Analysis of Streamflow, Water Quality, and Benthic Community Changes in North Creek (1999–2009)

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SUMMARY

Purpose. The purpose of this report is to measure changes in streamflow, water quality, and the benthic invertebrate community in North Creek between 1999 and 2009. North Creek is an intensively monitored small stream draining from the East Clayton Neighbourhood in the east-central portion of the City of Surrey. East Clayton was developed using a variety of innovative stormwater management strategies since 2001. Analyses examined statistical trends in time-series data, as well as indicators of streamflow, water quality, and the benthic inverterbrate community.

Results. The analyses found that streamflow, water quality, and the benthic invertebrate community changed substantially in North Creek downstream of the rapidly urbanizing East Clayton Neighbourhood between 1999–2009. Some were negative changes to stream condition associated with increasing urbanization, while others were positive changes linked to the use of low impact development measures in the developing catchment. Key results include:

- Streamflow as a proportion of precipitation has increased significantly over the study period, even though mean annual discharge has not increased significantly. This suggests that exfiltration galleries and other strategies to infiltration precipitation into the shallow subsurface drainage system has been effective.
- Maximum annual stormflow has decreased. This is contrary to the established pattern in urban watersheds where increased imperviousness and catch-basin and pipe systems increase peak stormflows. The innovative stormwater source controls appear to infiltrate precipitation that would typically contribute to stormflow.
- Water temperature has increased significantly during the study period. The large stormwater detention pond upstream of the water quality monitoring station is a likely cause of the elevated water temperature.
- Turbidity increased during the initial clearing and development phase (2002–2004), although the overall change was not statistically significant. The number of minor turbidity events has remained consistent during the study period, while more turbidity events classified as moderate occurred in 2003 and 2004 than in all other years combined. This suggests that moderate and minor turbidity events may have different causes.
- Specific conductivity has increased significantly and indicates that urbanization has substantial effects on chemical processes in small catchments. While conductivity is a broad measure of ionic concentration, it is likely a useful surrogate for contaminants of concern in urban streams including metals and nutrients.

- The benthic invertebrate community became more similar to other urban streams in the region because of the loss of sensitive taxa, and the establishment of taxa tolerant of environmental conditions in urban streams. The data indicate that the benthic invertebrate community is in transition as it responds to changing stream conditions accompanying urbanization of the East Clayton catchment. Taxa richness was lower before 2001, peaked between 2002–2004, and then declined.
- B-IBI, a composite measure of the benthic invertebrate community, increased significantly between 1999–2001. The significant increase in B-IBI was driven by changes in only four the ten component metrics, and specifically by the increase abundance of a single predator taxa – *Turbellarian* flatworms. Flatworms were not present until 2007 but account for up to 35% of the organisms collected in samples at Station N1.

Overall, the results of the analysis suggest that mitigation strategies to avoid or mitigate reduced summer baseflow and increased stormflows have been effective, but that the stormwater system has reduced but not eliminated the effects of urban development on water quality. Changes in the benthic invertebrate community were more variable and reflect the cumulative effects of changing streamflow, water quality, and other factors in North Creek.

Recommendations. The following recommendations are made to guide additional monitoring or data analysis:

1. The water quality monitoring programs should be expanded to assess concentrations of metals, nutrients (nitrate and dissolved orthophosphate), and fecal coliform bacteria.
2. The catchment boundary should be reviewed using the most recent stormwater system mapping. Flow patterns in several areas have been modified during recent development and require confirmation.
3. Land cover change (e.g., imperviousness, forest cover, etc) should be quantified using historic air photos for the period 1995–present. This would provide a complimentary assessment to better understand the effects of urbanization on North Creek.
4. Water yield per catchment area should be measured using the updated catchment boundary. Initial analysis found it was higher than expected based on regional values and more work is needed to confirm this parameter.
5. Water temperature should be measured upstream and downstream of the stormwater detention pond to better understand its effect on water temperature in North Creek.
6. Metal concentrations in streambed sediments should be measured in the same locations as benthic invertebrates. Sediment quality provides a complimentary assessment of stream condition.

ACKNOWLEDGEMENTS

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PART I – Introduction

The purpose of this report is to measure changes in streamflow, water quality, and the benthic invertebrate community in North Creek between 1999 and 2009. North Creek is an intensively monitored small stream draining from the East Clayton Neighbourhood in the east-central portion of the City of Surrey. East Clayton was developed using a variety of innovative stormwater management strategies since 2001 (City of Surrey, 2003). They include exfiltration[1] galleries, narrow streets, deep soils, and disconnected roof leaders (Hislop and Kipkie, 2004; KWL, 2006; Dube, 2009). The goal of the East Clayton stormwater management system is to reduce surface run-off and it associated changes to water quality and benthic invertebrate community that is caused by increased imperviousness and conventional stormwater conveyance systems. The target was to infiltrate 12–25 mm of initial rainfall which encompasses about 90% of total annual rainfall (Dube, 2009). Soils in the East Clayton area are composed of silt and clay which characteristic of many areas of the Lower Fraser Valley.

Site Description. North Creek is located in the east-central portion of the City of Surrey and drains to the Serpentine River (Figure 1.1; Appendices A1 and A2). Land use in the watershed includes remnant rural areas intermixed within suburban residential areas that have developed in the past 10 years (see Figure 1.2 for examples of current land use). The lowland (outside the monitored portion of the watershed) is used for agriculture. The East Clayton Neighbourhood is about 250 ha and includes residential, commercial, and educational land uses. Residential land use accounts for about 48% (120 ha) of the East Clayton neighbourhood. Most of the residential land use is dense with an imperviousness of around 70% (Dube, 2009).

North Creek supports coho salmon and cutthroat trout and a portion of its channel is contained with a forested ravine with important wildlife habitat values (Figure 1.2).

Land Use Change. Since 2001, the East Clayton Neighbourhood has changed from primarily rural land use with large lots and scattered forest cover, to suburban residential use including small residential lots and multifamily sites. Forest cover declined substantially. Appendix A3 shows land cover in 2001, 2005, and 2008 when the most rapid land use change occurred.

[1] "Exfiltration" refers to a loss of water from a drainage system as the result of percolation or absorption into the surrounding soil. Exfiltration tanks were the primary strategy to reduce stormwater runoff volume at the East Clayton.

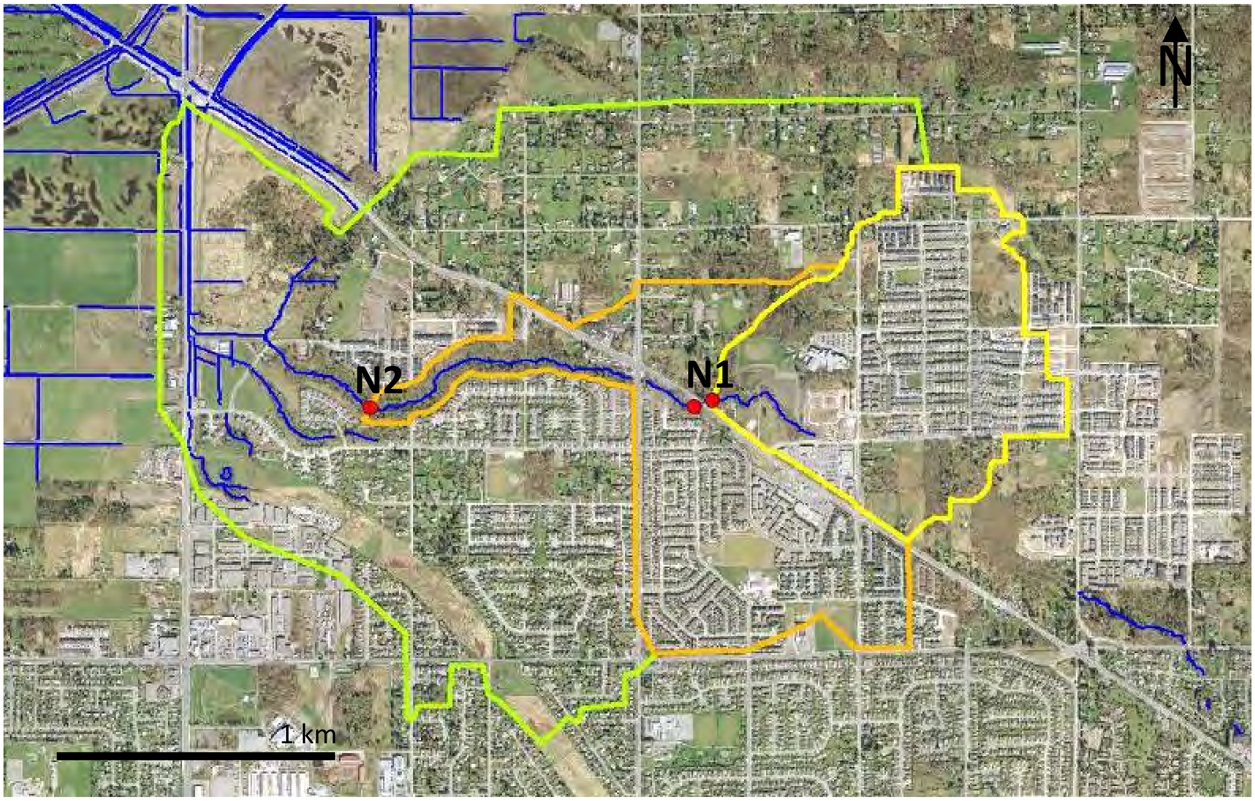

Figure 1.1. North Creek watershed in east-central Surrey. The overall watershed boundary is shown in green. The portions of the watershed upstream of monitoring Station N2 is shown in orange and the portion upstream of Station N1 is shown in yellow. Most of the analyses in the report relate to changes in the catchment shown in yellow.

Monitoring Program. Monitoring of streamflow, water quality, and benthic invertebrates in North Creek is summarized below. Additional stormwater-associated monitoring in the East Clayton Neighbourhood is also described. Monitoring sites are shown in Figure 1.3.

1. Streamflow. Streamflow has been monitored at a single site in North Creek since November 1996. The flow monitoring weir is located downstream of Fraser Highway (Figure 1.3). Water level is measured at 5 minute intervals.
2. Water Quality. Water quality has been monitored downstream of Fraser Highway (same site as flow monitoring; Figure 1.3) since 2002. Water temperature, conductivity, pH, dissolved oxygen, and turbidity are monitoring every 15 minutes.
3. Benthic Invertebrates. Benthic invertebrates have been collected twice per year (spring and fall) at two stations on North Creek (Stations N1 and N2; see Figure 1.3) since 1999. Three replicate samples with a 250 micron Surber sampler are collected at each station.

4. Groundwater. Water depth has been monitored in five shallow groundwater wells in the East Clayton Neighbourhood since February 2003. This dataset was not used for this report (see KWL, 2003 for more information), but more analysis is planned.
5. Stormwater Flows. Four pipe-based flow monitoring stations have monitored stormwater flow at different points of the East Clayton stormwater system since February 2003. This dataset was not used for this report (see KWL, 2003 for more information).
6. Climate. A climate station measuring was installed as part of the East Clayton Monitoring Program (note, we used climate data from Abbotsford because it was more complete).

Report Structure. The report is divided into five parts. Part I introduces the project, and describes the North Creek watershed. Parts II to IV focus on different aspects of the monitoring program: Part II - streamflow change; Part III - water quality change; and Part IV – benthic invertebrate community change. The final section (Part V) summarizes the results of the three analyses, discusses overall changes to the condition or health of North Creek, and makes recommendations for additional monitoring or analyses.

Figure 1.2. Representative photos: channel and riparian conditions in North Creek (top left: Station N2; top right: Station N1); land cover in East Clayton Neighbourhood (middle left: remnant rural areas; middle right: multifamily developments); soil conditions during development (bottom left); stormwater detention pond upstream of Station N1 (bottom right).

