Impacts of urbanization on West Nose Creek: a Canadian experience

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Abstract The lower reaches of West Nose Creek have been subjected to urbanization since the 1970s, leading to channel widening and excessive erosion. This paper discusses what would likely happen if urbanization were allowed to continue in the same manner. Comparisons are presented of the channel width and depth for both the upstream rural and downstream urbanizing reaches. Estimates of the evolution of the creek were generated by linking the dominant discharge to the entire shape and volume of the hydrograph that the creek is subjected to rather than solely considering peak discharges.

Potential remedial measures and stormwater management philosophies are discussed in relationship to instream flow needs (IFNs) initiatives. IFNs are generally developed by relating the amount of suitable aquatic habitat to the quantity of flow. The emphasis has so far been on IFNs for large river systems. Unfortunately, none of the IFN approaches cover streams that are subject to significant urbanization. In urbanized streams the issue is not as much the impacts due to withdrawals but due to significantly increased runoff rates and volumes generated within the urban areas. Examples are provided how fisheries habitat is impacted by the changed hydrologic regime and changed stream morphology.

Keywords Flow exceedance curves; instream flow needs; stormwater management; urban drainage; urbanization; watershed management

Introduction
West Nose Creek is a small creek at the transition between the foothills and prairie, north of Calgary, Alberta, Canada. It is the main tributary of Nose Creek, which drains large parts of the northern extents of Calgary, as well as rural areas north of Calgary. The main stem of West Nose Creek has a length of about 40 km while its gross and net tributary areas are 325 km² and 217 km², respectively. The difference reflects that large parts along the western perimeter of the watershed are not included in the effective area because the hummocky terrain is considered to be self-contained.

The watershed is located in a semi-arid region, east of the Rocky Mountains, with annual precipitation in the order of 400 mm. While the soils are largely glacial tills, the majority of precipitation replenishes soil moisture to evaporate during the summer months. Drainage densities are therefore relatively low and pre-development flow rates small compared to more humid and temperate regions.

As widely reported in the literature, the effects of urbanization can be diverse. The introduction of large extents of paved surfaces and compaction of soils leads to exponential increases in peak flow rates and runoff volumes, which, in turn, may result in flooding and erosion problems in downstream areas. Water quality impacts can be in the form of significantly increased sediment and nutrient loadings that may smother invertebrates and/or lead to excessive macrophyte growth. Examples of water quality impacts are low dissolved oxygen levels and high water temperature.

Along the lower reaches of West Nose Creek, evidence of the impacts are excessive erosion in the form of deepening and widening of the channel, undermining of abutments...
of foot bridges, undermining of outfalls and outflanking of gabions that had been installed at one time to protect pathway systems from “moving” creek meanders. A certain degree of erosion and channel movement, however, can be expected along any natural stream system. In order to quantify the impacts of urbanization, differences in fluvial morphologic characteristics along the creek were noted, from its headwaters to its confluence with Nose Creek. The creek was extensively surveyed within the City of Calgary with hundreds of cross-sections reflecting the very sinuous nature of the creek. Along the upper, rural reaches of the creek, representative cross-sections were surveyed as well.

Various geometric relationships between for instance channel width, channel depth, meander spacing and amplitude and bankfull or dominant discharge are reported in the literature concerning fluvial morphology. Figure 1 presents the relationship between the bankfull capacity of the channel at a particular cross-section and its upstream catchment area. This ratio appears to correlate geometrically for the upper reaches of West Nose Creek, upstream of the urbanizing areas within the catchment. The expression for this ratio follows closely what is reported in the literature (Newbury, 2004). Along the lower reaches, however, the observed ratio appears to greatly depart from the relationship for the upper reaches. One conclusion that can be drawn from Figure 1 is that the cumulative impact of urbanization so far can be interpreted as having caused an artificial, four-fold increase in catchment area, with a corresponding significant increase in dominant capacity.

