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Water Quality and Discharge of a Small Urban and Peri-urban Stream

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Abstract:

Stable isotopes ($\delta^{18}O$ and $\delta^{2}H$), geochemistry, and discharge analysis were conducted at six primary locations along Nose Creek and West Nose Creek from June 24 – September 4, 2009. Isotopes results showed lower $\delta^{18}O$ and $\delta^{2}H$ values towards the mouth site (NC1) due to depleted inputs from West Nose Creek, stormwater outfalls, and groundwater infiltration. Stagnant flow upstream of Airdrie (NC5) is subjected to greater amounts of evaporation; therefore samples appear to have higher $\delta^{18}O$ and $\delta^{2}H$ values. Results from the study show there is no flow upstream of Airdrie, suggesting that the watershed area north of NC5 does not contribute to the mainstem during the study period. Chloride mass flux of the creek increases towards the mouth site (NC1). Mass flux is controlled by discharge where an increase in discharge occurs without a dilution in [Cl]. Increased discharge and consistent contributions of [Cl] are assumed to be from stormwater outfall inputs. Grab sampling showed E.coli, TSS (total suspended solids), and TDS (total dissolved solids) levels exceeding guidelines at all six sites. Continuous monitoring was observed at two sites (NC5 and NC1) where dissolved oxygen levels fluctuated above and below guidelines on a daily basis. pH at NC5 was also above guidelines until late July. West Nose Creek, a significant tributary to the main stem, has overall better water quality and showed less variability in geochemistry, discharge, and isotope results. Licensed withdrawals within the upper watershed (upstream of NC5 and WNC) have similar withdrawal rates, however the mainstem appears to be more impacted where no flow exists upstream of NC5.

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Table of Contents:

List of Figures and Tables (See attached):

Introduction:

Small creeks are susceptible to rural, peri-urban, and urban impacts on both flow and water quality. Nose Creek, a Bow River tributary, originates in a rural area, and traverses two towns prior to entering the City of Calgary, within which it discharges to the Bow River (Figure 1). Nose Creek water quality is particularly important since it discharges on the north bank of the Bow River slightly upstream of the water withdrawal for the Western Irrigation District Canal, as well as the Pierce Estate Park Fishery. Previous studies by Cross, 2001, have shown the water quality of the creek is an ongoing issue with various parameters such as dissolved oxygen (DO), temperature, total suspended solids (TSS), total dissolved solids (TDS), and bacteria levels which tend to show significant departure from desired levels (Cross, 2001). Various water quality parameters have been monitored by ongoing partnerships between the City of Calgary, the City of Airdrie, the Municipal District of Rocky View, and Alberta Environment since the mid 1990s with sparse data from the 1980s.

Nose Creek discharge was gauged at the mouth by the Water Survey of Canada between 1911 and 1919. The flows were highly variable (ranging from 0.074 to 54.9 m^3/s, avg=1.68 m^3/s, median=0.58 m^3/s, std dev=3.59 , n=1893) with little seasonal variation evident, and clear excursions due to storm events (Figure 10a). Given the City of Calgary was undeveloped around Nose Creek, this likely represents natural flow. More recent discharge data shows the creek at the mouth has very low to no flow on almost a semi-annual basis, with higher discharge observed in late spring and early winter that was not apparent earlier in the century (Figure 10b). This suggests the stream discharge has been highly affected by development since the early 1900s.

Nose Creek water quality is poor due municipal and industrial surface runoff, storm water outfalls, and agricultural and ranching lands (Cross, 2001). Urban inputs along the creek are presumed to be mainly from stormwater outfalls and ponds including 25 in Airdrie (Moxham, 2002), and 72 outfalls (58 in the mainstem, and 14 in West Nose Creek) in Calgary (City of Calgary, personal communication). The West Nose Creek tributary is entirely rural upstream of Calgary. The Town of Crossfield has a wastewater lagoon located alongside the creek where treated wastewater is released on a scheduled basis (Moxham, 2002). Typically stormwater outfalls only flow during storms, however outfalls that flow continuously (i.e. 'baseflow') can affect the discharge of the creek.

Previous research by Grasby et al, 1997, was completed on water isotopes ($\delta^{18}O$‰ and $\delta^{2}H$‰) along the mainstem and West Nose Creek. Samples showed significant changes in $\delta^{18}O$ isotopic signatures between sampling points upstream of Airdrie (-12.51‰) and the mouth at the Bow River (-19.02‰). The Bow River had a $\delta^{18}O$ value of -18.80‰. The significant changes in isotopic values along the mainstem were attributed to infiltration of Bow River water via stormwater discharge or the leakage of municipal water supply into the creek via groundwater. More recent work on groundwater springs found an average isotopic composition of groundwater of -18.0 $\delta^{18}O$‰ (Green, 2007), suggesting groundwater may also be contributing to the stream flow.

This study measured creek discharge, isotopic composition, and geochemistry to evaluate changes in water quality and discharge at six primary sites between Airdrie and the mouth (Figure 1). Sampling consisted four 'seepage runs', with measurements of both discharge and water quality at all six primary sampling locations conducted in a single day. The seepage runs were supplemented with occasional grab sampling from stormwater outfalls, ponds, and the creek.

Chloride mass fluxes of the creek were used to further understand anthropogenic inputs into the creek. Mass flux refers to the mass of a specific dissolved solute, which passes through a unit area per unit time (Fetter, 1999). Chloride was used as the dissolved solute as it is a non-reactive, conservative ion. Chloride ions will not adsorb to minerals or organic surfaces and do not form insoluble precipitates. As well, chloride is used for many applications and can be added to surface waters via road salting, animal wastes (agriculture), sewage, and industrial discharges (Fetter, 1999). Chloride can also be added to surface waters from soil and mineral weathering (Cross, 2001). Therefore, chloride concentrations in groundwater are assumed to be from weathering or leaching of salts into the subsurface. Groundwater chloride concentrations range from 3 to 43 mg/L (avg = 11.43 mg/L, median = 7.53 mg/L, standard deviation = 12.24, n = 17), suggesting some anthropogenic influence (Green, 2007). Creek water with chloride concentrations exceeding background/groundwater levels would indicate anthropogenic inputs such as road salts, agricultural runoff, sewage, and/or industrial discharges.

In addition to the seepage runs and grab sampling, continuous monitoring was completed at two locations (NC5 and NC1; Figure 1) for a more detailed evaluation of water quality.

Site Description:

Nose Creek is a tributary located in the Bow River Basin, in Southern Alberta. The basin has a dry-subhumid climate with drier winters and more humid summers

(Grasby et al, 1997). The annual precipitation of the area is approximately 443mm, whereas the annual potential evaporation is approximately 771mm (Ozoray and Barnes, 1977). Nose Creek has one main tributary, West Nose Creek, which inputs into Nose Creek within Calgary City limits.

The subsurface geology of the area consists of pre-glacial alluvial and lacustrine deposits. Both the main tributary and West Nose Creek cut through lower surficial deposits composed mainly of clays, silts, and fine sands (M.D of Rocky View No 44). The groundwater in the area, which recharges both Nose Creek and West Nose Creek, is of Paskapoo formation origin, specifically the Dalehurst member (Figure 2).

Materials and Methods:

Grab samples were collected at the six primary sites on four 'seepage run' days throughout the summer (June 24, July 15, July 28, and August11). Field parameters tested at each site on these days included DO, pH, EC, and discharge. Equipment used to measure field parameters was kept consistent throughout the summer. Both DO and temperature were measured using a YSI ProODO where upon the probe was submerged in flowing water to stabilize for at least 30 seconds. Sites were sampled in the same order on all four days to get similar times for DO measurements given its diurnal variability (Figure 9). The pH of each site was measured using an Accumet AP62 model with a double junction combination electrode. The pH meter was calibrated before each use using a two-point calibration method (pH 7 and 10). The pH electrode was immersed in flowing water and stirred until the reading was stabilized. EC was measured in the field using the VWR model 2052 (2% temperature compensation). The EC probe was calibrated before each use, using 1000uS/cm standard solution. The EC probe was immersed in water and stirred until reading was stabilized.

Creek discharge was estimated by stream-gauging the creek using the velocity-area method (Sanders, 1998). The creek was divided into at least ten sections, where sections were of equal length. A SonTek flowtracker handheld ADV was used where a velocity meter was placed between depth measurements. Velocity measurements were completed at sixty percent of the total depth (Sanders, 1998). The same transect was used for each of the four sampling days. Specific transects across the creeks width were selected because they gave the best stream channel profile for each site.