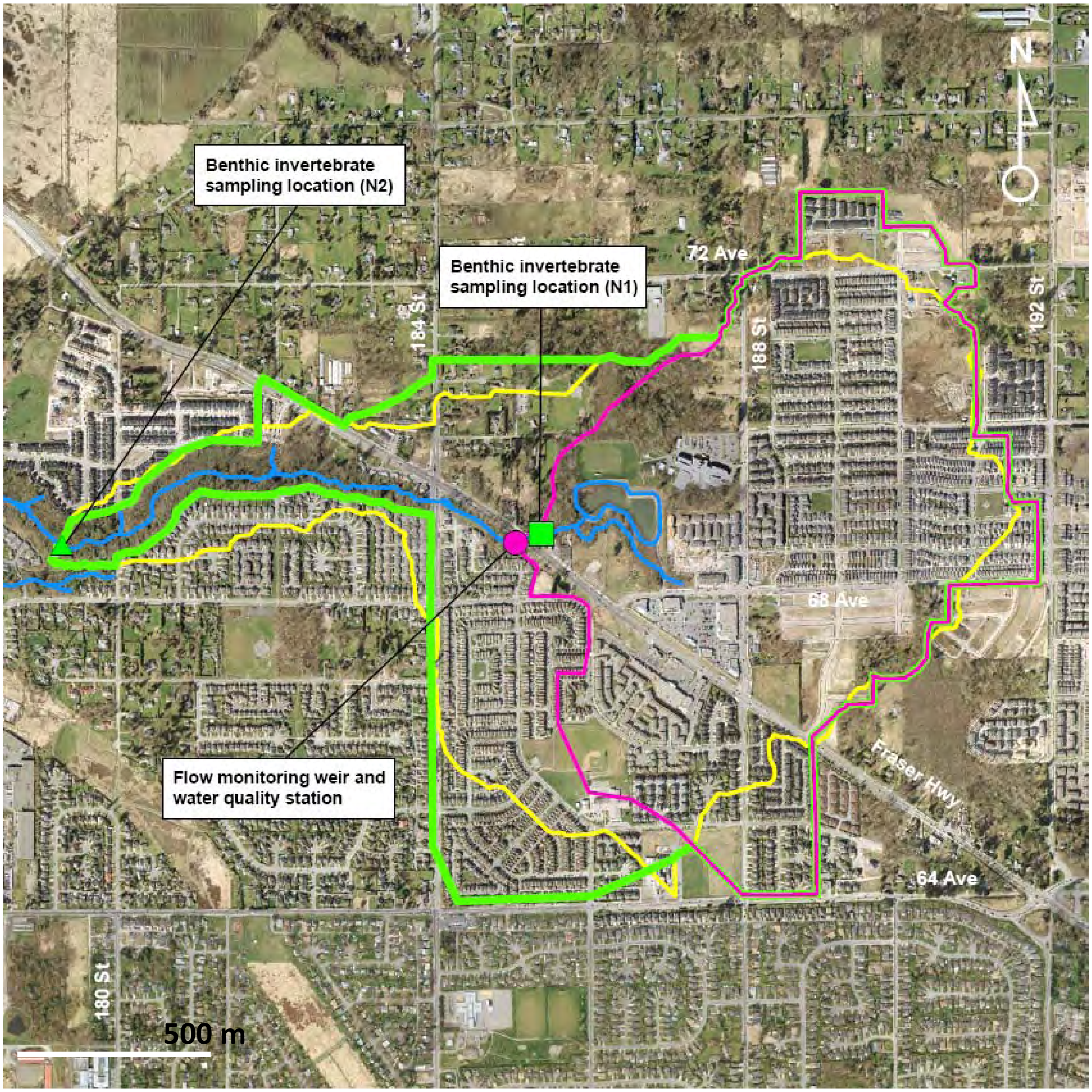

Figure 1.3. Catchment boundaries and monitoring station locations in the North Creek – East Clayton area (orthophoto base is from 2008 when some of the catchment was still being developed).

PART II – Streamflow Changes

Introduction

Changes to the rate, timing, and volume of streamflow accompany many forms of watershed-level disturbance and are particularly pronounced in urban watersheds (Hall, 1984; Booth et al., 2004; Konrad et al., 2005). Because of flow variability in response to precipitation, hydrological monitoring focuses on the collection of continuous recorded streamflow and precipitation data followed by statistical analysis of trends or the calculation of numerical metrics. In this section we assess changes in streamflow in North Creek that have occurred during the development phase of the East Clayton Neighbouhood.

Questions. The following questions were investigated:

1. Have there been any statistically significant changes in total annual runoff (discharge) in North Creek from 1998–2008? During this period, has there been any associated change in total annual precipitation?

2. During the same period, has there been an increase or decrease from year-to-year in the frequency, magnitude, and duration of discharge events (e.g., 0.5-year flood) exceeding certain thresholds?

3. Have summer and winter baseflows (7-day period) increased, decreased, or stayed the same?

4. For all of the above patterns, do these changes appear related to or independent of changes in precipitation patterns?

Methods

Monitoring Site and Weir Operation. All streamflow data from North Creek was collected as part of the City of Surrey's stormwater monitoring program. Flow monitoring equipment in North Creek was installed in November 1996 and consists of a permanent weir, pressure transducer (water level sensor), and data logger installed immediately downstream of Fraser Highway (Figure 2.1). Water levels over the weir are logged automatically at 5 minute intervals and data is downloaded manually every 30–45 days. Measurements have been taken near continuously (see further details below) since November 1996, except for a short period in 1997, and from August 2005 to December 2006 when the station was not operational. The station is currently operated by the Water Survey of Canada and data is managed by Kerr Wood Leidal Associates.

For the purposes of this project, available data included water level and discharge (streamflow) data from November 5, 1996 to December 31, 2008. Water levels (in meters) had been previously converted to discharge (in m3/s) by Kerr Wood Leidal Associates using an established stage-discharge relationship (rating curve) developed for the North Creek flow monitoring station. Only the discharge data was used for subsequent analyses. All flow data is available from the City of Surrey or through KWL's Emerald Flowworks website (www.flowworks.com).

Figure 2.1. Flow monitoring site on North Creek (downstream of Fraser Highway). The PVC pipe on the left houses the probe. The main flow of North Creek is from the culvert in the centre of photo.

Data Validation, Correction, and Gap Filling. Data validation and correction for the discharge data consisted of joining annual data files into a single time series, removing sections with null values indicating absent data (typically, -3 or -99), and removing abnormal or suspect values which may indicate inaccurate or incorrect data. Comparisons to available precipitation data from a nearby climate station at Surrey Municipal Hall was used to assist in the process.

Due to station servicing periods, power failures, sensor malfunctions, or other technical issues with the stations, some gaps existed in the data. Because many typical hydrologic analyses require complete years of data, gap filling was undertaken where possible. Small gaps of less than approximately four days (100 hours or less) with no significant precipitation recorded (such as stormflow recession or baseflow conditions) during the gap were filled using linear interpolation. For larger gaps, linear regression modeling was used to estimate streamflows using discharge data from nearby creeks with available data during the missing periods. Models were parametized for each gap separately by training on data near in time (generally within 30 days) to the gap to be filled. Discharge data from both Latimer Creek (at 192nd St) and Archibald Creek (at 142nd St) were used for modeling.

A data correction history was logged as part of the data correction and gap filling process. All data were validated, corrected, and modelled using AQUARIUS Time Series Software, developed by Aquatic Informatics Inc.

Analyses. We measured trends in streamflow using non-parametric trend analysis, as well as measured changes in hydrologic indicators that are commonly used to assess the ecological effects of changes in streamflow in urbanizing watersheds. Indicators were chosen to reflect a range of possible changes in flow characteristics (magnitude, duration, and frequency of flow events) in urbanizing watersheds.

1. Trend Analysis: Trend analysis was conducted on the full streamflow time-series (1996–2008) using a Mann-Kendall test (positive or negative trend). This is a non-parametric, rank-order based test specifically used to detect trends in time-series data over time. Because of the volume of data points, the signal was downsampled to a 1-day (1440-minute) time interval before conducting the analysis. This reduced the time required to run trend analyses and also reduced the effect of autocorrelation on the identification of significant trends.

2. Annual Mean Discharge (Q_{mean}): Annual mean discharge is the central measure discharge in a stream and an indicator of annual runoff volume. Changes in annual Q_{mean} without corresponding changes in timing of runoff indicate that changes are occurring to aquatic habitat in terms of the depth and wetted area of a stream.

3. Annual Discharge Response ($Q_{response}$): Because annual runoff also depends on volume of annual precipitation received across the watershed, we also looked at annual discharge response (volume per unit of precipitation) (in m^3s^{-1}/mm). $Q_{response}$ measures the proportion of precipitation leaving the catchment by streamflow in North Creek versus by other methods (groundwater recharge, evapotranspiration, evaporation). $Q_{response}$ was obtained by dividing Q_{mean} by total annual precipitation as measured at Abbotsford International Airport (YXX)[2].

[2] The North Creek catchment lies approximately halfway between Vancouver International Airport (YVR) and Abbotsford International Airport (YXX). These two weather station locations are the only stations with complete high-resolution (hourly) precipitation records across the study period. YXX likely more closely resemble actual precipitation conditions within the study area because of it is similar position within the central Fraser Valley (versus the more maritime position of YVR). City of Surrey weather data could not be utilized because a complete precipitation record was not available across the study period.

4. Annual 7-day Low Flow (Q_{min}): The minimum mean daily discharge for seven consecutive days. Q_{min} provides a measure of the lowest streamflow during summer baseflow conditions and the severity of annual droughts in a stream affecting habitat availability for fish and other aquatic life. Empirical data from other regions of North America have found that Q_{min} may increase, decrease, or remain unchanged as a result of urban development (Konrad and Booth, 2002).

5. Annual (instantaneous) Maximum Discharge (Q_{max}): The magnitude of the largest flood in a stream during a given year. Two- to ten-fold increases in Q_{max} have been measured in streams following urban development in Puget Sound (Konrad and Booth, 2002).

6. Annual Mean Discharge Exceedance (T_{Qmean}): The fraction of time that streamflow exceeds the annual mean discharge (Q_{mean}). Q_{mean} is a common discharge value and is typically equaled or exceeded about 1/3 of the time in urban streams (Booth et al., 2004). T_{Qmean} is higher in streams with gradual post-storm recession rates and relatively high baseflow and lower in streams where stormflows have high peaks and recede rapidly (i.e., "flashy" hydrographs). T_{Qmean} is likely to vary inversely with traditional urban development as a result of increased impervious area resulting in declining subsurface storage and runoff and increased overland flow (Konrad et al., 2005). T_{Qmean} was calculated based on daily discharge values.

7. Half-year Flood Exceedance ($T_{0.5}$): Records the fraction of time that a stream channel is exposed to a higher magnitude, less common flow. The half-year flood (also called the 0.5-year flood; the streamflow level exceeded twice per year on average), calculated from a partial-duration series of peak discharge (Langbein, 1949)[3], has been chosen as a useful discharge index because it has plausible geomorphic and biological significance: half-year floods occur often enough to exert persistent effects on stream biota (typically occurring about 100 hours per year in the sample set), and they transport streambed sediment in most alluvial channels (Pickup and Warner, 1976, Sidle, 1988). These are "wear-and-tear" events that likely cause many of the physical habitat changes seen in urban streams. The frequency of high flows in an urban stream is likely to increase more than the cumulative duration of those flows through the combination of increased peak streamflow and more

[3] The 0.5-year flood was determined by identifying all local maxima (peaks) in the 15-min time series above a certain threshold. If multiple local maxima were identified within 20 days of each other, only the largest was retained as a peak. The criterion of 20 days was selected because there is little hydrologic memory of preceding events after 20 days for even large urban catchments. The threshold streamflow was adjusted and the procedure was repeated until the partial duration series had between 30 and 50 streamflow peaks for the period of analysis. The return interval (R_Q) for a given streamflow (Q) was calculated as the number of years of analysis, Y, divided by the number of peaks (P_Q) equal to or greater than Q: $R_Q = Y/P_Q$.

rapid storm flow recession (Booth et al., 2004). $T_{0.5}$ was calculated based on a 15-min data time-series.

8. Storm Event Rise and Recession Rates: Calculated from daily mean discharge values using the Indicators of Hydrologic Alteration (IHA) software package (version 7.1) produced by The Nature Conservancy (Richter et al., 1996). IHA calculates 33 different hydrologic parameters for measuring change. The rise and recession (fall) rate parameters assess the rate and frequency of water condition changes. Rise and recession rates are expected to increase with traditional forms of urban development.

For all annual statistics (#2–8), parametric tests (e.g., linear regression) were generally suitable for detecting trends in each indicator over time.

Although hydrologic data is often analyzed by water year (typically a 12-month period from October 1–September 30, named by year in which period ends), we used calendar years for all analyses for ease of interpretation and because this resulted in more complete years of data during the study period. Only complete years of data (1998–2004, 2007–2008) were used for analyses involving annual values. The year 1997 was also used for indicators assessing high and low flow conditions because high and low flow periods appeared to be captured by the data available for this year, although a full year's worth of data was not available.

Results

The time-series of streamflow (hydrograph) over time for the North Creek monitoring station from 1996–2008 (including interpolated and modeled data sections) is shown in Table 2.1 and Appendix B1. As expected, streamflow in North Creek has a pronounced pattern driven by seasonal rainfall, which is typical of small lowland catchments in the lower Fraser Valley (Rood and Hamilton, 1994). Higher flows and more flow variability occur from late fall (Oct–Nov) to early winter (Apr–May) when soils are near fully saturated and a higher proportion of runoff occurs as overland flow. The highest flows typically occur from December to January each year corresponding with the largest storms of the season. Lower, more stable flows are associated with drier conditions during the summer months and more soil storage.

The following key results were an outcome of the analysis:

1. Streamflow in North Creek, as measured by daily mean discharge values, showed a significant increasing trend from 1996–2008 (Mann-Kendall test: slope = +0.0000, p = 0.01).

Table 2.1. Annual streamflow summary statistics for North Creek from 1996–2008.