Figure 2a and b illustrate the difference between the upper, non-urbanized reaches and the lower, urbanized reaches which demonstrates the evolution of West Nose Creek due to urbanization of the watershed. A widening and deepening of the channel is taking place, which apparently is still ongoing. The latter is no surprise given that there is a certain lag time for the evolution to be complete. In addition, urbanization is still continuing within the watershed so that the widening and deepening is being repeated because of the still changing hydrologic regime of the creek. The depth in the lower reaches is currently greater than for ultimate conditions, while the widening is still continuing. This reflects the condition that the scour due to the increased shear stresses resulting from the higher and longer duration of flow commences at the bottom of the channel. The deeper channel...
triggers instability of the banks, which start to slough and hence widen the channel until a new equilibrium is reached. The process results in the introduction of large amounts of sediment into the stream. In addition, the profile of the channel is being lowered as well.

Evolution of stormwater management practices

Development started in the late 1970s and early 1980s near the confluence with Nose Creek. At that time, stormwater management practice merely consisted of putting storm sewer pipes into the ground with the premise of getting rid of the runoff as quickly as possible. The drainage system was designed with the help of the so-called rational method for a 1:5 year design storm condition. In addition, no attention was paid to the performance of the drainage system for more severe storm conditions. While this area has been spared major flooding because of the slope of the land, the possibility exists that uncontrolled overland flows could enter the creek during severe events in addition to the discharges from the storm sewer system.

Simultaneous with the downturn in Calgary’s economy in the mid 1980s, which led to a standstill in development for a number of years, it was increasingly noticed that this “out of sight – out of mind” philosophy of the previous decades did not really hold up. Certain parts of Calgary were hit by severe flooding of public and private property on a number of occasions, which made it difficult to put drainage out of mind. This brought about the adoption of a philosophy in the late 1980s where the practice was to temporarily detain runoff in new development areas and release it based on the available capacity within the downstream drainage system. In the case of Nose Creek and West Nose Creek, some straightening of the creeks was proposed which allowed a limited increase in flow compared to pre-development conditions. This led to the introduction of stormwater storage facilities, dry ponds and wet ponds that would allow the temporary storage of runoff in excess of a 2.6 L/s/ha release rate for a 1:100 year event, which was the permissible release rate that was adopted for the majority of the new communities.

At that time, no attention was paid to
- any other storm events but a 1:100 year event;
- the smaller, more frequent storm events;
- runoff volumes; and/or
- water quality.

Water quality received scant attention until the update of the provincial stormwater management guidelines in the late 1990s. This led to the widespread use of wet facilities, wet ponds or constructed wetlands, rather than dry ponds, to retain sediments greater than 75 microns in size (i.e., fine sand). As of this date, little attention is paid to smaller...
Analysis

A joint HEC-RAS/XP-SWMM computer model was established to simulate rainfall–runoff conditions within the watershed and to evaluate the impacts of urbanization on the creek. This model incorporated the existing stormwater management infrastructure within the already established communities and the envisioned infrastructure for the new communities based on available master drainage plans or following current design practice. The contribution from the rural areas to the north was based on the recorded stream flow at an Alberta Environment stream gauge, just north of the city limits. This greatly enhanced the credibility of the model because it allowed the circumvention of the challenges of modelling the rainfall–runoff process in small, rural catchments.

A comparison between discharge rates from several outfalls along the creek for typical design storm events and flow rates in the upper, rural watershed – based on stream flow monitoring carried out by Alberta Environment – show that the former can be an order of magnitude greater. As is to be expected, the highest flow rates on a unit area basis were observed within areas that have no large-scale stormwater storage facilities in place. However, even those outfalls where the flow is supposedly controlled to a 1:100 year condition (albeit with a limited increase in rate) show rates that are significantly greater than pre-development conditions, especially for the smaller, more frequent events.

One observation that was made concerns stormwater storage facilities in series: drainage systems that have these types of facilities are very unlikely to control flow rates for the smaller, more frequent events. The permissible release rate for the most downstream facilities is a function of the entire upstream catchment that flows through the control structure in question. Because of the travel time within the drainage system, runoff generated by the most downstream parts of the catchment has essentially discharged in an uncontrolled manner before the runoff from the upper parts of the catchment arrives. This is exacerbated by the fact that precipitation does not fall uniformly over the entire catchment as is usually assumed in design practice. This observation should not come as a surprise because most of these systems were still designed on the same premise of getting rid of runoff as quickly as possible. In the case of dry ponds, this was considered advantageous as most ponds are used for multiple purposes such as sports amenities.

So far, the previous paragraphs have only considered the increase in peak flow rates compared to pre-development conditions. The increase is aggravated by the sustained duration of flows at higher rates, resulting from the increase in runoff volumes with urbanization.