Two grab samples were taken from each site for lab analysis; 500ml for alkalinity, ion chromatography (IC), stable isotopes, *E.coli* and total coliform, and 1000ml for TSS. Samples were kept in a cooler with ice packs throughout the day. Duplicate samples and/or trip blanks were completed on grab sampling days for quality assurance/quality control to minimize error introduced in the lab or field. Major anions and cations were analyzed with a Dionex model ICS-1000 ion chromatograph. Both anions and cations used a self-regenerating suppressor. Anions were run using an ASRS 300 4mm suppressor model along with an IonPac AS14 column. Cations were run using a CSRS 300 4mm suppressor along with an IonPac CS12A column. Both diluted and undiluted filtered cation and anion samples were ran through the IC where samples were filtered within 12 hours of sample collection with 45um cellulose nitrate filter papers. Results from major cation and anion concentrations were plotted using AquaChem. Chloride mass fluxes were estimated as:

Flux = [Cl]/[Q]

Where [Cl] is chloride concentration (in kg/m^3) and Q is discharge (m^3/day).

Alkalinity analysis was determined in the lab within 24 – 48 hours post field collection using a HACH Digital Titrator 1600 model. Total coliform and *E. coli* tests were analysed within 24 hours of sample collection using the IDEXX Colilert 24 hour test with the Quanti-tray/2000 (97) tray method. Conditions were kept sterile while performing total coliform and E. coli tests to prevent any cross contamination. TSS was measured by filtering between 250 – 1000 ml of sample through glass filter paper. Filter papers were kept in dry storage and were weighed prior to vacuum-filtering the sample. The volume of sample filtered depended on how much sample clogged the filter paper with sediments. After filtering was complete, filters with added sediment from samples, were placed in oven and left at 105°F overnight then weighed the next day.

Stable isotopes were sampled during 'seepage runs' at the six primary sites. Samples were analyzed for δ^{18}O‰ and δ^{2}H‰. Further grab sampling was completed on Nose Creek in addition to 'seepage run' sampling. Two transects were sampled on July 23, 2009; between JXN – NC2 (Appendix 8), and on July 24, 2009; between NC5 – NC4 (Appendix 9). These transects were sampled to measure δ^{18}O‰ and δ^{2}H‰ and chloride concentrations. Samples were collected from Nose Creek, as well as from accessible inputs (stormwater outfalls and ponds). Grab samples were also collected on September 4, 2009 from headwater sites located in Figure 1, along with outfalls located at WP007, WP013, and WP014_SWP (Appendix 8, 9). Two samples were collected at NC5 on September 4th, 2009, one at the NC5 site, and the other just downstream of WP013. Waypoint (WP) locations were determined by using a handheld Garmin eTrex High

Sensitivity GPS unit. Isotopes were analyzed in a separate isotope lab located in the physics department at the University of Calgary.

Continuous monitoring was conducted at NC5 and NC1 (Figure 1). Datasondes were installed in stilling wells (1.8m high, 15 cm diameter, 1/4" holes drilled in the lower portion) on June 23, 2009. Steel collars were placed around the well stilling, and 't-posts' hammered 3 ft into the creek subsurface. Stilling wells were strategically placed in areas of the creek where flow was continuous, even in low flow. The well at NC1 was knocked over three times by high flow before it was replaced with lighter ABS casing and steel posts to hammer it down. No data were collected from the datasonde at NC1 during that time. The datasonde at NC5 (where flow is low, if not stagnant) was functional throughout the summer. Continuous monitoring was collected at NC5 by a YSI 600XLM and at NC1 by a Hydrolab MS5 where temperature, DO, EC, pH, and relative stage were collected every 30 minutes. Both datasondes were calibrated in the field every two weeks and batteries were replaced.

Results:

Discharge:

Stream-gauging measurements from seepage run sampling showed variations in discharge throughout the summer (Figure 3a). The discharge at NC1 was consistently high whereas NC5 was consistently low. Flow at NC5 was so low that field measurements on July 28th, 2009 gave negative discharge values suggesting upstream flow. This observation is consistent with a previous Nose Creek water quality study completed (Schonekess, 1981), which stated that the mainstem of Nose Creek was a slower moving creek with "pond-like" stretches. This is similar to what was observed in the stretches upstream of NC5 where the creek is "pond-like" with little to no flow.

Approximately 350m downstream of the NC5 site, the City of Airdrie has two outfalls that input into the creek (WP 013, Appendix 9). Of the two, the most upstream outfall was continuously running between June - September (no data collected post September 4, 2009). Just downstream of these outfalls was the first observation of any flow in the mainstem. Throughout the City of Airdrie there are numerous stormwater outfalls and ponds that input into the creek however the exact volume of discharge from these inputs was not estimated. An increase in flow between NC5 and NC4 was observed on all four stream-gauging days (Figure 3a), which indicates inputs from the City of Airdrie. Discharge increases within this reach ranged from 0.12 to 4.6×10^{-4} m^3/s (Appendix 10).

Discharge results show an overall increase in flow between NC5 and NC1. The most significant increase in flow occurs between the NC2 and the JXN and was observed consistently throughout the summer. NC2 has relatively low flow (ranges between 0.03 – 0.18 m^3/s) whereas the JXN site has an overall higher flow (ranges between 0.21 – 0.62 m^3/s). The input of West Nose Creek is considered for the increase in discharge (average = 0.11 m^3/s), however it does not account for the total increase. Further investigation was completed along the stretch between NC2 and the JXN to record any visible signs of discharge input. Along the stretch there are seven outfalls (N38 – N44), most which are not accessible (e.g. located on private land). One outfall, N38 (Appendix 7) was continuously flowing throughout the summer (and into the fall up until it was last checked on November 12, 2009). The contribution from this outfall alone (although not gauged) appears to be significant (Appendix 11), and possibly accounts for some increase in discharge along the NC2 – JXN stretch. Additionally, fourteen unobserved outfalls are located between the WNC – JXN stretch, which could also contribute to the increase in flow observed at the JXN. Lastly, discharge results show a significant increase in flow observed between the JXN and NC1 on July 15th, 2009, which occurred after a series of heavy rain events. This is likely due to stormwater discharge, and not stormwater baseflow.

The increased flow throughout the creek is apparently contributed from an increased number of stormwater outfalls located within the City of Calgary limits (Appendix 7). The field visits along the mainstem, upgradient of Airdrie, revealed little to no flow in the mainstem above Airdrie, and a dry creek bed above Crossfield. It thus appears that Nose Creek mainstem water is primarily from urban inputs with little groundwater infiltration. Stormwater introduced into West Nose Creek occurs within the City of Calgary. Upstream of WNC shows consistent groundwater input since water exists in the creek bed and appears to have low flow (not gauged).

Licensed withdrawals (Table 2) from Alberta Environment were investigated where a volume of 2.86 x 10^6 m^3/year is legally withdrawn from the creek throughout the watershed. Withdrawals north of Airdrie extract a volume of 3.37 x 10^5 m^3/year, while withdrawals north of WNC extract a volume of 2.72 x 10^5 m^3/year. Both upstream areas (upstream WNC and NC5) have similar withdrawal rates, however the mainstem appears to be more impacted, where no flow exists at NC5, and a dry creek bed upstream of Crossfield.

Historical discharge data from 1911-1919 was plotted and shows the fluctuations in discharge over an 8-year period when the creek had low development impacts and thus likely represents natural flow (Figure 10a). Discharge rates during this period showed an average of 1.68m^3/s, where flow rates rarely dropped below 0.1m^3/s. In contrast, more recent historical data was plotted from results between 1972-1986 when the creek was more impacted by development and licensed withdrawals (Figure 10b). The average discharge rate during this 14-year period was 0.27m^3/s, where flow rates dropped well below 0.1m^3/s on a regular basis. The change is discharge from the 1919 – 1972 suggests stream discharge has been highly affected by development since the early 1900s. Historical data was obtained by the Water Survey of Canada.

Chloride Mass Flux

Consistently high chloride concentrations (43 - 90 mg/L) were observed, with no consistent trend observed between sites (Figure 3b). Creek discharge consistently increased with creek flow distance over all four days of stream-gauging, with the largest increase between NC2 and the JXN site (as discussed previously). The chloride mass flux also increases with flow distance (Figure 3c). If precipitation or groundwater (with median chloride concentrations of about 7 mg/L; M.D. Rocky View, 2002) were the main sources behind the increased flow, a dilution, or decrease, in the chloride concentrations would occur. The increase in chloride mass flux towards the mouth of Nose Creek indicates consistent high-chloride concentrations in water inputting into the creek. This concludes that there is increased discharge from stormwater outfalls, which are also contributing chloride to the creek since no dilution in the conservative ion is observed.