Year	# of data points	Proportion of year	Q_{mean} m^3/s	$Q_{response}$ $(m^3/s)/mm$	Q_{min} m^3/s	Q_{max} m^3/s	T_{Qmean} %	Days above Q_{mean}	$T_{0.5}$	Hours above $T_{0.5}$
1996*	16011	15.2%	0.104							
1997*	92113	87.4%	0.051		0	4.7				
1998	105120	100.0%	0.042	862.8	0	2.7	20.0%	73	0.090%	7.9
1999	105120	100.0%	0.049	863.3	0.0002	3.5	21.6%	79	0.270%	23.7
2000	105408	100.0%	0.029	658.2	0.0010	1.7	19.9%	73	0.011%	1.0
2001	105120	100.0%	0.033	701.9	0.0018	2.7	18.6%	68	0.158%	13.8
2002	105120	100.0%	0.035	873.3	0.0010	1.8	17.5%	64	0.040%	3.5
2003	105120	100.0%	0.045	912.1	0.0010	2.8	18.4%	67	0.260%	22.8
2004	105407	100.0%	0.050	1007.8	0.0010	2.1	24.3%	89	0.022%	1.9
2005*	63743	60.6%	0.052							
2006*	0	0.0%	-	-	-	-	-	-	-	-
2007	105120	100.0%	0.062	1153.3	0.0021	2.3	24.7%	90	0.018%	1.6
2008	105408	100.0%	0.046	1189.0	0.0050	2.0	31.1%	114	0.004%	0.3
Overall mean**			0.043	913.5	0.0013	2.6	21.8%	80	0.097%	8.5
Trend**			not signif.	**increase**	**increase**	not signif.	**increase**	-	not signif.	-
(p-value)			*p = 0.12*	***p = 0.005***	***p = 0.027***	*p = 0.068*	***p =0.025***		*p = 0.22*	

*incomplete years of data, not included in trend analysis

**includes only years for which appropriate data was available (1998-2004, 2007-2008, 1997 included for min and max values)

2. Using the years for which complete data was available (1998–2004, 2007–2008), annual mean discharge (Q_{mean}) for North Creek ranged from 0.027–0.062 m^3/s (low in 2000, high in 2007) (Figure 2.2, Table 2.1). Across all years included in the study period, overall mean discharge was 0.043 m^3/s. Although Q_{mean} appeared to show an increasing trend from 1998–2008, the trend was not significant (linear regression: $F = 3.16$, $p = 0.12$). In contrast, total annual precipitation (as measured at Abbotsford International Airport) appears to show a slightly decreasing trend, although that trend is not significant (linear regression: $F = 1.39$, $p = 0.26$) (Figure 2.3).

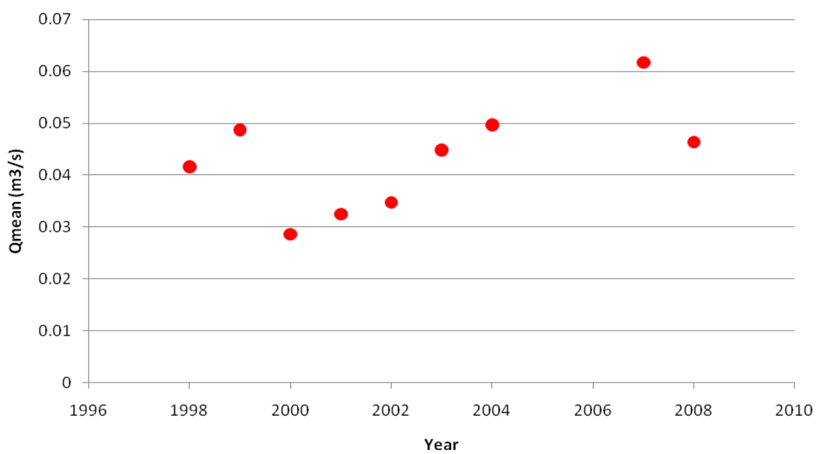

Figure 2.2. Annual mean daily discharge, Q_{mean} (in m^3/s), for North Creek from 1998–2008 (no significant change).

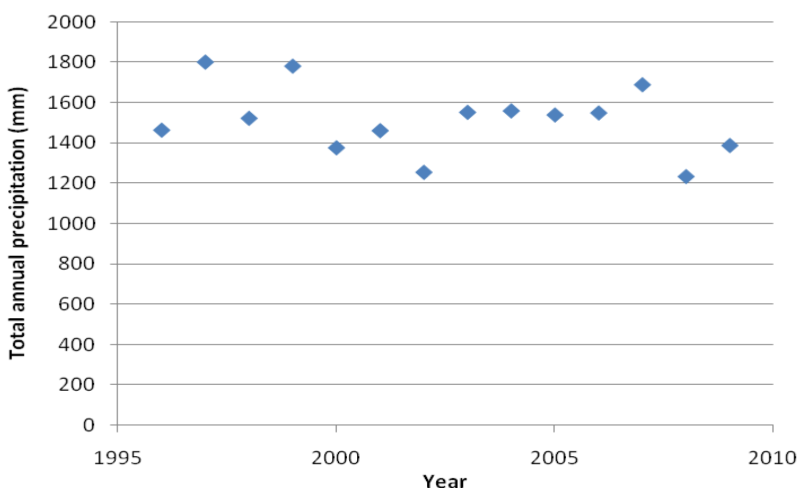

Figure 2.3. Total annual precipitation as measured at Abbotsford International Airport (YXX) from 1996–2009.

3. There was an increasing trend for annual discharge response (linear regression: F = 15.87, p =0.005) suggesting that the proportion of rainfall is running off the catchment has increased over the study period (Figure 2.4, Table 2.1). Therefore, this suggests the lack of trend reported for Q_{mean} is simply due to the high variability in total annual precipitation over the study period and that there is an increasing trend in annual discharge which would likely show up if measured over a longer time period.

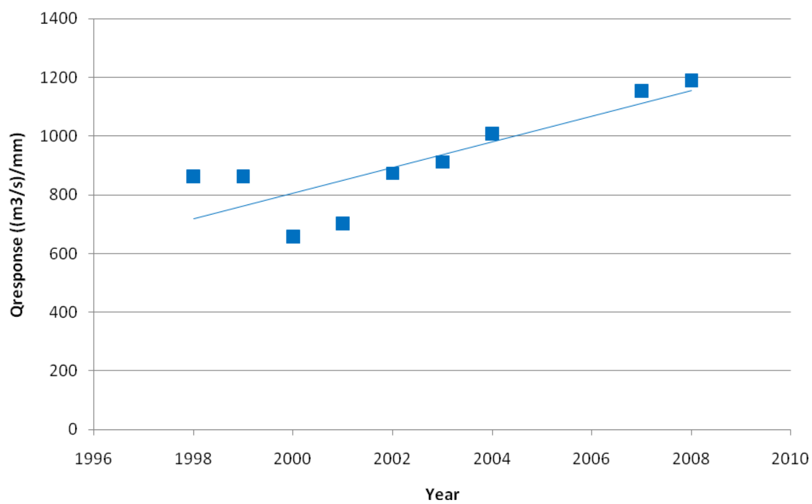

Figure 2.4. Annual discharge response, $Q_{response}$ (in m^3s^{-1}/mm), for North Creek from 1998–2008.

4. In terms of low and high annual streamflows in North Creek, annual 7-day low flows (Q_{min}) increased from 1997 to 2008 (linear regression: F = 18.2, p = 0.0027) although the magnitude of the increase was small (+0.005 m^3/s) (Figure 2.5, Table 2.1). Q_{min} was lowest in both 1997 and 1998 when zero flow was measured in North Creek. It is not known whether streamflow actually ceased for a period during these years or if the weir was simply not able to record streamflow below a certain level. Q_{min} was highest in 2008 at 0.005 m^3/s.

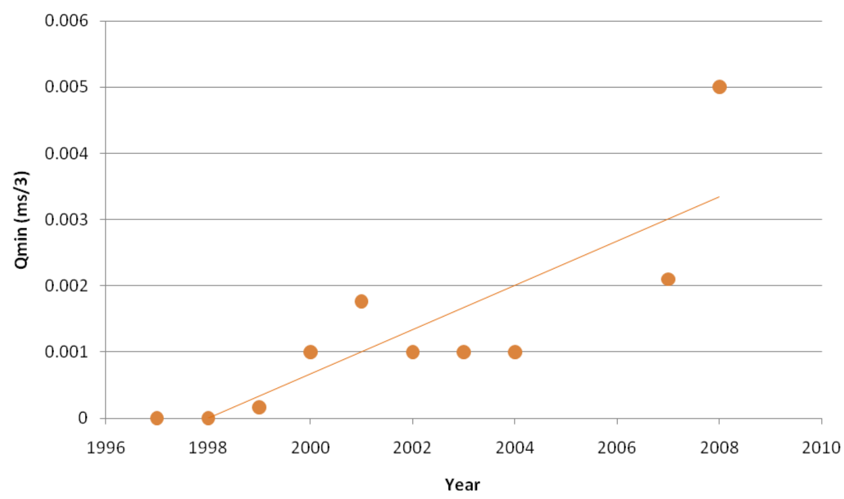

Figure 2.5. Annual 7-day low flows, Q_{min} (in m^3/s), for North Creek from 1997–2008.

5. Annual maximum discharge (Q_{max}) appears to have declined during the same period although the trend is only marginally significant (linear regression: $F = 4.4$, $p = 0.068$) (Figure 2.6, Table 2.1). Q_{max} was highest in 1997 at 4.7 m^3/s and lowest in 2000 at 1.74 m^3/s. As mentioned above, during the same period, there has been no significant trend in total annual precipitation at Abbotsford International Airport (YXX) during the same period.

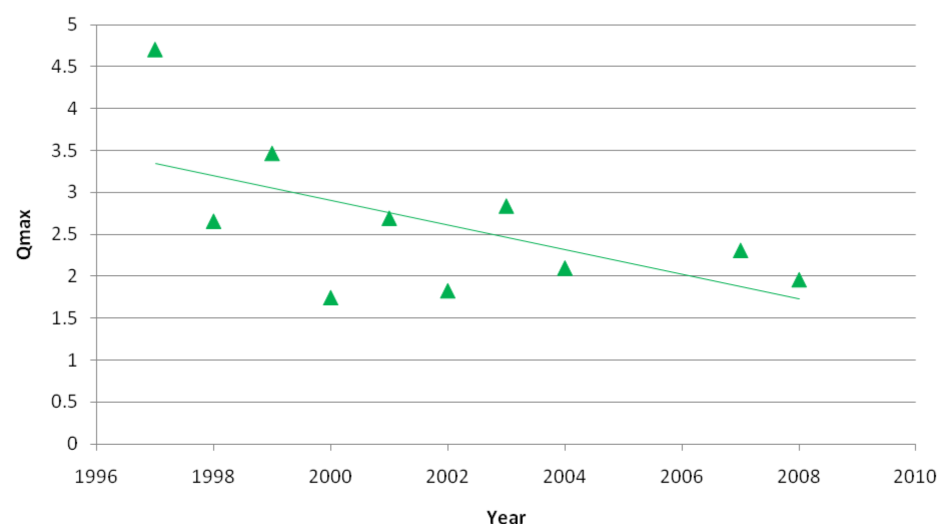

Figure 2.6. Annual maximum (instantaneous) discharge, Q_{max} (in m^3/s), for North Creek from 1997–2008.

6. In contrast to most urbanizing catchments, annual mean discharge exceedance (T_{Qmean}) in North Creek increased during the study period (linear regression: $F = 8.02$ $p = 0.025$) (Figure 2.7, Table 2.1). The cumulative number of days above annual mean discharge ranged from 64 days (in 2002; 17.5% of year) to 114 days (in 2008; 31.1% of year).

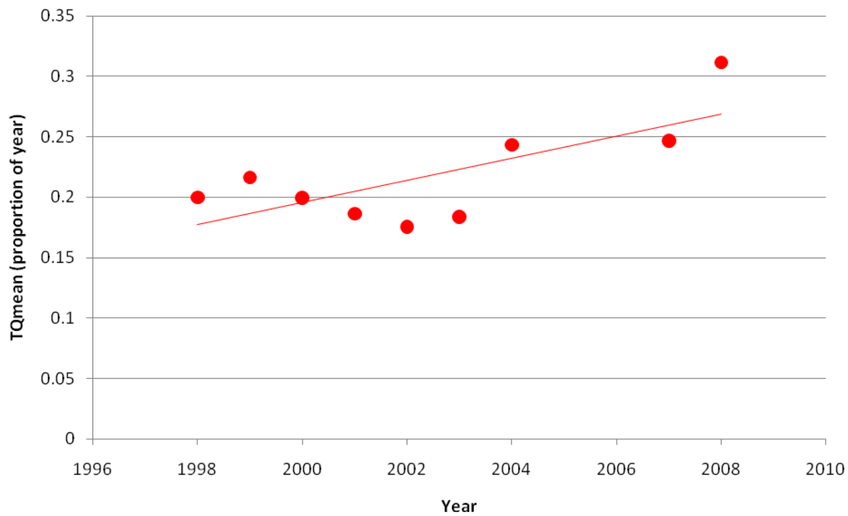

Figure 2.7. Annual mean discharge exceedance, T_{Qmean} (as a proportion of year), for North Creek from 1998–2008.

7. In contrast, half-year flood exceedance ($T_{0.5}$) showed a decreasing but non-significant trend towards lower values (linear regression: $F = 1.8$, $p = 0.22$) (Figure 2.8, Table 2.1). The cumulative number of hours where streamflow was above the half-year flood ranged from 0.3 hours in 2008 to 23.7 hours in 1999.

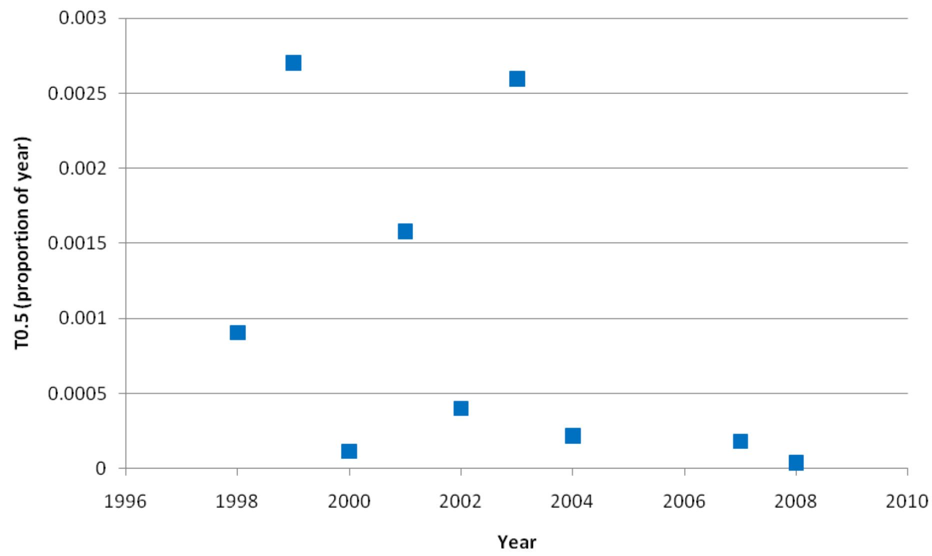

Figure 2.8. Half-year flood exceedance, $T_{0.5}$ (as a proportion of year), for North Creek from 1998–2008.