Figure 3, which shows the percentage of time that a certain flow rate in West Nose Creek is exceeded, illustrates the combined effect of increases in discharge rate and runoff volume. As a result of this combination, it is inevitable that significantly increased stresses are exerted on the bed and banks of West Nose Creek. Similar graphs were established for key parameters such as flow depth and velocity, shear stress and stream power. The output from the HEC-RAS/XP-SWMM model was hydrographs all along West Nose Creek for six of the years that stream gauge data was available; the model covered a wide range of stream flow and meteorological conditions. These hydrographs were subsequently expressed as flow frequency exceedance curves.

Bledsoe (2002) and Nehrke and Roesner (2002) among others have reported that conventional stormwater management practices where it is attempted to match post-development peak flow rates to pre-development peak flow rates still lead to downstream...
flooding and significantly accelerated erosion in the receiving streams, even if matching of a range of return periods is tried. Indeed, with respect to downstream flooding, Argue et al. (Urban Water Resources Centre, 2004) comment that only runoff volume control may offer relief. Similarly, increased runoff volumes can be interpreted as additional amounts of energy that exert stresses on the bed and banks for prolonged periods of time. Indeed, classical texts by Leopold et al. (1964) already showed examples how changes in the hydrologic regime of a stream cause changes in the morphology of these same streams. While Leopold’s research may not necessarily have focused on urban streams, the very same principles apply, albeit with some differences. Typically, in fluvial morphology, a 1:1.5 to 1:3 year instantaneous peak discharge rate is used as expression for the dominant discharge. This is postulated not to be appropriate for urbanizing streams because of the exponential increase in runoff volume and the sustained duration of high flows. Instead, it is proposed to express the dominant discharge as a function of the frequency of exceedance of flow. The resulting dominant discharge is then entered into the morphologic relationships depicted in Figure 2a and b to derive estimates of the resulting geometric parameters such as channel width and depth.

Comparison of computed with actual channel widths for 2002 indicated that the widths are comparable for the lower reaches of West Nose Creek when the dominant discharge is in the order of the magnitude of flow that corresponds to a 1–3% exceedance in Figure 3. Incidentally, a similar relationship was detected for Forest Lawn Creek in southeast Calgary, where the dominant discharge as estimated independently from channel characteristics, coincided with a 1–3% exceedance.

By relating the observed main channel capacity to the flow frequency exceedance curves and entering the estimated new dominant discharge rates into the fluvial morphologic relationships of Figure 2a and b, it is possible to “predict” the evolution of West Nose Creek. Figure 4 is an example of what would likely happen to the width of West Nose Creek if development within the City of Calgary were allowed to proceed while continuing the current stormwater management policies. It is proposed that the above procedure be utilized to evaluate the consequences of various stormwater management practices with respect to impacts on this creek.

Figure 3 Flow duration curve
Nose Creek watershed management plan and instream flow needs

In the late 1990s, the provincial government created a comprehensive new statute, the *Water Act*, to ensure sustainable water management and a healthy aquatic environment. Recognizing that effective and efficient water management planning is essential, Alberta Environment developed a document, The *Framework for Water Management Planning (Framework)*, to guide this planning. A major component of the Framework and a requirement of the *Water Act* is the *Strategy for the Protection of the Aquatic Environment (Strategy)*. The *Strategy* details the provincial government’s commitment to maintaining, restoring or enhancing the condition of the aquatic environment.

In 2002, the need for a Nose Creek Water Management Plan (NCWMP) was identified through a consultative process between the Nose Creek Watershed Partnership and Alberta Environment. It was determined that, with the cumulative effects of increasing subdivision development, industrial growth, stormwater discharge, agricultural activities and channelization occurring within the Nose Creek Watershed, a water management plan would provide an essential decision-support tool to help ensure sustainable water management and a healthy aquatic environment.

