apr-16	13:00	8.4	75	67.6	7.67	6.52	100
Trib @ Murray Rd	19-Apr-16	15:00	8.2	78	69.2	7.91	6.34	
Trib @ Murray Rd	25-Apr-16	12:45	4.8	78	66.4	8.07	6.40	
Trib @ Murray Rd	20-May-16	12:05	14.2	96	20.1	1.97	6.34	100
Trib @ Murray Rd	23-May-16	11:40	16.5	124	13.5	1.25	6.46	100
Trib @ Murray Rd	27-May-16	14:15	15.6	147	12.3	1.16	6.47	100
Trib @ Murray Rd	31-May-16	13:30	14.3	151	14.6	1.42	6.62	100
Trib @ Murray Rd	01-Aug-16	12:45	21.5	115	14.2	1.15	5.99	100
Trib @ Murray Rd	24-Aug-16	13:20	20.7	163	9.0	0.84	6.42	49
Trib @ Murray Rd	02-Sep-16	11:20	15.3	128	11.6	1.11	6.28	100
Trib @ Murray Rd	06-Sep-16	11:15	17.7	161	3.0	0.27	6.34	66
Trib @ Murray Rd	06-Sep-16	11:30	18.4	112	5.0	0.44	6.11	100
Trib @ Murray Rd	08-Sep-16	14:45	18.4	112	0.0	0.00	6.46	78
Trib @ Murray Rd	08-Sep-16	12:45	17.3	119	10.9	0.99	6.50	50
Trib @ Murray Rd	12-Sep-16	12:55	15.9	129	10.0	0.93	6.39	96