PART III – Water Quality Changes

Introduction

Five water quality parameters were monitored continuously in North Creek since 2002: (1) water temperature; (2) specific conductivity; (3) pH; (4) turbidity; and (5) dissolved oxygen. Dissolved oxygen data was excluded from analysis because probe failure or error frequently occurred. The other four are described in more detail below.

Water Temperature. Maintaining suitable water temperatures is important to the survival and growth of fish and other aquatic life in streams. Water temperatures can affect the development of fish eggs, rearing of juvenile fish, and the return of adult salmonids to spawn. Fish and invertebrate assemblages in Surrey's small streams are generally adapted to cold water conditions. Altered thermal regimes can be caused by changes to streamside vegetation affecting exposure to solar radiation, reductions or increases in streamflow volume, or thermal pollution from industrial sources.

Specific Conductivity. Specific conductivity is a measure of the ionic concentration of water; salts, metals, and other substances increase conductivity. Small streams in the Georgia Basin flowing from undeveloped forested areas typically have a specific conductivity below 75 µS/cm, while urbanized streams are typically >150 µS/cm. Rainwater is very low in ions (2–5 µS/cm) so specific conductivity declines rapidly during storms.

pH. pH measures the relative acidity or alkalinity of a solution based on the concentration of hydrogen ions. Stream pH level depends on the geology of the surrounding area, and usually falls between 6.5 and 8.0. Streams that drain soils with high mineral content usually are alkaline, whereas streams that drain coniferous forests usually are acidic. Changes in pH can indicate the presence of particular effluents that may be detrimental to aquatic life, such as road runoff or a spill. For example, the introduction of concrete wash water can raise pH to above 10. Most aquatic organisms are sensitive to small pH changes and prefer a near-neutral pH (7.0).

Turbidity. Turbidity is a measure of the amount of light intercepted by suspended particles in the water column, including sediments, microscopic organisms, and pollutants. It is typically measured in Nephelometric Turbidity Units (NTU)[4]. Turbidity often increases with urbanization,

[4] NTU = Nephelometric Turbidity Unit. The term *nephelometric* refers to the way the instrument estimates how light is affected by suspended particulate material in the water. A nephelometer, also called a turbidimeter, uses a photocell to estimate

particularly during the development process when land clearing occurs and stormwater drainage features are under construction. During precipitation events, sediments and pollution are washed off impervious surfaces and into streams and stormwater pipes. Increased peak flows may also increase channel erosion rates. Without proper sediment control measures, active land clearing and construction sites can introduce large amounts of fine and coarse sediment to the stream.

Questions. The following questions were asked regarding changes in water quality parameters:

1. Have there been any statistically significant trends in water quality parameters (water temperature, conductivity, pH, and turbidity) in North Creek from 1999–2009?

2. Has there been an increase/decrease from year-to-year in the frequency, magnitude, and duration of events in which water quality exceeds provincial and federal guidelines or other thresholds?

Methods

Monitoring Site and Probe Operation. Available water quality data from North Creek was collected as part of the City of Surrey's ongoing stormwater monitoring program. A water quality monitoring probe (multi-parameter sonde; YSI 6920) was installed in 2002 immediately downstream of Fraser Highway (Figure 3.1). The probe has logged measurements of water temperature, conductivity, dissolved oxygen, pH, and turbidity automatically at 15 minute intervals and data was downloaded manually every 30–45 days. Table 3.1 summarizes the sensor types, resolution, and range for each parameter. Measurements have been taken near continuously (see further details below) since 2002, except from August 2005 to December 2006 when the station was not operational. The station is currently maintained by staff from the Water Survey of Canada. All data is available from the City of Surrey or through KWL's Emerald Flowworks website (www.flowworks.com).

scattered rather than absorbed light. This measurement generally provides a very good correlation with the concentration of particles in the water that affect clarity.

Table 3.1. Summary of continuous stormwater monitoring parameters measured in North Creek.

Parameter	Sensor Type	Resolution	Range
Water Temperature	thermistor	0.01°C	-5°C – +50°C
Conductivity	4 electrode cell with autoranging	0.001–0.1 mS/cm (range dependent)	0–100 mS/cm
Dissolved Oxygen		0.01 mg/l	0–50 mg/l
pH		0.01 pH units	pH 0–14
Turbidity	Optical sensor with 90° scatter with mechanical swipe	0.1 NTU	0–100 NTU (2002–2004) 0–200 NTU (2004–2009)

Figure 3.1. Water quality monitoring site on North Creek (downstream of Fraser Highway). The PVC pipe on the left houses the probe.

Data Review and Correction. While data collection has been near-continuous, a number of factors have reduced the accuracy and completeness of the datasets. Typical errors include sensor calibration drift, sensor fouling, data outliers, and other technical issues with the sensors. Data was also not collected during downloading and calibration periods, or, in a small number of cases, due to human error. While some of these factors result in missing data or data gaps, other factors lead to inaccurate or incorrect measurements which must be excluded or corrected prior to statistical analysis or interpretation.

To account for the above issues, all data were validated and corrected prior to analysis. Data corrections were performed on the available water temperature, specific conductivity, pH and turbidity data collected during the time period of January 2002 to August 2009[5]. Data validation and correction consisted of joining downloaded data files into a single time series, removing sections of data where the probe was out of the water for downloading or calibration (as identified by a specific conductivity reading of 0 µS/cm) and removing any other sections of the data in error. Additionally, for the turbidity signal, offset corrections were conducted on each downloaded data segment to eliminate negative values. As well, an additional statistical filter, consisting of a 1-hour (4-point) moving minimum was to remove noise, which is typical of data from optical turbidity sensors.

A data correction history was logged as part of the data correction process. All data were validated, corrected, and gap filled using AQUARIUS Time Series Software.

Derivation of Specific Conductivity. Because conductivity varies with temperature, this can have a confounding effect when making comparisons between time periods or across watersheds. In contrast, specific conductivity (SC) normalizes conductivity to a temperature of 25°C, eliminating this complication and is a preferred measure of water quality in urbanizing catchments. Consequently, SC was used in subsequent analyses and was derived using the conductivity and temperature signals (point-by-point conversion) collected from North Creek based on the following relationship:

$$SC = \text{Conductivity} / (1 + 0.0191 \times (\text{Temperature} - 25))$$

Gap Filling for Turbidity Data. Turbidity sensors are susceptible to fouling or light scattering and often become non-functional for short periods of time. Therefore, to prepare the turbidity data for magnitude-duration analysis (see below), an additional process of linear interpolation was used to fill gaps in the data less than 30 hours (120 data points) in length. This gap filling was completed to minimize partial events in the analysis and better capture the duration of turbidity events that may extend on either side of such gaps but would be otherwise treated as separate events.

No gap filling has been conducted using either interpolation or modeling from surrogate signals for any of the other signals at this time.

[3] This excludes the period from August 2005 to December 2006 when the sampling was not operational as well as periods when individual sensors were not functioning correctly.

Analyses. To look at changes in the water quality of North Creek over the study period, we used the following statistical analyses were performed on the corrected water quality data:

1. Trend Analysis. We used parametric regression methods to look for trends in the four water quality time series (water temperature, conductivity, pH, and turbidity). Because of the sheer volume of data points, the signal was downsampled to a 1-day (1440-minute) time interval before conducting the analysis. Prior to analysis, each data series was examined for normality and both the conductivity and turbidity signals were log-transformed to improve fit. Missing data patterns were analyzed and data gaps were interpolated using daily average values. All four series were corrected for the assumptions of violation such as non-stationarity normality and an ARIMA (Auto-Regressive Integrated Moving Average) trend model was fitted after adjusting the data for potential seasonality through 12th differencing. Moving average trend models with lags 1 and 12 were found appropriate for all four series. The predicted (forecasted) and the actual data were plotted along with upper and lower 95% confidence lines and a trend line was fitted through the forecasted series. All trend analyses were conducted in SAS statistical software.

2. Descriptive Statistics. Annual minimums, maximums, and means (including standard deviation) were calculated for each parameter.

3. Exceedance. The number of days and the percentage of time spent in exceedance of recommended guidelines (such as the BC Water Quality (BCWQ) Approved Guidelines) were calculated for water temperature, pH, and turbidity. The BC Water Quality (BCWQ) Approved Guideline for water temperature depends on the fish species present within the stream. The recommended maximum temperature guideline for streams with rearing coho salmon and/or cutthroat trout is 17°C (versus 19°C for streams with unknown fish distribution and a +/- 1°C change from natural ambient background temperature for marine and estuarine environments). For pH, we calculated the amount of time spent above or below the recommended pH range for freshwater aquatic life of pH 6.5–9.0. For turbidity, we calculated the amount of time and the number of days that turbidity was in exceedance of 20 NTU. Because the BCWQ guidelines for turbidity are dependent on background turbidity levels in a stream[6], they are difficult to apply when there is a lack of concurrent baseline data and rapid watershed change is already occurring. Since research has shown that physiological and behavioural effects can begin to occur in salmonids at turbidity levels

[6] The BC Water Quality Approved Guideline for turbidity is 8 NTU for a duration of 24 hours when background is less than 8 NTU (undisturbed streams in coastal BC generally have a background turbidity level less than 5 NTU).

between 10–30 NTU (Bash et al., 2001), 20 NTU is an informative threshold for understanding potential effects on fish populations. (Similarly, 20 NTU was also used as the threshold to define the start and end of turbidity events for magnitude-duration analysis – see further details below.) There are no provincial guidelines for specific conductivity. However, based on the range of specific conductivity values in the data, we chose 1000 µs/cm as an informative threshold to look at change over time.

4. Magnitude-duration Analysis (turbidity only). Newcombe (2003) proposed a method to assess potential 'severity of ill effects' (SEV) of turbidity on clear water fishes that takes into account both the magnitude and duration of events, since short-duration high turbidity events as well as chronic exposure to lower turbidity levels can have detrimental effects on fish. Using available scientific literature and consensus-based peer consultation, Newcombe developed an index identifying a series of threshold turbidity events which define the onset of ill effects caused by excessive turbidity to clear water fishes and conditions under which the rates of serious ill effects are likely to escalate (Newcombe 2003). SEV index scores can be calculated and used to determine whether the effect of turbidity events on fish is nil ($SEV<0.5$), minor ($0.5 \leq SEV<3.5$), moderate ($3.5 \leq SEV<8.5$), or severe ($SEV \geq 8.5$) (see Appendix C1 for more information). For the purposes of our analyses, we defined a turbidity event as a period during which turbidity exceeded 20 NTU and consider a turbidity event to potentially impact fish populations only if $SEV \geq 0.5$.

Results

Water Temperature. Water temperature in North Creek showed an increasing trend from 2002–2009 (chi-square test: $p < 0.0001$) (Figure 3.2). Seasonal variation was not significant ($p > 0.05$) meaning that there was no difference in the observed trend when seasons were examined separately.

Over the study period, water temperatures ranged from 0.0°C to 22.5°C, with an overall mean temperature of 12.3°C (SD=5.0°C) (Table 1 in Appendix C2). The three highest annual mean temperatures were in 2004 (16.5°C), 2005 (16.5°C) and 2007 (13.6°C) (Table 1). The four lowest annual mean temperatures were in 2002 (10.2°C), 2003 (11.3°C), 2008, and 2009 (11.8°C in both years).

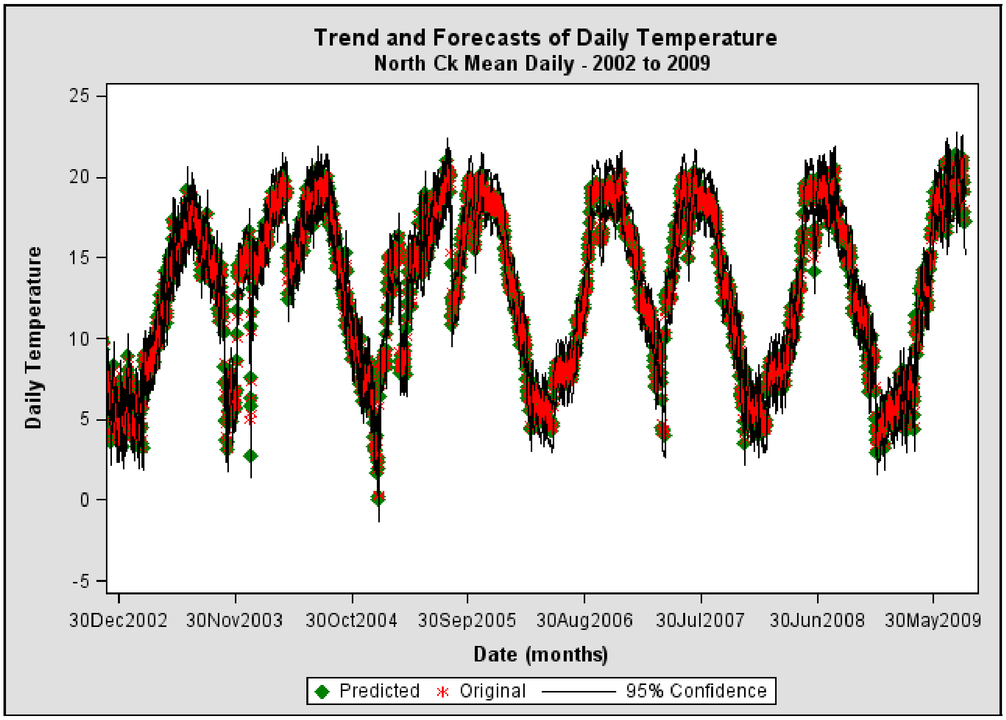

Figure 3.2. Actual and predicted mean daily water temperature in North Creek with 95% confidence band. There was an increasing trend observed from 2002–2009.