In early 2003, the Partnership and Alberta Environment issued the terms of reference for developing the first phase of an approved, multi-phase NCWMP. One of the first steps in creating the NCWMP was the identification of instream flow needs (IFNs) for the water courses in the Nose Creek Basin. IFNs are an integral element of Alberta Environment’s water management plan for the protection of aquatic habitat. These IFNs are generally developed by relating the amount of suitable aquatic habitat to the quantity of flow. The main emphasis has so far been on the establishment of IFNs for large river systems that are subject to regulation (e.g., for power generation) or withdrawal (e.g., for irrigation). Unfortunately, none of these approaches (Instream Flow Council, 2002) cover streams that are subject to significant urbanization such as the lower reaches of Nose Creek and West Nose Creek. In heavily urbanized streams the issue is not as much the impacts due to withdrawal of flow but the impacts due to significantly increased runoff rates and volumes generated by the hard surface area within the urban areas.

![Figure 4 Estimated widening of West Nose Creek for various development scenarios](https://iwaponline.com/wst/article-pdf/53/10/237/432042/237.pdf)
In the absence of the means for multi-year, broad-scaled field studies, the preliminary IFNs for the rural reaches are based on the application of the simplified Tessman method (year unknown), which uses mean monthly flow values, rather than more recent sophisticated incremental flow methods. The low-flow IFNs for the urban reaches can be based on those for the rural areas with the stipulation that channel enlargement should be avoided. The latter can be accomplished by meeting the intermediate-flow IFNs for the urban areas which state that future flows in West Nose Creek should conform to the flow duration curves for the upper undeveloped areas; an example of a flow duration curve was presented in Figure 3. The high-flow IFNs for the urban areas follow conventional discharge rates based on flood protection.

In the case of desired withdrawals within the urbanizing areas, a habitat suitability analysis should preferably be conducted to evaluate the impacts, especially where channel enlargement has already occurred or is expected to occur. This analysis should account for the channel changes using the predictive model of future geometry of the stream as a function of the future flow regime.

The importance of maintaining the original channel characteristics for fisheries habitat protection is illustrated in Figure 5 for a typical riffle in the lower reaches of West Nose Creek. Figure 5 was derived by combining the flow exceedance curve of Figure 3 with a hydraulic-related habitat suitability curves for the White Sucker species which is common in the basin. These suitability curves had been developed by the Fish and Wildlife Service of the United States Department of the Interior (Twomey and Williamson, 1984). Figure 5 shows that the riffle velocity suitability index is initially slightly reduced but worsens when the channel reaches its new geometry.

Similar analyses for other riffles, pools and runs show that the impact of urbanization on the analyzed suitability indexes is greatly dependent on the local conditions. It is believed that the above analysis would be quite useful to examine the impacts of the various stormwater management strategies in the catchment, specifically for the areas that are currently developed. Impacts will be more pronounced further downstream where there is a larger urban tributary area. In addition, impacts within the analysed reach will

Figure 5 Habitat suitability exceedance curve
become more pronounced when development continues north of Calgary because of the cumulative effects.

Conclusions
Argue et al. (Urban Water Resources Centre, 2004) as well as Emerson et al. (2005) comment that widespread detention in urbanizing catchments is insufficient to relieve downstream flooding. In fact, runoff volume control is required. Similar considerations apply to channel enlargements processes, as reflected in current approaches to stormwater management in British Columbia (2002) and Washington State. Control of discharge rates to for example 1:2 year pre-development flow rates, as suggested by some in the Calgary area, offer little chance of success, because the detention facilities would never empty as these rates are extremely small.

It is expected that the 1–3% exceedance percentage for the dominant discharge may be different for other streams due to the fact that the values for West Nose Creek are based on the period of April–October given that no records are available for the remainder of the year when the stream is frozen over. Additional differences would be the result of time lag effects reflecting the fact that the channel enlargement does not happen overnight but might take decades to materialize. Nevertheless, we believe that the above approach is a powerful tool in evaluating the impacts of urbanization and possible stormwater management techniques on streams. Indeed, it has already proven its use in discussions with the Nose Creek Watershed Partnership and public at large.

Opportunities exist to reduce impacts on our streams due to changes to the hydrologic regime resulting from urbanization. Examples include “strengthening” of riffles, as suggested by Newbury (2004) or the provision of drop structures, as practised in the Denver metropolitan area. Because these measures, in principle, should be implemented along the entire impacted reach, they are potentially very intrusive. In addition, by themselves they will not address all impacts due to urbanization. An added advantage of runoff volume control is that it significantly reduces contaminant loadings to our urban water resource. It is envisioned that a combination of in-stream measures and new stormwater management philosophies will ultimately be required. This will first require a discussion of what we as a society envision for our urban streams.

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