Chloride sources are assumed to be mainly from sewage, agricultural runoff, and road salts. To investigate this further, stormwater outfalls, which appeared to be continuously flowing over the summer, were sampled for chloride concentrations and stable isotope analysis. Stable isotopes were analyzed along with chloride to help determine the source.

Stable Isotopes

Results from isotope analysis indicate that the mainstem has lower $\delta^{18}O$ and $\delta^{2}H$ values towards NC1 (average = -15.9 $\delta^{18}O$‰), (Figure 4). Low $\delta^{18}O$ and $\delta^{2}H$ values seen at NC1, contrast to higher $\delta^{18}O$ and $\delta^{2}H$ values observed at NC5 (average = -11.1 $\delta^{18}O$‰) where $\delta^{18}O$ and $\delta^{2}H$ values increase due to evaporative effects on low flow water (NC5). During evaporation the principle observation is that water becomes progressively enriched in both water $\delta^{18}O$‰ and $\delta^{2}H$‰ (Clark and Fritz, 1997). As the main Nose Creek stem begins to flow, less evaporation occurs, resulting in more depleted (lower value) samples. West Nose Creek (average = -16.6 $\delta^{18}O$‰) inputs at the JXN site (average = -15.7 $\delta^{18}O$‰), which lowers the isotopic signature of the mainstem and hence the large decrease in values seen between NC2 and JXN (Figure 4). Depletion also occurs along NC2 to JXN stretch because water with lower $\delta^{18}O$ and $\delta^{2}H$ values is continuously inputting from outfall N38 (-17.2 $\delta^{18}O$‰) (Figure 5b). The stretch between NC5 – NC4 shows similar results where lower $\delta^{18}O$ and $\delta^{2}H$ values were observed at NC4 (average= -14.2 $\delta^{18}O$‰) versus NC5 (average = -11.1 $\delta^{18}O$‰), (Figure 4). Isotope samples were further collected between NC5 – NC4 (Figure 5a). Isotope results from the NC5 – NC4 stretch showed a large decrease in $\delta^{18}O$ and $\delta^{2}H$ values slightly downstream of NC5 (WP013, Appendix 9), as well as downstream of a continuously flowing City of Airdrie outfall. This outfall was sampled on September 4, 2009 where a low value of -16.2 $\delta^{18}O‰$ was measured (Figure 5a). Further investigation into the number of continuously flowing outfalls, as well as their discharge rates, will help determine the impact these outfalls have on the isotopic signature of the creek.

Results from isotope samples from West Nose Creek and the mainstem were plotted with groundwater samples (Green, 2007) and Bow River samples (Hogue, 2009) against the Local Meteoric Water Line (Peng et al, 2004), to help determine the source water for the creek, and observe evaporative effects (Figure 6). West Nose Creek samples are similar to groundwater samples, where both show consistently lower $\delta^{18}O$ and $\delta^{2}H$ values. In contrast to West Nose Creek, stagnant water upstream of Airdrie (higher $\delta^{18}O$ and $\delta^{2}H$ values) plots further away from the line indicating greater evaporative effects (Peng et al, 2004), (Figure 6).

The study found that isotopically the $\delta^{18}O‰$ and $\delta^{2}H‰$ signature of the mainstem is affected by stormwater outfalls, particularly from continuously flowing outfalls. As a result, it was concluded that continuously running outfalls, West Nose Creek's input, groundwater infiltration, and decreased amounts of evaporation subjected to the creek, all influence the lower $\delta^{18}O$ and $\delta^{2}H$ values seen in the isotopic signature of Nose Creek towards the mouth (NC1) site. This conclusion opposes the original assumption from the study done by Grasby, et al, 1997, where it was assumed that the lower $\delta^{18}O$ and $\delta^{2}H$ values occur as a result of Bow River water infiltration from high-pressure water pipes within the City of Calgary and City of Airdrie.

Geochemistry

Grab sampling from seepage runs showed increased chloride concentrations (Figure 3b), indicating inputs from anthropogenic sources, which was previously discussed in the chloride mass flux section of this paper. Results from major cations and anions were plotted on piper plots to observe any trends or mixing occurring between sites (Figure 7). Results from surface water samples were compared to the groundwater chemistry from a regional groundwater assessment for the M.D of Rocky View No. 44 (Appendix 6). The mainstem geochemistry ranges from Ca-Mg-HCO_3 (similar to West Nose Creek) to Na-SO_4, with increasing chloride component. West Nose Creek shows geochemistry closer to that of groundwater, with lower chloride concentrations (Figure 7, Appendix 6). Piper plot results therefore suggest that West Nose Creek is less anthropogenically impacted, in contrast to the mainstem.

Major cation and anion analysis showed a large variability in concentrations between the sampling days (Figure 8). Results show an overall decrease in [Na^+] and an overall increase in [Ca^{2+}] towards the mouth site. However, no significant trend in cations or anions was seen.

The average grab sampling results from the six primary sites are recorded in Table 1. Results showed a large variability between sites, as well as within each site, on various sampling days (hence the large standard deviations observed in Table 1). Sites consistently exceeded concentrations in TDS (> 500 mg/L), however no single ion concentration exceeded guidelines. The EC exceeded healthy levels (> 1.0 mS/cm) at all sites, excluding WNC, where a higher concentrations of TDS could result in a high EC. Results from TSS showed unhealthy levels in all six primary sites excluding WNC again. Results from TSS and TDS of WNC, showed a healthier water quality than the main stem

(Table 1), which further indicates groundwater as a significant source, in contrast to urban inputs in the mainstem. NC1 site had the greatest variability in TSS where levels ranged between 13 – 103 mg/L. The high concentration in TSS suggests increased stormwater outfall inputs since stormwater runoff is typically high in suspended solids (Moxham, 2002). Results from pathogen indicators indicate elevated levels of *E.Coli* at sites closest to agricultural impacts (WNC and NC5, Figure 1). The remaining sites showed *E.Coli* levels exceeding recreational guidelines on a regular basis with the exception of NC4. Total coliform levels were consistently highest at NC1, where levels were above detection limit on all four sampling days over the summer. Increased bacteria counts are also indicative of increased stormwater runoff (Moxham, 2002). Results from DO and pH were variable throughout the summer where at times unhealthy levels were recorded (Table 1).

Continuous Monitoring

Continuous monitoring was completed at two sites (NC5 and NC1) to record parameters at the most upstream site (NC5), and most downstream site (NC1). Parameters recorded at both sites included DO, EC, pH, relative stage, and temperature (Figure 9). DO concentrations fluctuate to unhealthy levels (< 5mg/L, > 9.5 mg/L) at both NC1 and NC5 site, however little data is collected from NC1 due to high flow interfering with data collection. EC is consistently high at both sites (> 1.0 mS/cm) where an apparent decrease occurs during increased relative stage from dilution due to rain events. Unhealthy levels of pH (> 9) are observed at NC5 up until late July. Water flow at NC5 is considered stagnant due to the low discharge observed at the site (Figure 3a). Low recirculation of water at NC5 is considered for the low DO levels (< 5mg/L) at the site. Fluctuations to extremely high DO levels (>> 9.5 mg/L) at this site are assumed to be influenced by dissolved nutrients such as phosphate and/or nitrate where excessive nutrients in water can effect oxygen concentrations through photosynthesis/respiration and decay of organic matter (Cross, 2001). Further investigations into the nutrient concentrations at this site should be analyzed to explain the large DO fluctuations.

Conclusion:

The watershed area north of NC5 did not contribute significant flow to the main stem between late June and mid-August, 2009. Creek water in the upstream stretches (above NC5) is mainly stagnant (or absent above the Town of Crossfield) because of the low discharge rates. Baseflow discharge and geochemistry in the main stem below NC5 varies both temporally and spatially, suggesting multiple and variable influences. This is in strong contrast to the main tributary, West Nose Creek, which has relatively constant discharge and geochemistry. This is somewhat puzzling given the West Nose Creek watershed land use is reasonably similar to that of the mainstem above NC5.

Although licensed withdrawals and discharges into the mainstem could be partially responsible for the variable flow, the total annual licensed withdrawal in the watershed is 2.85×10^6 m^3/year (Table 2). This would be equivalent to a constant flow of approximately 0.09 m^3/sec. The licensed withdrawals above Airdrie (336,708 m^3/year) and above the WNC sampling point (271,607 m^3/year) are similar.