Across the entire period for which data was available, water temperature exceeded 17^{o}C (the BCWQ guideline for streams containing rearing coho salmon and cutthroat trout) 22.1% of the time and ranged from a low of 1.1% in 2002, the first year of the study period, to 41.3% in 2005 (Table 1 in Appendix C2). Exceedance was highest in 2004, 2005, and 2007 (no monitoring occurred in 2006). Since 2004, water temperatures have been above 17^{o}C for a cumulative 40 days or more in every year for which data were collected.

Specific Conductivity. Specific conductivity in North Creek has increased from 2002–2009 (chi-square test: $p < 0.0001$) (Figure 3.3). There was no significant difference in this observed trend between seasons ($p > 0.05$).

During the study period, specific conductivity in North Creek increased from values typical of catchments with low-moderate levels of development (around 100 uS/cm) to values more typical of a highly urbanized catchment. Year-over-year increases in annual mean specific conductivity occurred every year from 2002–2009 (Table 2 in Appendix C1). Annual mean specific conductivity increased from 113.2 µS/cm in 2002 to 502.8 µS/cm in 2009. The largest year-over-year increases occurred between 2003 and 2004 and between 2008 and 2009.

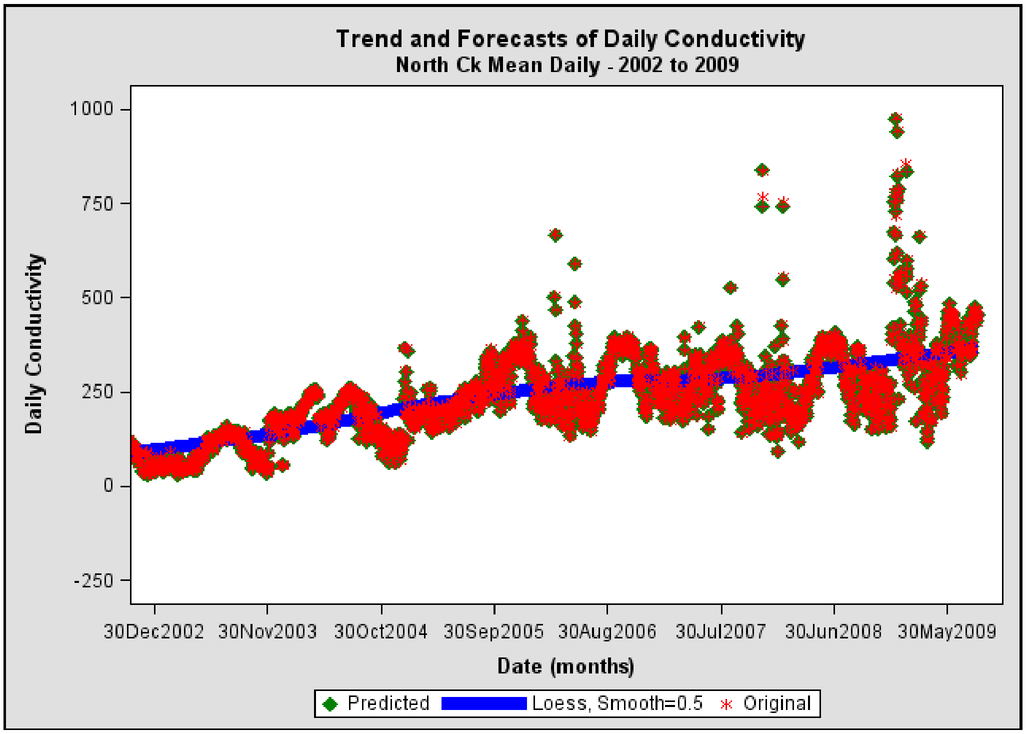

Figure 3.3. Actual and predicted mean daily conductivity in North Creek with 95% confidence band. There was an increasing trend observed from 2002–2009.

The lowest instantaneous specific conductivity was measured in 2003 (29.3 µs/cm) and the highest was measured in 2009 (6392.2 µs/cm) (Table 2 in Appendix C2). The low value appears related to a large rainfall event in March 2003. The high value appears related to winter road salting and snowmelt runoff in March 2009.

Exceedance of the 1000 µs/cm threshold occurred for the first time in the data in 2005 and exceedance rates increased year-over-year from 2005 (0.2%, 0.3 days total) to 2009 (4.3%; 6.8 days total) (Table 2 in Appendix C2). The largest peaks in specific conductivity (those greater than the threshold) appear to be associated with runoff from winter road salting. The expansion of the road network in the East Clayton area increases the use of salt for road de-icing.

pH. pH in North Creek showed a slightly increasing trend across the study period, but the trend was not significant (chi-square test: $p > 0.05$) (Figure 3.4). Additionally, there were no observed trends on a seasonal basis.

Instantaneous pH values in North Creek ranged from 6.3 (in November 2003) to 9.6 (in May 2005) with an overall mean of 7.6 (SD=0.3) across the study period (Table 3 in Appendix C2). Annual mean pH values for North Creek ranged from 7.3–7.8.

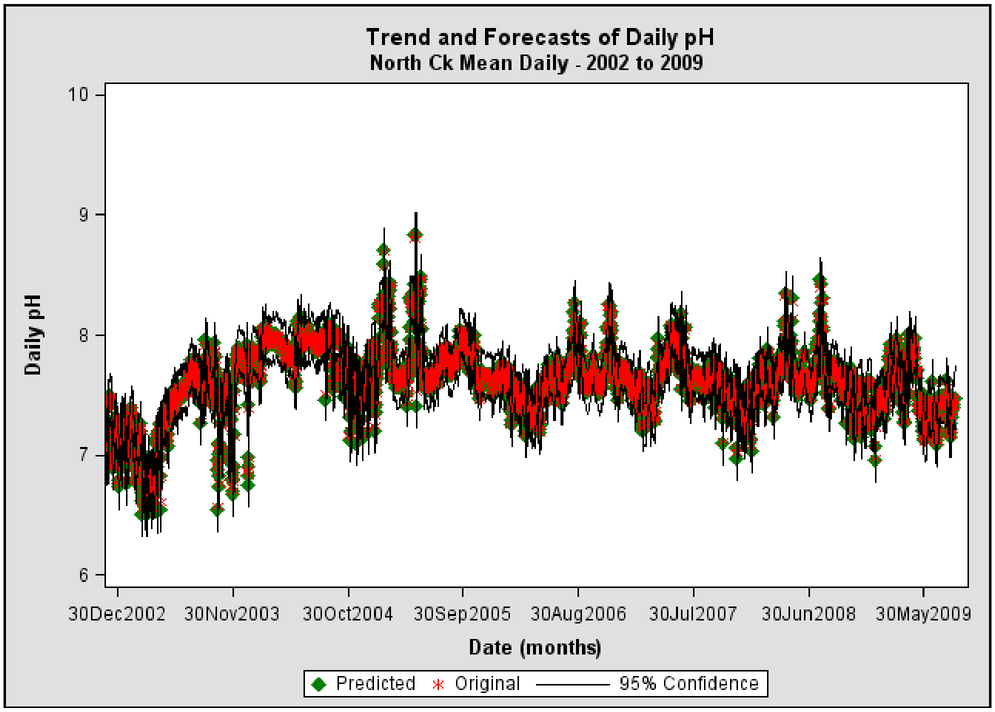

Figure 3.4. Actual and predicted mean daily pH in North Creek with 95% confidence band. There was no statistically significant trend observed from 2002–2009.

Exceedances of pH values above or below recommended BCWQ guidelines occurred only in two years (Table 3 in Appendix C2). pH dropped below 6.5 for a cumulative 2.4 days in 2003. These low pH values occurred on several occasions over the course of the year and are not attributable to a single event. In contrast, pH rose above 9.0 only on one occasion for a single 19-hour period in 2005. This event may be attributable to a spill of concrete wash water from construction activities or a similar event. Spikes in pH were observed on several other occasions (Figure 3.4).

Turbidity. Turbidity levels in North Creek decreased from 2002–2009 (chi-square test: $p < 0.0001$) (Figure 3.5). However, the pattern of the trend appears to be more accurately described as humped-shaped rather than linear. From the graph, it can be seen that daily mean turbidity values increased from 2002–2003, reached a peak from 2003–2004, and decline from 2004–2009. A simple trend analysis does not capture this pattern.

Instantaneous turbidity values measured in North Creek ranged from 0 NTU to 199.7 NTU[7] (Table 4 in Appendix C2). Over the period covered by the data, mean turbidity was 18.6 NTU

[7] Due to limits on the range of the turbidity sensor, high turbidity values >100 NTU from 2002–2004 and >200 NTU from 2004–2009 were simply measured as the upper sensor limit. This limitation affects the accuracy of the reported results, including maximum values, means, and standard deviations. It does not affect minimum or exceedance values.

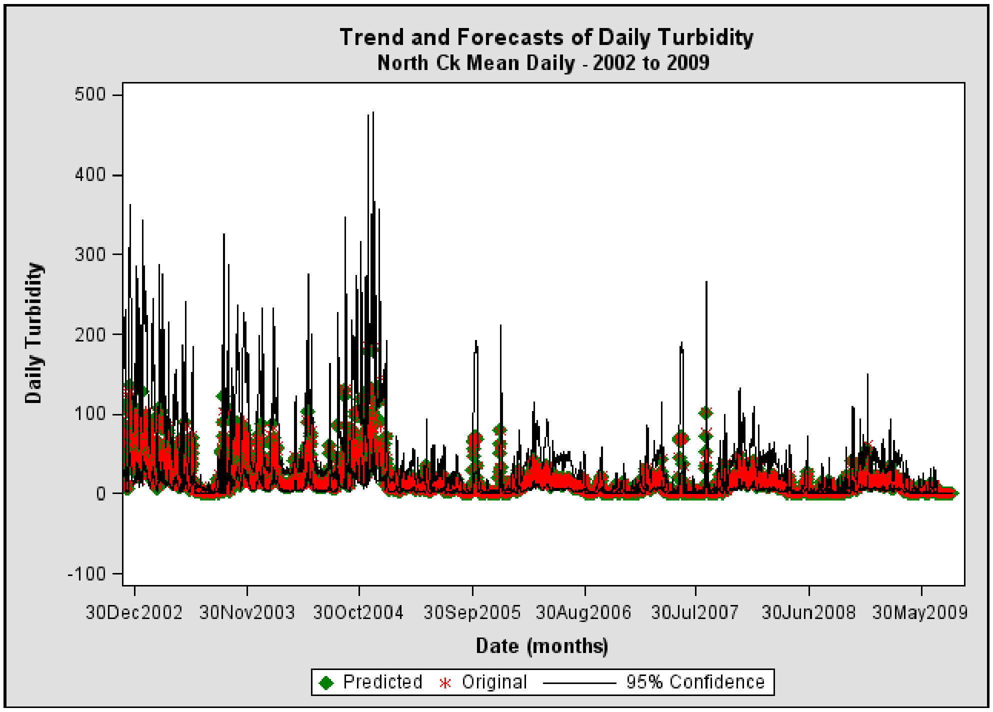

Figure 3.5. Actual and predicted mean daily turbidity in North Creek with 95% confidence band. There was no statistically significant trend from 2002–2009.

(SD=25.9). Annual mean turbidity values rose from 2002–2004 and declined steadily from 2004–2009. The two years with the highest mean turbidity values occurred in 2003 (32.5 NTU) and 2004 (37.9 NTU). The two years with the lowest mean turbidity values occurred in 2002 (9.1 NTU) and 2009 (9.4 NTU). Variability in turbidity was also highest in 2003–2004.

Over the study period, annual exceedance of 20 NTU ranged from 8.5% (11.2 days total) in 2009 to 55.9% (124.2 days total) in 2004 (Table 4 in Appendix C2). Exceedance was significantly higher in 2003 and 2004 than in any other years at 54.0% and 55.9%, respectively which coincided with initial land clearing. Exceedance was below 20% in all other years.

Based on the magnitude-duration analysis, no turbidity events which would be classified as 'severe' (SEV ≥8.5) occurred during the study period, although at least one 'moderate' event (3.5≤SEV<8.5) occurred every year from 2002 to 2009 (Table 3.2). A greater number of turbidity events classified as moderate occurred in 2003 and 2004 than in all other years combined, 27 and 16 events, respectively.

Table 3.2. Number of North Creek turbidity events (>20 NTU) in each severity-of-ill-effects (SEV) score class as per Newcombe (2003).

Year	Number of turbidity events by SEV score			
	Nil	**Minor**	**Moderate**	**Severe**
2002	14	23	5	0
2003	18	25	27	0
2004	25	25	16	0
2005	25	15	2	0
2006	-	-	-	-
2007	34	17	6	0
2008	87	54	7	0
2009	55	21	1	0

While it appears that the number of moderate events has declined over the study period, the trend is not significant (linear regression: $F = 1.8$, $p = 0.24$). In constrast, the number of minor turbidity events has remained consistent or may have even increased though there is also no significant trend (linear regression: $F = 0.44$, $p = 0.54$). The highest number of minor turbidity events occurred in 2008 (54 events). This suggests that moderate and minor turbidity events may have different causes.

PART IV – Benthic Invertebrate Community Changes

Introduction

Benthic (streambed) invertebrates in small streams are influenced by natural and human activities that occur throughout the upstream catchment. Numerous management agencies in the Pacific Northwest use them as indicators of stream health because they experience the hydrologic, chemical, and physical conditions that occur throughout the year. In urbanizing watersheds the composition and structure of the benthic invertebrate community shows a predictable response including declining taxa richness, loss of sensitive species, and increasing dominance of a few tolerant species (Karr, 1998; Cuffney et al., 2009).

The City of Surrey has monitored benthic invertebrates in 29 stations encompassing 19 streams and rivers since 1999 including two stations on North Creek (N1 and N2): Station N1 is approximately 35 m upstream of the culvert under Fraser Highway, and Station N2 is 165 m downstream of the 180th Avenue right-of-way (see Figure 1.3). Sampling is undertaken in spring (late-April) and in fall (early-November). This is the largest benthic invertebrate monitoring program in Metro Vancouver.

Benthic invertebrate data is summarized using a 10-metric benthic index of biological integrity (B-IBI) system developed for small streams in Puget Sound (Karr, 1998; Karr and Chu, 1999; Fore *et al.*, 2001). B-IBI is a numeric index composed of metrics that summarize information on the taxa richness and structure of benthic invertebrate assemblages. The metrics selected for inclusion in the Pacific Northwest B-IBI were derived from numerous regional studies (Karr, 1998). B-IBI values from a 10-metric scoring system range from 50 (indicating best condition) to 10 (indicating poorest condition).

Questions. Analysis of benthic invertebrate community change in North Creek between 1999–2009 focused on the following questions. Most of the questions emphasize changes at Station N1 which is most directly affected by land use change in the East Clayton neighbourhood:

1. What is the trend in B-IBI between 1999–2009 in North Creek? Are there differences between B-IBI values between fall and spring sampling periods or between Stations N1 and N2?

2. Has total taxa richness or EPT taxa richness changed over time between 1999–2009 in North Creek? Are total taxa richness or EPT taxa richness different between Stations N1 and N2?

3. Which B-IBI metrics have caused changes in B-IBI values in North Creek Station N1?

4. Are there specific taxa whose presence or abundance are driving observed compositional changes over time? If so, which taxa are changing and how are they changing?

Methods

Field Sampling. Samples were collected at two stations on North Creek between 1999–2009 in spring and fall (see Appendix D1; Figure 4.1 for Station N1). At each station, three replicate samples were collected with a 250 micron Surber sampler (1 Surber placement per jar) from riffle habitats. Substrate within the 30 x 30 cm sampler frame was disturbed with a trowel or rake for one minute to a depth of 5–10 cm and invertebrates and debris was swept into the Surber net. Invertebrates adhered to large substrates were dislodged using a soft brush. All material within the Surber sampler net was rinsed through a 250 micron secondary screen and carefully transferred to 500 ml plastic bottles. Samples in 2008–2009 were preserved with a 10% formalin solution in the field to fix soft-bodied organisms. After 2–4 weeks, samples were rinsed and preserved with 85% ethanol (final concentration 40–70% ethanol). Sample preservation methods for samples from 1999–2007 were not defined.

Figure 4.1. Stream character at benthic sampling location at North Creek Station N1 Upstream of Fraser Highway).

Laboratory Processing and Identification. Sorting, subsampling, and identification of City of Surrey benthic invertebrate samples was undertaken by three different consultants since 1999 using slightly different methods:

1. Applied Technical Services identified samples from 1999–2002 and spring 2004. They used a semi-quantitative subsampling method and identified most organisms to species or genus including Chironomidae (midges) to genus, Oligochaeta (worms) to species, and Acari (mites) to genus. A reference collection was not developed although there are some subsamples archived from 1999.

2. Biologica Environmental Services identified samples from 2003, fall 2004, 2005, and 2006. They used a Folsom Plankton Splitter for subsampling, and identified most organisms to species or genus, Chironomidae to genus, Oligochaeta to species, and Acari to genus. There is a reference collection for all the samples collected in 2006.

3. Rhithron Associates identified all samples from 2007–2009. They used a Caton grid for subsampling, identified organisms to lowest practical taxonomic level based on Plotnikoff and White (1996) which includes Chironomidae to subclass, Oligochaeta to family, Acari to subclass. They have created a reference collection encompassing all taxa encountered from 2007–2009.

Data Review and Correction. Three steps were used to improve the consistency of the dataset. First, taxonomic names in the historic data were corrected using standard resolution requirements and taxonomic conventions. The master taxa list was a compilation of all taxonomic names from all historic data spreadsheets (for samples processed from 1999–2006) and an extraction of names from Rhithron's database (for 2007–2009 samples). Changes to taxonomic names in the historic data were verified by consulting information from the Integrated Taxonomic Information Service (USDA: http://www.itis.gov/). Changes were consistent with current industry standards for lowest practical taxonomic resolution, which is the protocol required for use of the B-IBI.

Second, some species-level data was amalgamated ("rolled up") to create a dataset with a consistent taxonomic standard. Plotnikoff and White (1996) was selected as the most appropriate taxonomic standard because it is a balance of high taxonomic resolution and practicality. In particular, this standard reduced identification time and lab costs for Chironomids, Oligochaetes, and mites (Acari).

Third, we removed all non-unique taxa from the dataset. These are typically juvenile or damaged individuals that cannot be conclusively identified. If they are left in the dataset, they can inflate taxa richness because they are interpreted as "unique" taxa. For non-unique individuals in the Baetid family, we added them to *Baetis tricaudatus* and *Baetis bicaudatus* based on the proportions of these taxa in other samples from the same stream. Terrestrial insects were removed from the dataset.

B-IBI Calculation. B-IBI index values were calculated for each replicate sample using a 10-metric scoring system developed for Puget Sound (Appendix D2; Fore *et al.*, 2001). Expectations for metrics included in the B-IBI were derived from values observed for stream invertebrate communities in undisturbed streams (Karr and Chu, 1999). To calculate B-IBI, each metric was scored as a 5, 3 , or 1 according to whether they are similar to values observed at reference sites (score = 5), deviate somewhat from expected values (3), or deviate substantially from expected values (1). Scores are summed to obtain an overall B-IBI value. Life history trait information used for B-IBI metric scoring was based on a current dataset maintained by Rhithron Associates.

For all analyses of temporal changes, mean B-IBI values were used (mean of 3 replicate samples from each station).

Taxa Richness Calculation. Taxa richness and EPT (stonefly, mayfly, and caddisfly) taxa richness values used in the analysis were calculated as the sum of all taxa found in a station (composite of 3 replicate samples).

Analyses. Four analyses were undertaken to answer the research questions defined previously:

1. Regression analysis (linear and non-linear (quadratic)) was used to measure trends in mean B-IBI, total taxa richness, and total EPT taxa richness over the entire study period at Stations N1 and N2.

2. Differences in mean B-IBI, total taxa richness, and total EPT taxa richness were tested using paired t-rest. We compared differences between spring and fall sampling periods, and between N1 and N2 sampling stations.

3. Trends in individual B-IBI metrics were not analyzed statistically but were assessed using non-parametric spline fits which show the general direction and magnitude of change. As well, we examined scoring changes to determine which metrics affected overall B-IBI values.

4. Taxa-specific changes (loss of species, establishment of species, pronounced changes in abundance) were assessed using a combination of indicator species analysis and qualitative review of data.

Results

Changes to B-IBI. Mean B-IBI value (mean of 3 replicate samples) has increased significantly at the North Creek Station N1 since 1999 (Table 2.1; Figure 2.2). In contrast, mean B-IBI value at North Creek Station N2 has declined since 1999 although the change is not statistically significant (Table 4.1; Figure 4.2). B-IBI change at Station N2 had more of a hump-shaped pattern, but the non-linear regression (quadratic) relationship was not significant.

Table 4.1. Changes in B-IBI values, total taxa richness, and total EPT taxa richness for North Creek Stations N1 and N2 (1999–2009). The co-efficient of determination (r^2) and significance values (p) are provided for linear and non-linear (quadratic) regression results.

Parameter	Linear	Quadratic
B-IBI - Station N1	r^2 = 0.27, p = <u>0.0155</u>	r^2 = 0.29, p = <u>0.0456</u>
B-IBI - Station N2	r^2 = 0.01, p = 0.6414	r^2 = 0.30, p = 0.0504
Total Taxa Richness - Station N1	r^2 = 0.05, p = 0.3604	r^2 = 0.60, p = <u>0.0003</u>
Total Taxa Richness - Station N2	r^2 = 0.00, p = 0.7804	r^2 = 0.12, p = 0.3476
Total EPT Taxa Richness - Station N1	r^2 = 0.03. p = 0.4232	r^2 = 0.34, p = 0.3766
Total EPT Taxa Richness - Station N2	r^2 = 0.06, p = 0.2988	r^2 = 0.01, p = 0.0920

Significant changes are underlined.

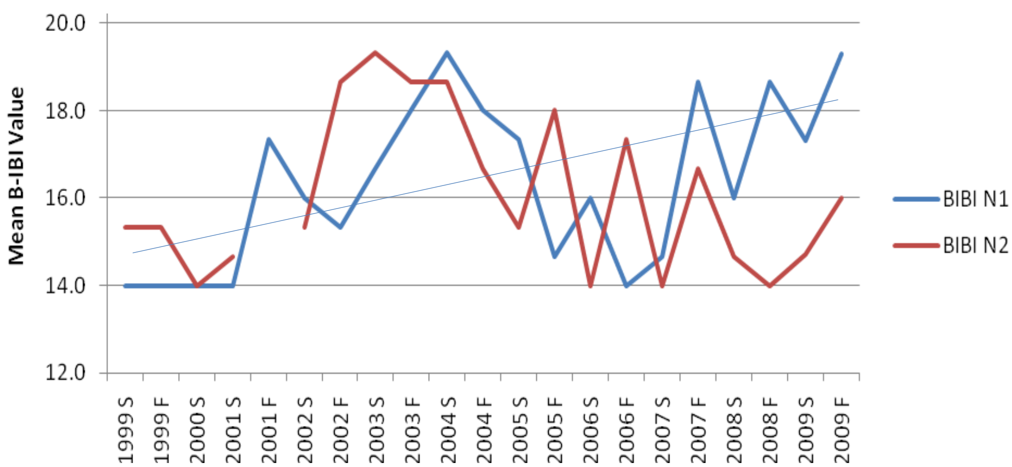

Figure 4.2. Differences in mean B-IBI values in North Creek Stations N1 (blue) and N2 (red) between 1999–2009. The significant linear regression trend in B-IBI in Station N1 is shown with a blue line (the trend at Station N2 was not significant).

Differences in B-IBI between Sampling Stations and Seasons. Mean B-IBI values in Stations N1 and N2 were not significantly different over the study period (Table 4.2). As well, mean B-IBI values for samples collected at spring and fall at the same sampling station (e.g., N1 spring vs. N1 fall) were not significantly different (Figure 4.3). Similarly, there were no significant differences in mean B-IBI value between spring (e.g., N1 spring vs. N2 spring) and fall samples between the two sampling stations. This suggests that sampling two seasons per year may not provide additional information on trends in stream health. The highest mean value at Station N1 was 19.3 in May 2004, and 19.3 in May 2003 in Station N2 (Table 4.2; Appendix D1).

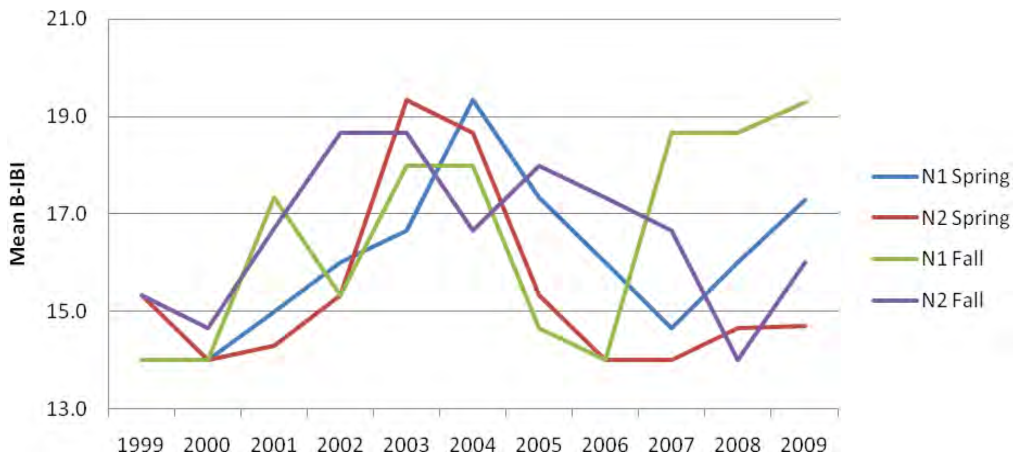

Figure 4.3. Differences in mean seasonal (spring and fall) B-IBI values in North Creek Stations N1 and N2 between 1999–2009.