Geochemically, West Nose Creek is also distinct from the mainstem. The mainstem geochemistry ranges from Ca-Mg-HCO_3 (similar to West Nose Creek) to Na-

SO_4 with increasing chloride component. Mainstem water isotopes vary from high (evaporated) values at NC5, to increasingly lower values as sampling points approach the mouth. Inputs from stormwater outfalls, West Nose Creek, and groundwater infiltration contribute more depleted waters to the main stem. The isotopic composition, combined with geochemistry and discharge measurements, implies that mainstem water is mainly comprised of stormwater base flow (i.e. leaking water and/or wastewater pipes, groundwater infiltration), direct groundwater infiltration, and West Nose Creek inputs.

Continuous monitoring and grab sampling along the mainstem indicated that water quality guidelines are frequently exceeded.

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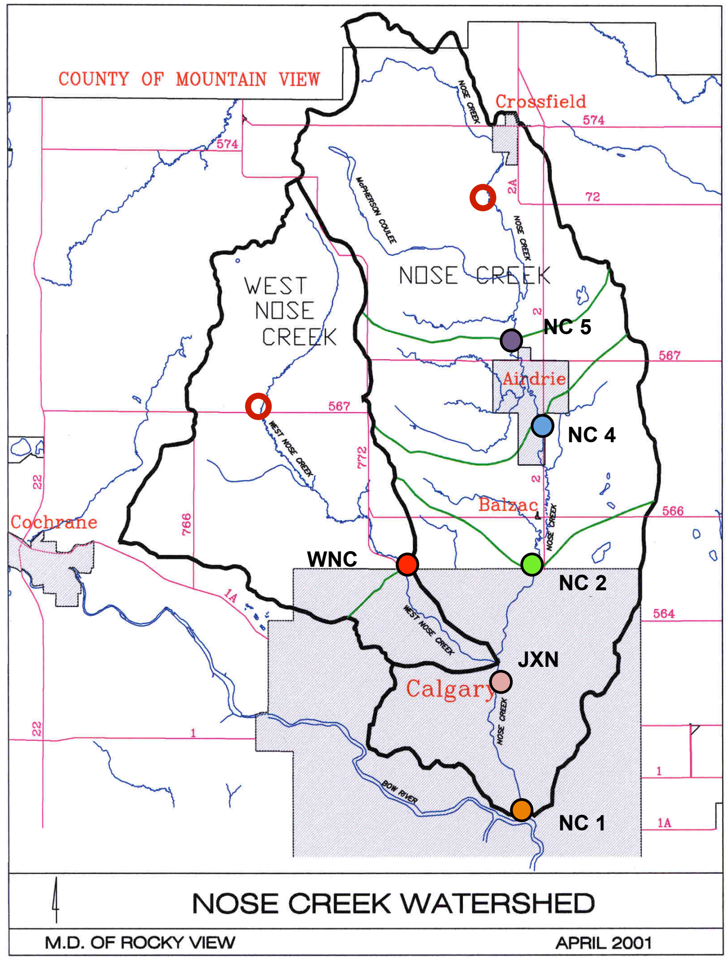


Figure 1: Map of Nose Creek Watershed and site locations. Six primary sites were used from June – August (NC1, NC2, WNC, JXN, NC4, NC5). NC1 is located at the mouth of the Bow River whereas NC5 is north of Airdrie. WNC is the only site upstream of urban inputs where NC5 experiences effects from Crossfield. The JXN site refers to the junction of West Nose Creek and the main Nose Creek stem. Sites labeled with open circles were sampled on September 4, 2009 for headwater geochemistry and isotopes. Headwater sampling sites were selected based on where water was first observed in the creek bed at an accessible point.

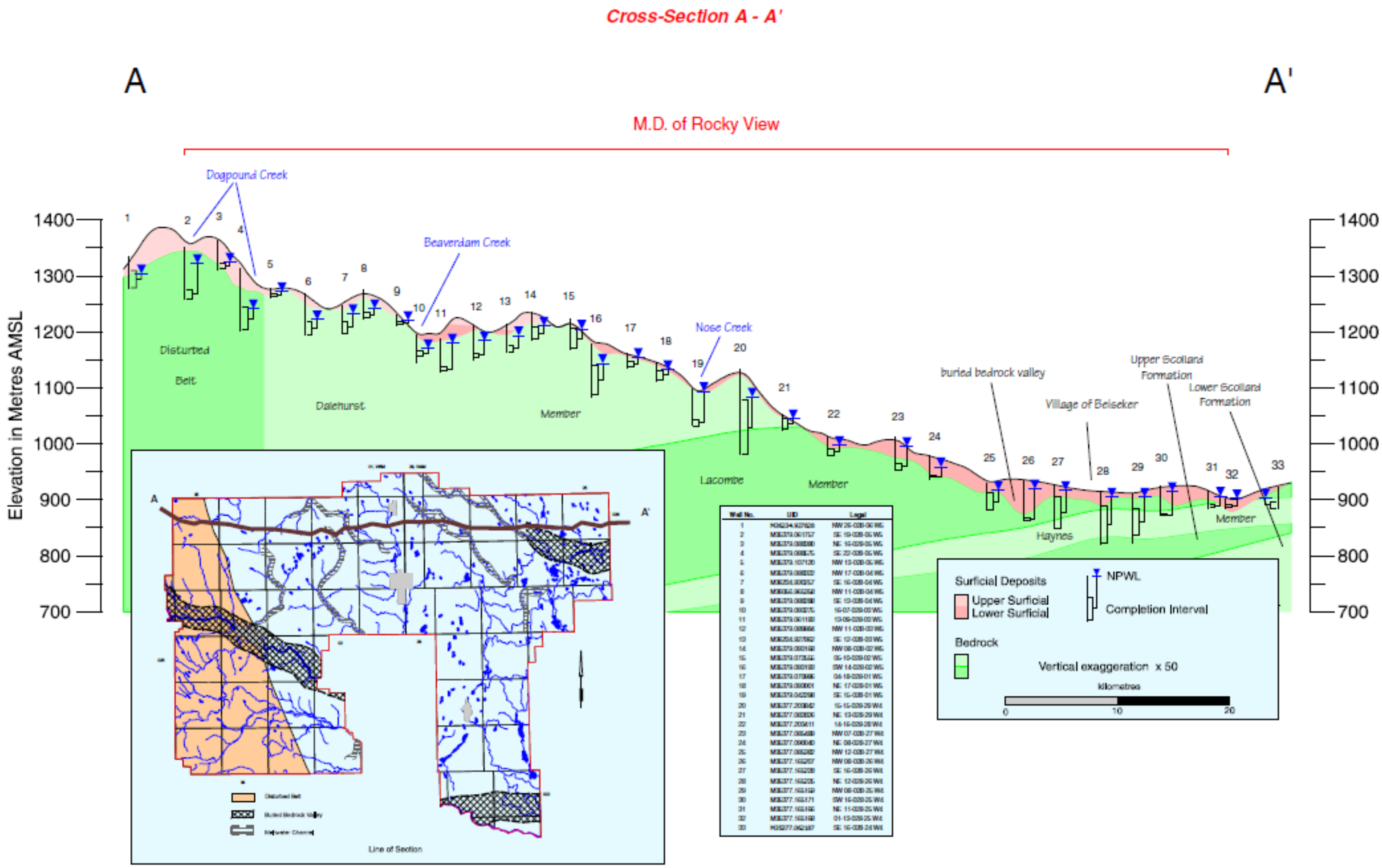
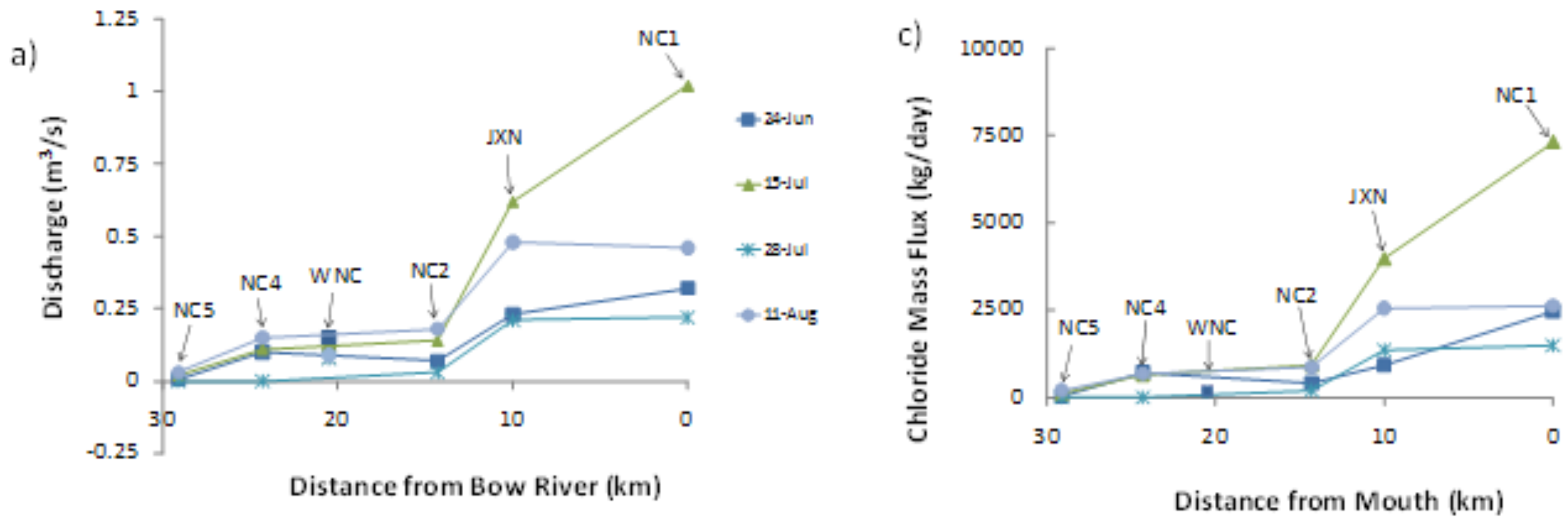