Table 4.2. Summary of mean B-IBI values, total taxa richness, and total EPT taxa richness for North Creek Stations N1 and N2 (1999–2009). P-value (test for significant difference between N1 and N2 or seasonal pairs of samples) using a paired t-test, is also shown.

Parameter	Station N1	Station N2	P-value*
Number of samples (1999–2009)	21	20	-
Mean B-IBI value and standard deviation	16.3 (1.9)	16.1 (1.8)	0.6615
Maximum and minimum mean B-IBI values	14.0, 19.3	14.0, 19.3	-
Mean spring B-IBI value and standard deviation	16.3 (1.7)	15.6 (1.8)	0.4381
Maximum and minimum mean spring B-IBI values	14.0, 19.3	14.0, 19.3	-
Mean fall B-IBI value and standard deviation	16.3 (2.2)	16.6 (1.7)	0.0582
Maximum and minimum mean fall B-IBI values	14.0, 19.3	14.0, 18.7	-
Difference between N1 spring and N1 fall B-IBI			0.4381
Difference between N2 spring and N2 fall B-IBI			0.0582
Total taxa richness and standard deviation	19.3 (4.6)	22.8 (5.5)	<u>0.0129</u>
Maximum and minimum total taxa richness	8, 27	13, 33	
Total EPT taxa richness and standard deviation	3.8 (2.0)	9.3 (2.4)	<<u>0.0001</u>
Maximum and minimum total EPT taxa richness	1, 8	6, 14	

* significant difference using paired t-test are underlined.

Trends in Taxa Richness. Total taxa richness and EPT taxa richness showed a similar trend at both sampling stations. Both measures of taxa richness were lower before 2001, peaked between 2002–2004, and then declined (Figures 4.4 and 4.5). Non-linear (quadratic) regression showed a significance unimodal peak in taxa richness at the midpoint of the study period at Station N1, but not at Station N2. Changes in total EPT taxa in Stations N1 and N2 did not show a significant linear or non-linear response, but the pattern of highest taxa richness between 2002–2004 is apparent in Figure 4.4.

The cause of the increase and then gradual decline of taxa richness is unclear, but is likely associated with changing stream conditions caused by land use change in the East Clayton catchment. Warmer temperatures and increased nutrients from fine sediment may have provided additional resources which allowed new taxa to establish. The peak in taxa richness at the mid-point of the study is likely caused by the establishment of new invertebrate taxa tolerant of conditions in urban streams, while at the same time more sensitive taxa were still present. The more recent decline is caused by the subsequent loss of sensitive taxa.

Differences in Taxa Richness between Sampling Stations. Total taxa richness was significantly higher at Station N2 than Station N1 (Figure 4.4; Table 4.2). Similarly, total EPT taxa was significantly higher at Station N2 (Table 4.2). Figure 4.5 shows the dramatic difference in EPT taxa richness between Station N1 and N2 (mean of 3.8 vs. 9.3).

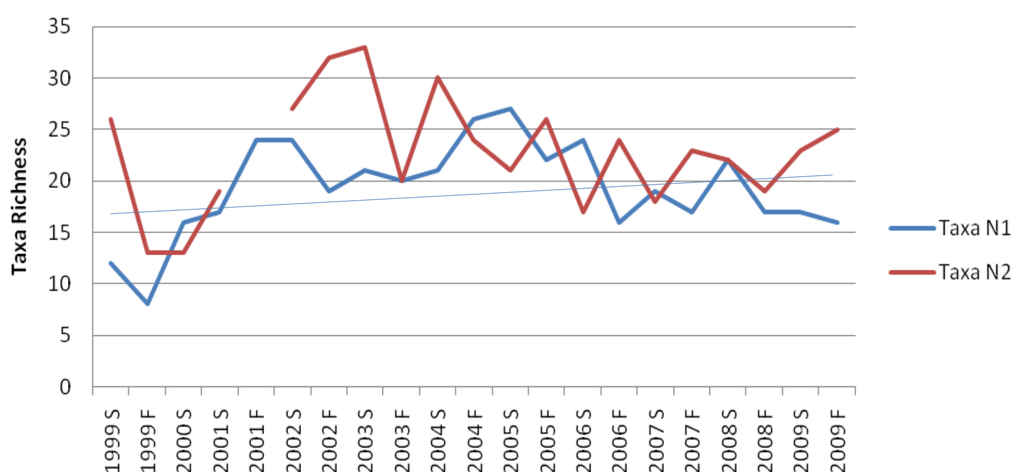

Figure 2.4. Total taxa richness values in North Creek Stations N1 (blue) and N2 (red) between 1999 –2009. The significant linear regression trend in B-IBI in Station N1 is shown with a blue line (the trend at Station N2 was not significant).

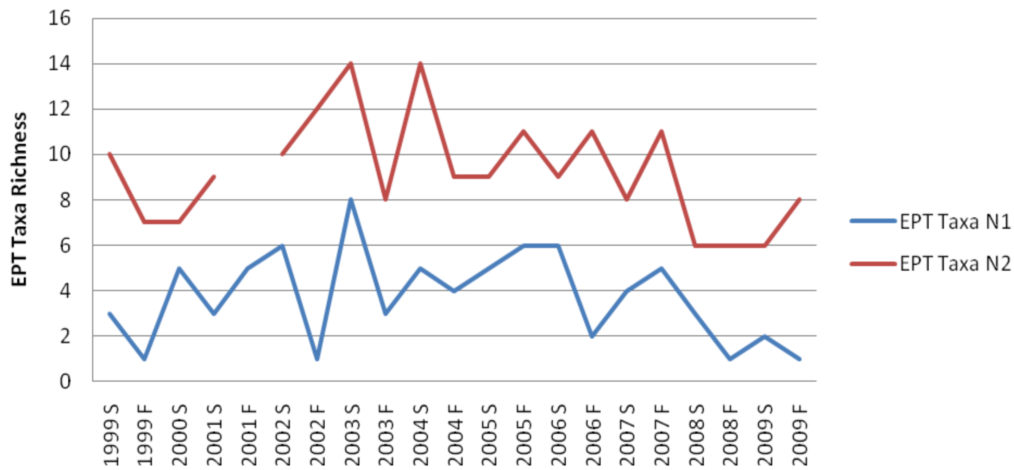

Figure 4.5. Mean seasonal B-IBI values in North Creek Stations N1 (blue) and N2 (red) between 1999–2009. Neither trend was statistically significant.

Changes to B-IBI Metrics. Changes to mean B-IBI in Station N1 was driven by changes to only four of the ten component metrics: total number of taxa (Metric 1); % of tolerant organisms (Metric 7); % of predator organisms (Metric 8); and % dominance (Metric 10). Figure 4.6 and Appendix D4 provide a graphical depiction of B-IBI metric changes in Station N1. These changes are discussed in more detail below.

- Total Number of Taxa. Total taxa richness includes all the different invertebrates collected from a stream site: mayflies, caddisflies, stoneflies, true flies, midges, clams, snails, and worms. As described previously, taxa richness was lower in the first three years of the study period, increased between 2002–2004, and then declined.

- Percent of Tolerant Organisms. Organisms that are tolerant of poor water and habitat quality are present at most stream sites, but as disturbance increases, they represent an increasingly large percentage of the assemblage. Invertebrates designated as tolerant represent the 5–10% most tolerant taxa in a region.

  The percent of tolerant organisms has generally increased since 2004 but only affected B-IBI metric scoring in fall 2007 and spring 2008 (Figure 4.6).

- Percent of Predator Organisms. Predator taxa represent the peak of the food web and depend on a reliable source of other invertebrates that they can eat. The percentage of animals that are obligate predators provides a measure of the trophic complexity supported by a site. Less disturbed sites support a greater diversity of prey items and a variety of habitats in which to find them.

An increase in the % of predator individuals (Metric 8) has had the largest effect on mean B-IBI values at North Creek Station N1 (Figure 4.6). The abundance of predator individuals rapidly increased since 2007 even though the number of predator taxa declined. The increase has been large enough for the scoring for Metric 8 to go from 1 point to 5 points (see Figure 2.4) resulting in a significant increase in B-IBI described previously. The increase in predator individuals is primarily caused by the increase in abundance of *Turbellaria* flatworms which thrive in fine sediments common in urban streams. However, they are more abundant in North Creek than in other urbanized streams in the City of Surrey.

- Percent Dominance. As diversity declines, a few taxa generally dominate the benthic invertebrate community. Opportunistic species that are less particular about where they live replace species that require special foods or particular types of physical habitat. Dominance is calculated by adding the number of individuals in the three most abundant taxa and dividing by the total number of individuals collected in the sample.

  Despite the general pattern observed in urbanizing streams, percent dominance has declined in North Creek during the study period. When the most abundant three taxa account for >80% of individuals in a sample, it is a sign of stress (metric score of 1). While dominance has been variable, it has averaged 80% in the past three years resulting in a higher B-IBI metric score (see Figure 4.6). The most abundant taxa have been Oligochaete worms, *Chironomid* midges, the flatworm *Turbellaria*, and the isopod *Caecidotea*.

  We also found that there has been a significant increase in evenness which typically indicates a more stable and less stressed community. Evenness is the equality of abundance of different taxa in a community (Magurran, 2004).

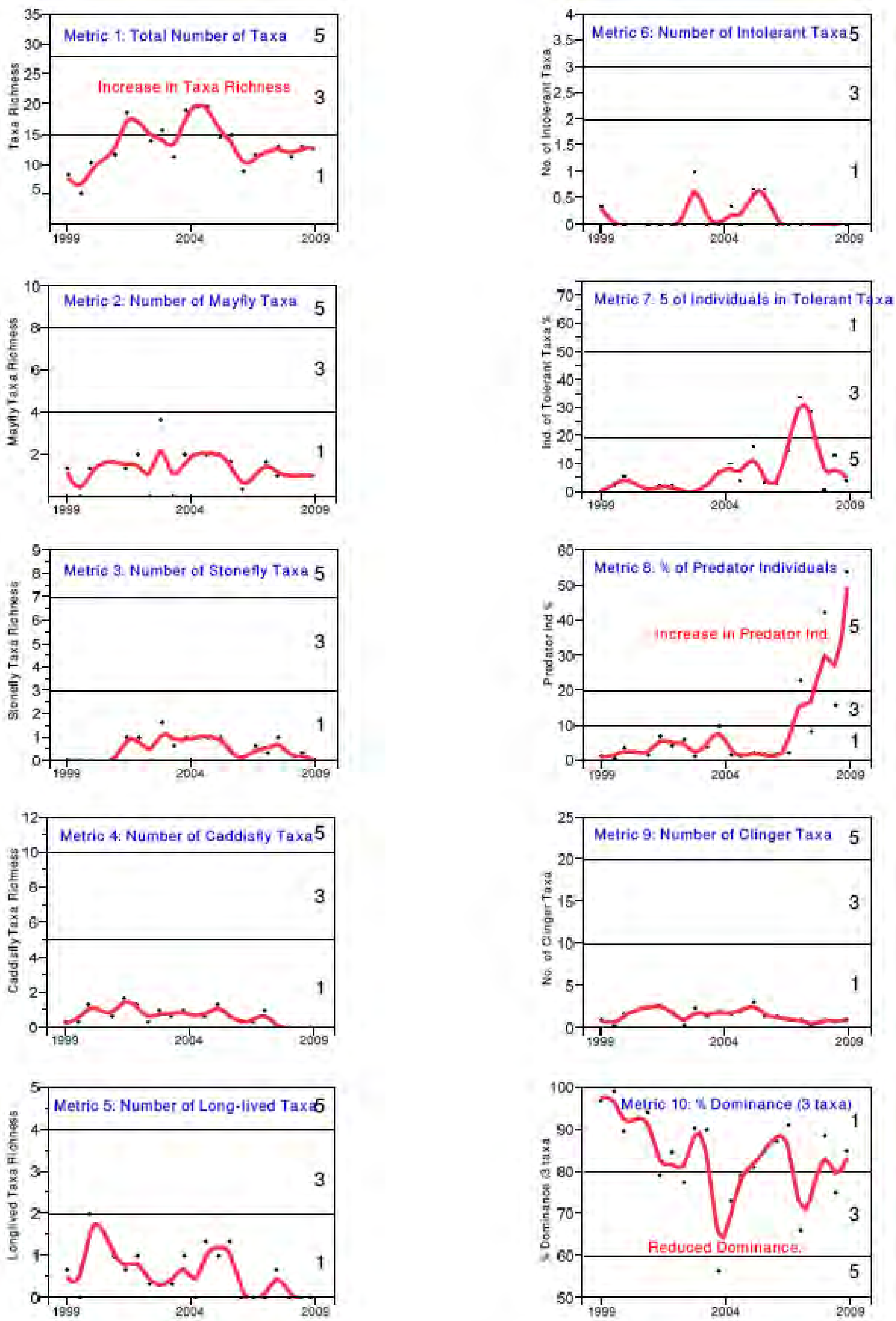

Figure 4.6. Changes in B-IBI metric values at North Creek Station N1 between 1999 –2009. The red lines is a spline fit showing the general pattern of changes in abundance or richness of taxa in different group. Metric scores (1, 3, or 5) are shown graphically.