Figure 2: Cross section of Nose Creek subsurface geology. Nose Creek cuts through lower surficial deposits which are underlain by Dalehurst member of the Paskapoo Formation. West Nose Creek cuts through the same lower surficial deposits (MD Rocky View No. 44, Regional Groundwater Assessment, 2002).



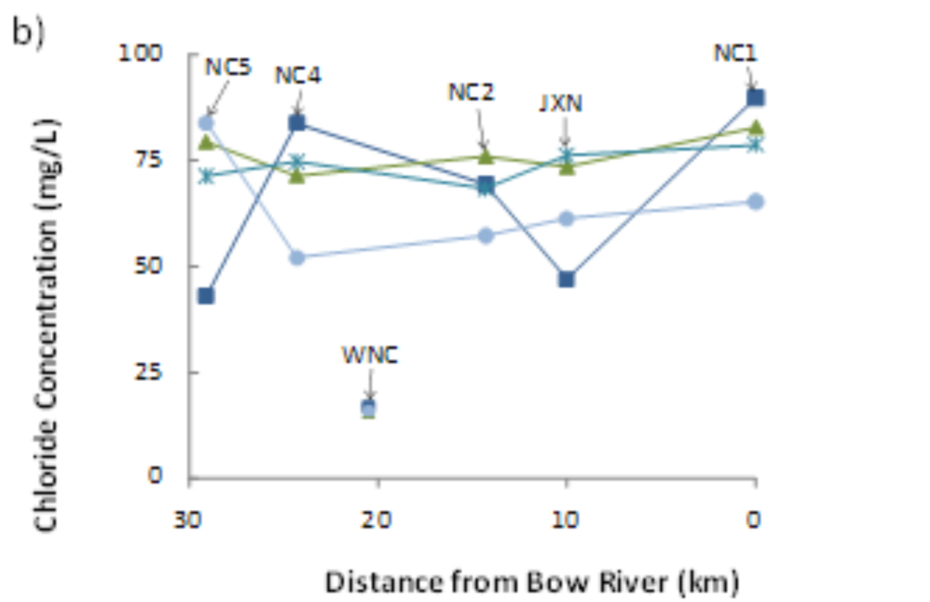


Figure 3: Chloride mass flux vs distance (c) is determined from the discharge (a) and chloride concentrations (b) measured on the corresponding sampling days. Sampling locations along the main Nose Creek stem are plotted as a line whereas West Nose Creek is plotted as a point. Separate lines indicate different sampling days from June 24 – August 11, 2009. The chloride mass flux of the creek shows similar trends to the discharge therefore it is discharge controlled. Discharge data shows no flow upstream of NC5, where negative discharge was measured on July 28. Discharge increases towards the NC1 site. Chloride concentrations are variable in the main stem (fluctuate between 43 – 90 mg/L) and are consistent in West Nose Creek (15 – 17 mg/L).

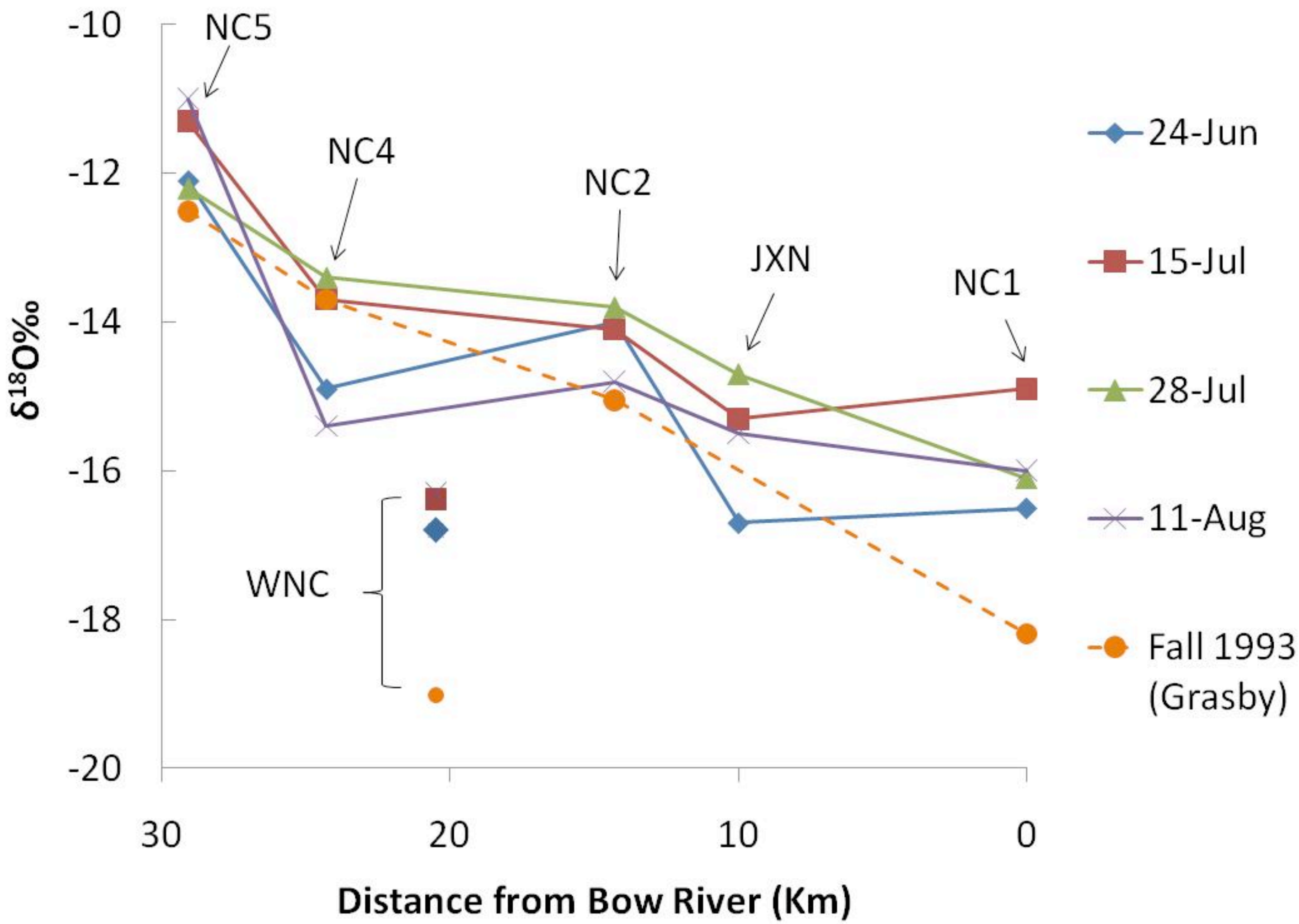


Figure 4: $\delta^{18}O$‰ plotted over distance on four separate sampling days from June 24 – August 11, 2009. Samples have higher $\delta^{18}O$‰ values at NC5 and lower $\delta^{18}O$‰ values at sites closer to the mouth (NC1, JXN). WNC shows consistently lower $\delta^{18}O$‰ values and inputs at the JXN site, therefore showing an overall depletion from NC2 – JXN site. Data from Grasby, et al, 1997 shows similar trends with lower $\delta^{18}O$‰ values towards the NC1 site.

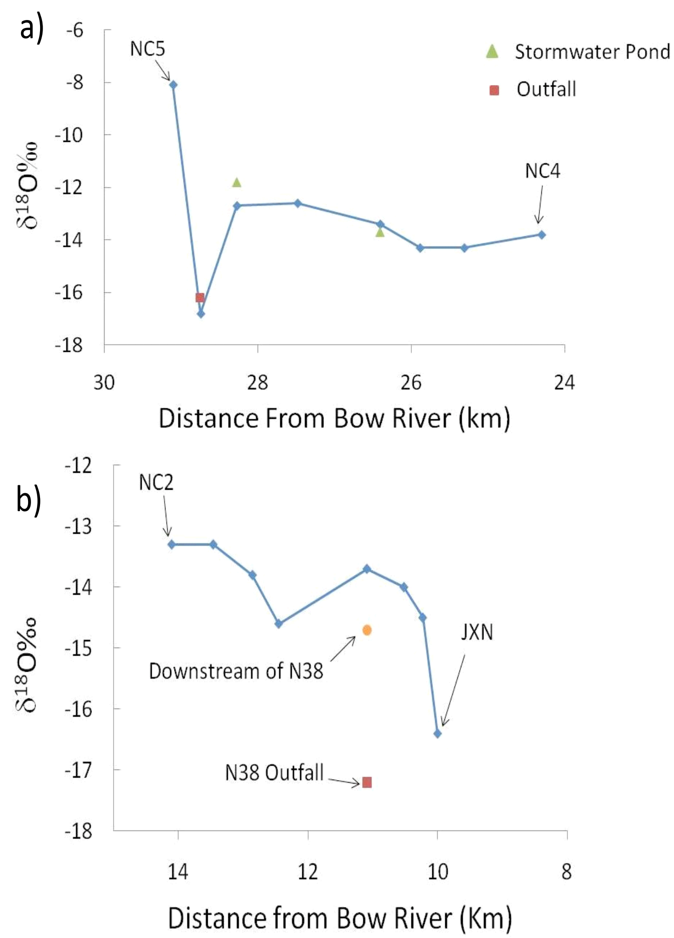


Figure 5: δ^{18}O‰ plotted over distance from Bow River. Two separate stretches along the main Nose Creek stem were completed on July 23, 2009 (b) and July 24, 2009 (a). Samples collected from the creek are plotted as a line, where as outfalls and stormwater ponds are plotted as points. Samples collected just downstream of outfalls were also plotted as a point. The sampling stretches were completed between site NC5 – NC4 (a) and NC2 – JXN (b) to determine where depletion in isotopic signatures occurred. The JXN sample (b) was collected just downstream of where WNC inputs, therefore WNC's depleted signature (Figure 4) should also be taken into account for the significant depletion observed between NC2 – JXN. The outfall sample collected downstream of NC5 (a), along with outfall N38 (b), flowed continuously throughout the study period (June 24 – Sept 4 (a), June 24 – Nov 12 (b)).

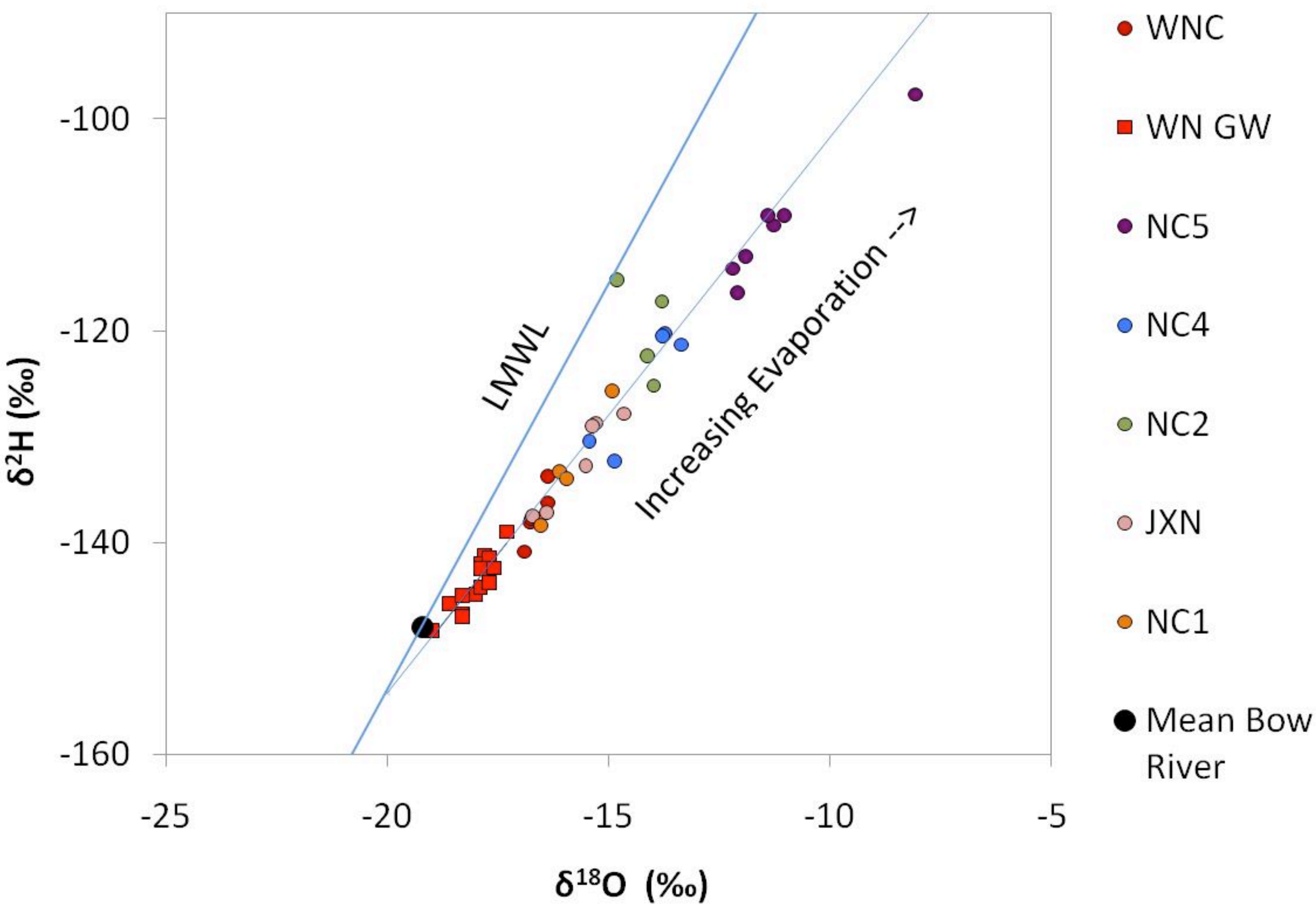


Figure 6: $\delta^{18}O$‰ and $\delta^{2}H$‰ are plotted against each other from surface water samples (2009) with West Nose groundwater samples (Green, 2007). Samples show deviation from Local Meteoric Water Line (LMWL) (Peng et al, 2004), which indicates evaporation (Clark and Fritz, 1997). NC5 undergoes the most evaporation due to low flow water (stagnant). Results from the Bow River are from Hogue, 2007, and show no deviation from LMWL. West Nose groundwater samples show slight deviation and are similar to West Nose Creek surface water samples. Source water is considered to be from local precipitation, Bow River, or groundwater.

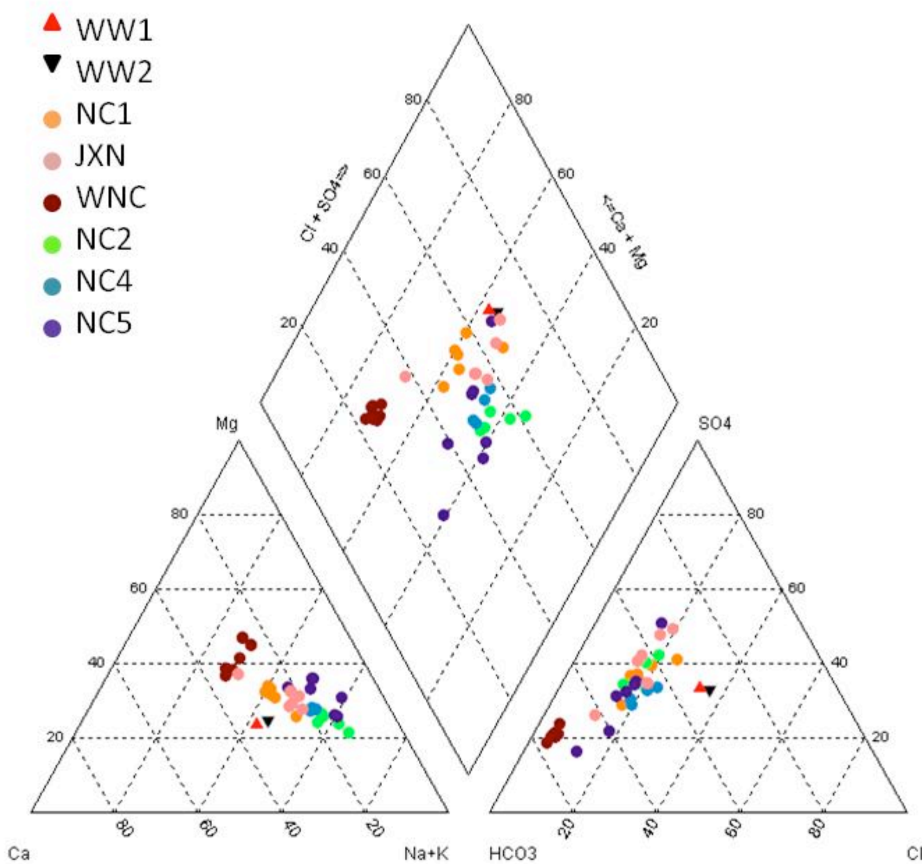


Figure 7: Piper plot of major anions and cations. Surface water samples from West Nose Creek and the main Nose Creek stem are plotted against waste water influent (WW1 and WW2). No significant trend or mixing is observed in the samples indicating the creek is variable on a daily basis. West Nose Creek has the most similar chemistry to groundwater (Appendix 6) where low chloride concentrations are observed. Groundwater in the Nose Creek Watershed typically has Na – SO4 rich water (M.D Rocky View No 44).

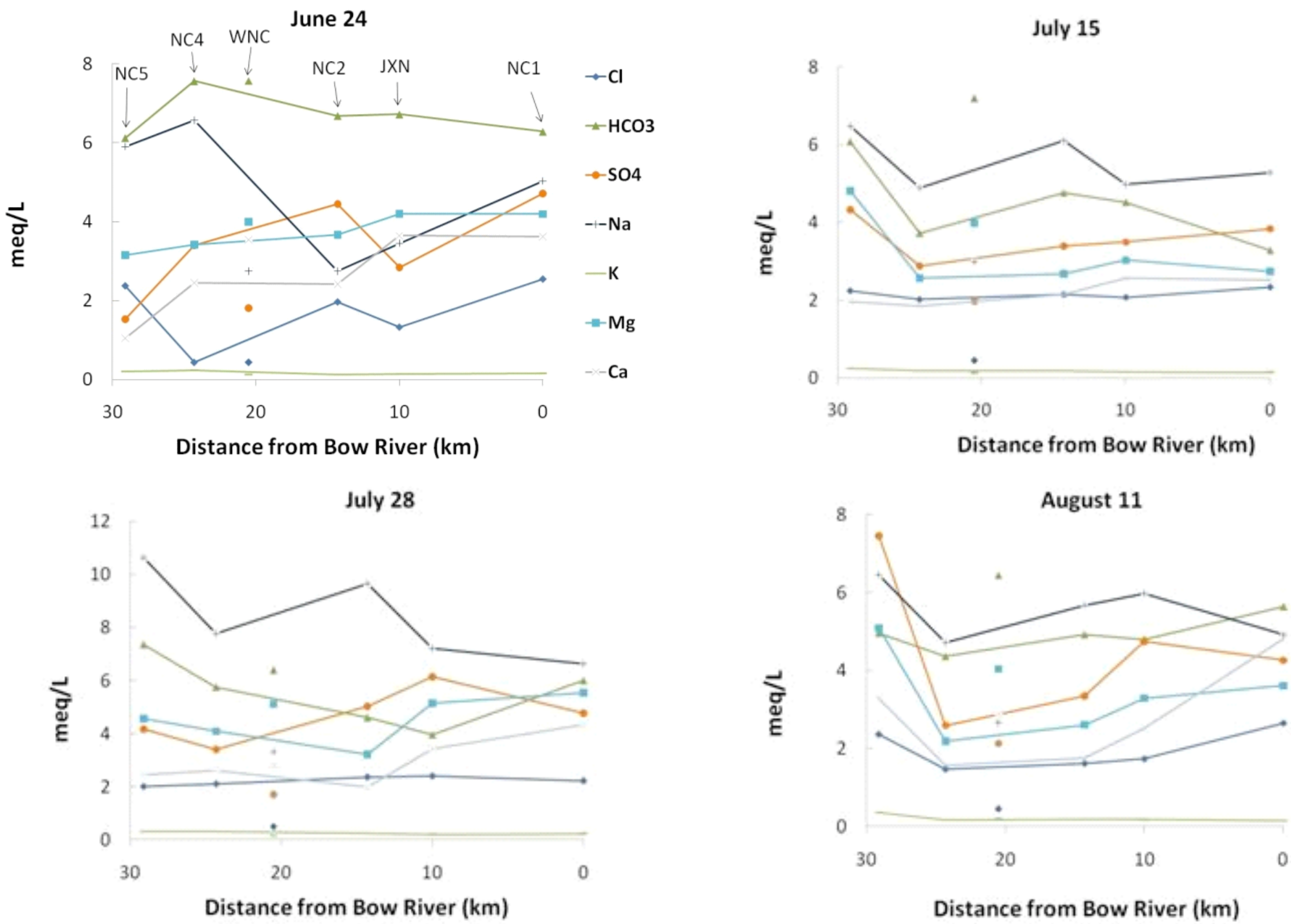


Figure 8: Major dissolved ion concentrations for seepage run sampling days. Concentrations are compared to results from Grasby et al, 2007 (Appendix 3).

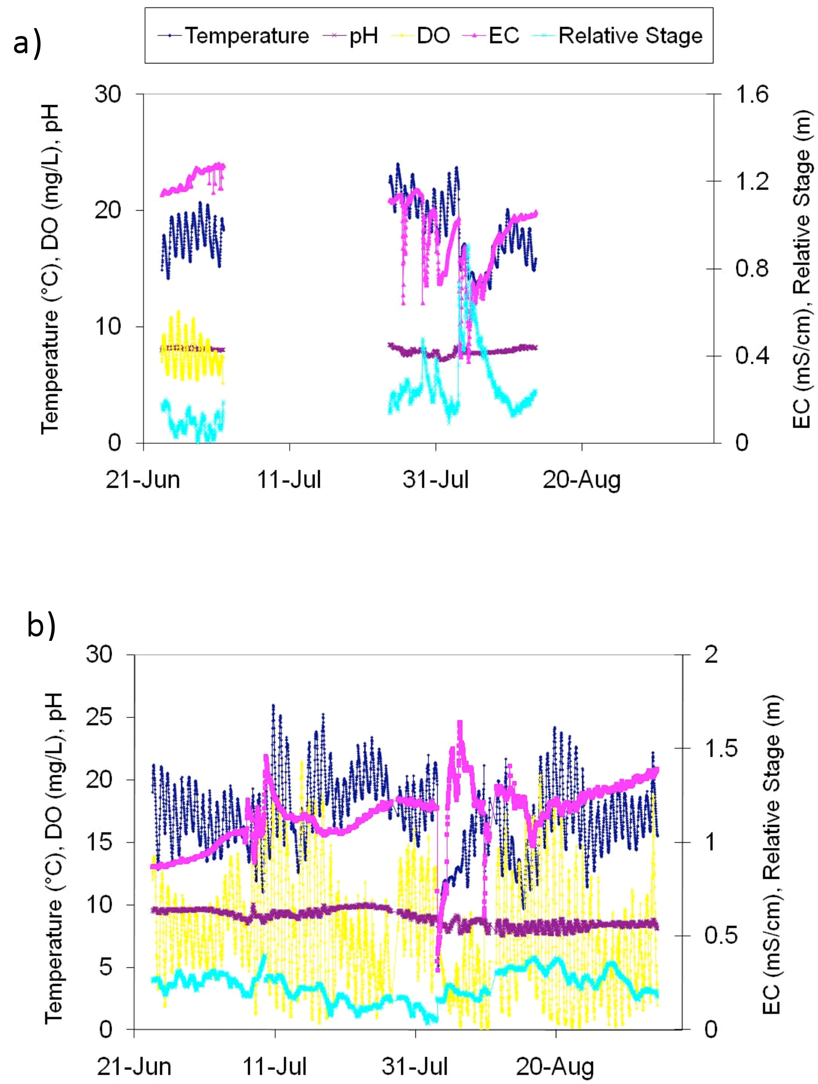


Figure 9: Continuous monitoring results from NC1 site (a) and NC5 (b), (Figure 1). No data recorded from July 1 – 24, 2009 at NC1 due to high flow consistently toppling stilling well over. No dissolved oxygen recorded at NC1 from July 24 – August 13, 2009 due to a broken DO cap. Dissolved oxygen recorded at both sites shows concentrations fluctuating to unhealthy levels (5 – 9.5 mg/L). Decreased EC levels are observed during increased relative stage due to rain events and dilution occurring. Unhealthy pH levels (>9) are observed until late July at NC5.

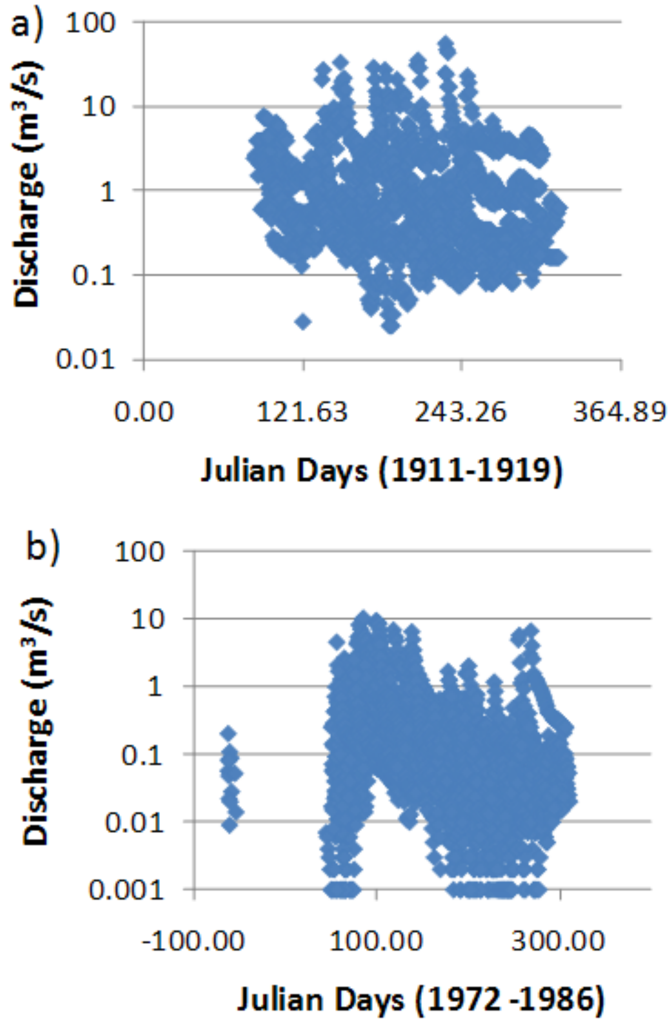


Figure 10: Historical discharge data from 1911-1919 (a) and 1972-1986(b), (Water Survey of Canada). Discharges were measured at NC1 site (Figure 1). Discharge data from 1911-1919 had an average of 1.68m^3/s (median = 0.58 m3/s, standard deviation = 3.59, n = 1893). Data from 1972 – 1986 had an average discharge of 0.27 m^3/s (median 0.079 m^3/s, stdev = 0.75, n =3647).

Table 1: Average concentrations recorded for seepage run sampling days from June – August, 2009. Average concentrations are bolded, with corresponding standard deviation values below.

Sites	NC1	JXN	NC2	NC4	NC5	WNC	Guidelines				
Location	Nose Creek at Mouth	WNC input into Nose Creek	Upstream of Calgary	Downstream of Airdrie	Upstream of Airdrie	Upstream of Calgary WNC	Drinking Water	Livestock Watering	Irrigation	Aquatic Life	Recreation
Temperature (°C)	**15.50**	**18.72**	**18.43**	**17.03**	**15.35**	**16.53**					
	2.72	0.64	1.33	1.53	1.59	1.13					
pH (pH units)	8.23	8.69	8.72	8.37	9.00	8.54	6.5 - 8.5 (a)			6.5 - 9 **	
	0.11	0.18	0.20	0.44	0.63	0.11					
Electrical Conductivity (mS/cm)	**1.089**	**1.068**	**1.114**	**1.008**	**1.074**	**0.854**			1.000 (a)		
	0.136	0.069	0.136	0.151	0.150	0.080					
Dissolved Oxygen (mg/L)	**7.13**	**12.14**	**10.04**	**6.15**	**7.34**	**11.93**				5 - 9.5 **	
	1.12	1.02	2.07	2.48	4.69	1.92					
Total Suspended Solids (mg/L)	**42.66**	**32.70**	**34.93**	**30.22**	**16.00**	**4.95**				10 *	
	36.37	10.05	8.14	5.03	9.42	2.69					
Total Dissolved Solids (mg/L)	**902.21**	**840.40**	**846.27**	**768.29**	**952.10**	**707.26**	500 (a)	3000 **	500 - 3500 **		
	129.95	87.40	105.73	135.70	119.63	50.44					
Calcium (mg/L)	**73.04**	**61.09**	**41.65**	**45.00**	**44.36**	**63.30**		1000 **			
	16.67	10.06	4.87	10.15	13.75	8.44					
Sodium (mg/L)	**131.89**	**134.73**	**174.84**	**145.07**	**173.48**	**69.01**	200 (a)				
	21.95	36.96	39.47	33.37	46.45	5.30					
Magnesium (mg/L)	**53.59**	**49.31**	**38.01**	**39.80**	**54.65**	**56.04**					
	15.61	11.57	5.77	10.65	7.62	7.35					
Potassium (mg/L)	**6.95**	**7.09**	**8.82**	**9.05**	**10.76**	**5.69**					
	1.25	1.44	1.58	2.37	2.03	0.96					
Sulphate (mg/L)	**212.44**	**221.64**	**198.36**	**151.55**	**197.30**	**88.95**	500 (a)	1000 **			
	31.95	63.13	35.18	19.20	87.51	8.54					
Chloride (mg/L)	**81.16**	**67.03**	**70.98**	**73.06**	**73.44**	**16.11**	250 (a)		100 (a)		
	10.21	13.78	9.77	12.85	13.88	1.16					
Nitrate - N (mg/L)	**0.78**	**0.51**	**0.10**	**0.16**	**0.65**	**0.22**					
	0.16	0.26	0.00	0.07	0.94	0.22					
Ammonia -N (mg/L)	**0.58**	**0.10**	**0.22**	**0.10**	**0.44**	**0.16**					
	0.46	0.00	0.27	0.00	0.56	0.10					
E.Coli (#/100ml)	**399.1**	**330.8**	**257.7**	**136.6**	**602.8**	**585.0**	0**				200**
	295.3	193.1	128.2	99.1	902.0	358.3					
Total Coliform (#/100ml)	**2419.6**	**2012.3**	**1738.8**	**1930.0**	**1301.8**	**1901.9**			1000 **		
	0.0	694.4	677.2	979.3	894.3	810.1					

Indicates guideline exceeded

Indicates below detection limit

Inidcates above detection limit

* Alberta Environment, 1999

(a) P.Cross, 2001

** CCME Canadian Water Quality Guidelines, 1999

Table 2: Licensed withdrawal volumes/year from Nose Creek Watershed (Alberta Environment). Greatest withdrawals are extracted within City of Calgary limits (upstream of JXN site), and City of Airdrie limits (NC4 – NC5 stretch).

Area	Withdrawals within reach (m^3/year)	Total Withdrawals (m^3/year)
North of Airdrie	336708	2856065
NC4 - NC5	793115	
NC2 - NC4	83948	
Upstream WNC	271607	
Upstream JXN	901957	
JXN - NC1	468730	