Taxa Changes. As an initial review, we examined changes to five functional groups of benthic organisms: collector-filterer, collector-gatherer, predator, scraper, and shredder (see Figure 4.7). Three patterns were apparent. First, there is a general hump-shaped pattern to most functional groups with low values before 2001, an increase between 2001–2006, and a decline since 2007. This pattern was not tested statistically. Second, collector-gatherer taxa have increased over the study period. Finally, scraper taxa have declined including the loss of snails such as Helisoma, Planorbidae, and Lymnaeidae.

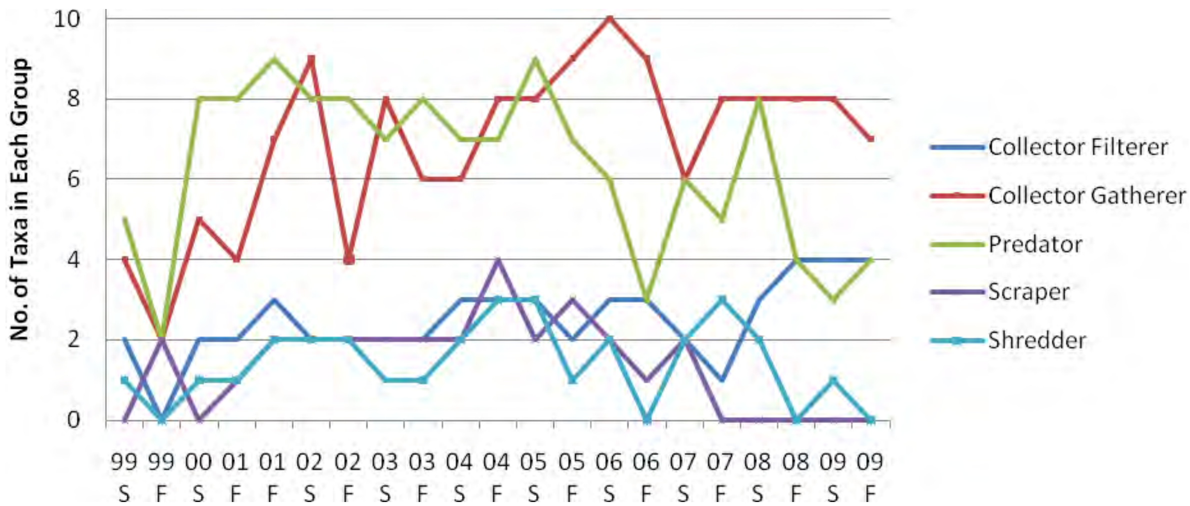

Figure 4.7. Changes in benthic invertebrate taxa richness by functional group (1999–2009).

The presence or abundance of several taxa has undergone noteworthy changes over the study period at Station N1 (see Appendix D5). We have separated these into four groups of taxa: (1) taxa that have declined or been eliminated; (2) taxa who were only present during the middle part of the study period (transient presence); (3) new taxa that established around 2003 (early establishment); and, (4) new taxa that established around 2006 (recent establishment). We selected six taxa to illustrate these patterns (Figure 4.8).

- <u>Declining.</u> A broad group of benthic taxa have been eliminated or declined to remnant populations in North Creek Station N1 between 1999–2006. They include *Ramellogammarus* amphipods, the nemourid stonefly *Zapada*, Hirudinea (leaches), *Paraleptophlebia* mayflies, *Probezzia* midges, *Helisoma* snails, Copepods (crustaceans), and the caddisfly *Rhyacophila*. Ostracods (a small shrimp-like crustacean) declined substantially but persisted. Many of these taxa also declined or were eliminated from Station N2 during this same time. Most of these taxa are found in moderately urbanized streams in Metro

Vancouver, and their decline or elimination indicates a change to more heavily urbanized conditions in North Creek.

- Transient Presence. *Planorbidae* snails and *Hydrozoa* (hydras) were present between 2003–2006.

- Early Establishment. *Malenka* (stonefly) , Ceratopogoninae (biting midges), and the amphipod Corixidae established or were first detected around 2003, although only Ceratopogoninae, and the amphipod Corixidae are abundant (Malenka presence is variable).

- Recent Establishment. Since 2006 *Turbellaria* flatworms, *Caecidotea* isopods, *Hyalella* amphipods, and *Cyclopoida* (small crustaceans) have either established or increased substantially in abundance. Isolated occurrences of *Turbellaria* flatworms were recorded prior to 2006 (mean of <1 per year), but are now one of the dominant organisms found at Station N1.

It is important to note that changes to sampling methods and taxonomic standards over the study may affect presence-absence or abundance data. However, none of the organisms described in this section are rare or confusing taxonomically and the general patterns of species change are unlikely to be affected.

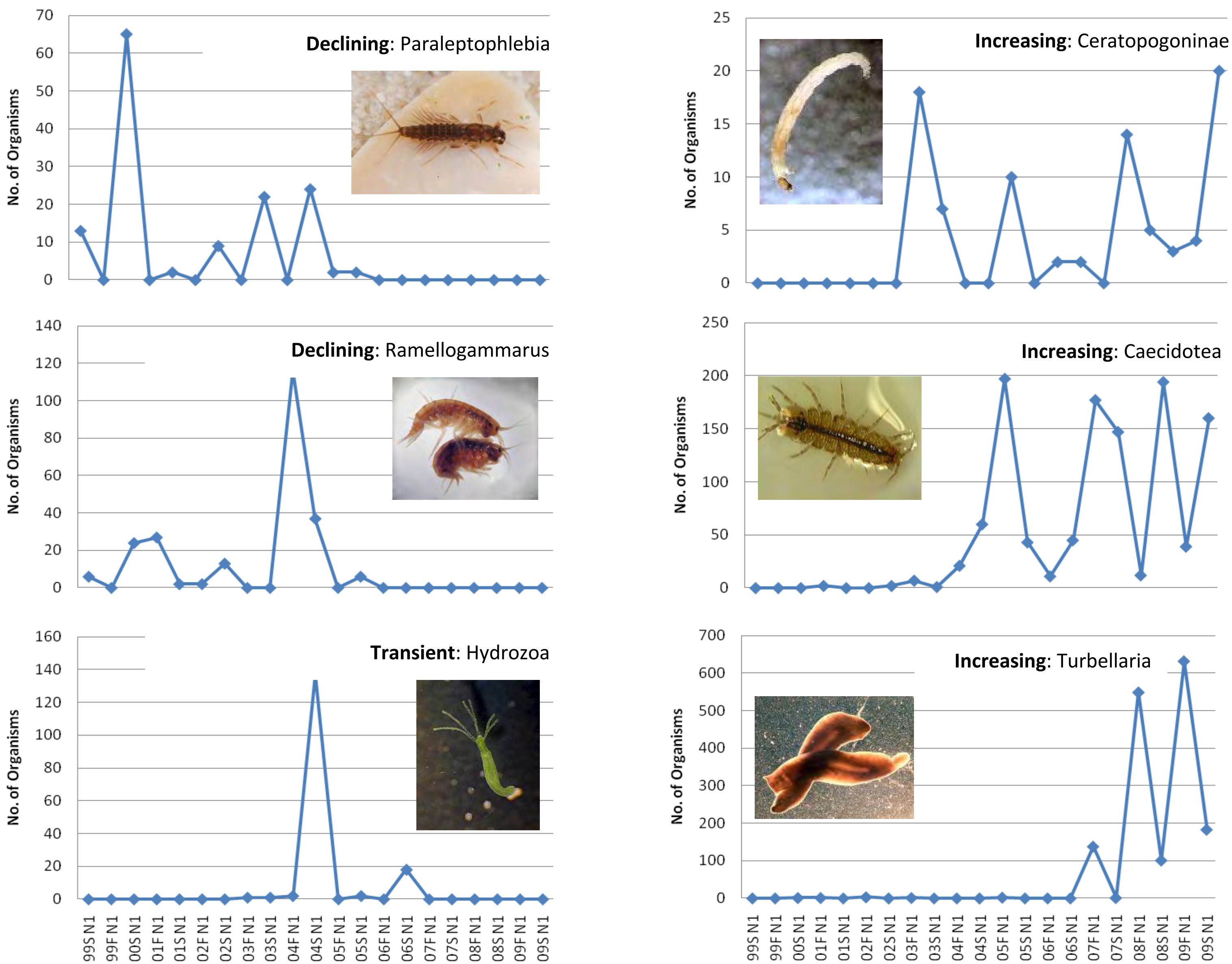

Figure 4.8. Changes in presence and abundance of selected invertebrate taxa from North Creek.

PART V – Summary and Recommendations

Streamflow, water quality, and the benthic invertebrate community changed substantially in North Creek downstream of the rapidly urbanizing East Clayton Neighbourhood between 1999–2009. Some were negative changes to stream condition associated with increasing urbanization, while others were positive changes linked to the use of low impact development measures in the developing catchment. Important results are described below.

Streamflow. Summer baseflow has increased significantly and winter stormflow magnitude (annual maximum discharge) has decreased significantly in North Creek during the study period. These changes are likely caused by the use of exfiltration systems and other stormwater source controls on the East Clayton Neighbourhood. Mitigation strategies to avoid or mitigate reduced summer baseflow and increased stormflows have been effective.

Streamflow as a proportion of precipitation has increased significantly over the study period, even though mean annual discharge has not increased significantly. Runoff yield typically increases in urbanizing watersheds because of the increase in impervious surfaces, soil compaction, and loss of vegetation. However, two results indicate that East Clayton's novel stormwater system has mitigated some of the hydrologic effects of urbanization. First, summer baseflow has increased indicating that exfiltration galleries and other strategies to infiltrate precipitation into the shallow subsurface drainage system has been effective. While research has shown variable responses of baseflow in urban watersheds, our experience with urban streams in the Lower Fraser Valley has been that summer baseflow declines as urban land cover increases.

Second, the maximum annual stormflow has decreased. This is contrary to the established pattern in urban watersheds where increased imperviousness and catch-basin and pipe systems increase peak stormflows. The innovative stormwater source controls appear to divert flow that would typically contribute to stormflow, to the shallow subsurface groundwater system where it increases baseflow.

Water Quality. General water quality parameters (water temperature, specific conductivity, pH, and turbidity) changed markedly over the study period in North Creek. All of the changes are associated with urban development and declining stream condition. The data suggests that the East Clayton stormwater system has reduced but not eliminated the effects of urban development on water quality.

The most important water quality changes were:

- Water temperature has increased significantly during the study period. The overall mean was 12.3^{o}C and the three highest annual mean temperatures were in 2004 (16.5^{o}C), 2005 (16.5^{o}C) and 2007 (13.6^{o}C). Temperature has declined recently (11.8^{o}C in both 2008 and 2009). Water temperature is likely influenced by the large stormwater detention pond upstream of the water quality monitoring station (see Figure 1.3). The pond is poorly shaded, although red alder has established along its perimeter.

- Turbidity increased during the initial clearing and development phase (2002–2004), although the overall change was not statistically significant. This is similar to other water quality datasets we have reviewed which found that even with erosion and sediment control measures, increased turbidity is unavoidable during site clearing and initial development.

- Specific conductivity has increased significantly and indicates that urbanization has substantial effects on chemical processes in small catchments. While conductivity is broad measure of ionic concentration, it is likely a useful surrogate for contaminants of concern in urban streams including metals and nutrients. The expanded road network also is a source of spikes in specific conductivity caused by road salt runoff. The effect of these events on stream biota is poorly understood.

Benthic Invertebrate Community. The benthic invertebrate community became more similar to other urban streams in the region because of the loss of sensitive taxa, and the establishment of taxa tolerant of urban streams. However, B-IBI, a composite measure of the benthic invertebrate community, increased significantly between 1999–2001.

Two patterns provide some explanation for these contradictory results. First, the benthic invertebrate community in North Creek is in transition as it responds to changing stream conditions accompanying urbanization of the East Clayton catchment. Taxa richness was lower before 2001, peaked between 2002–2004, and then declined. The peak in taxa richness at the mid-point of the study is likely caused by the establishment of new invertebrate taxa tolerant of conditions in urban streams, while at the same time more sensitive taxa were still present. The more recent decline is caused by the loss of sensitive taxa.

Second, the significant increase in B-IBI was driven by changes in only four the ten component metrics, and specifically by the increase abundance of a single predator taxom – *Turbellarian* flatworms. Flatworms were not present until 2007 but has become abundant in the last three years (Figure 4.8). They now account for up to 35% of the organisms collected in samples at

Station N1. *Caecidotean* isopods are also much more abundant in samples collected after 2004. In the case of North Creek, B-IBI is likely too coarse a measure to understand the overall change to the benthic invertebrate community.

Recommendations

The following recommendations are made to guide additional monitoring or data analysis:

7. The water quality monitoring programs should be expanded to assess concentrations of metals, nutrients (nitrate and dissolved orthophosphate), and fecal coliform bacteria in North Creek.

8. The catchment boundary should be reviewed using the most recent stormwater system mapping. Flow patterns in several areas have been modified during recent development and require confirmation.

9. Land cover change (e.g., imperviousness, forest cover, etc) should be quantified using historic air photos for the period 1995–present. This would provide a complimentary assessment to better understand the effects of urbanization on North Creek.

10. Water yield per catchment area should be measured using the updated catchment boundary. Initial analysis found it was higher than expected based on regional values and more work is needed to confirm this parameter.

11. Water temperature should be measured upstream and downstream of the stormwater detention pond to better understand its effect on water temperature in North Creek.

12. Metal concentrations in streambed sediments should be measured in the same locations as benthic invertebrate sampling. Sediment quality provides a complimentary assessment of stream condition.

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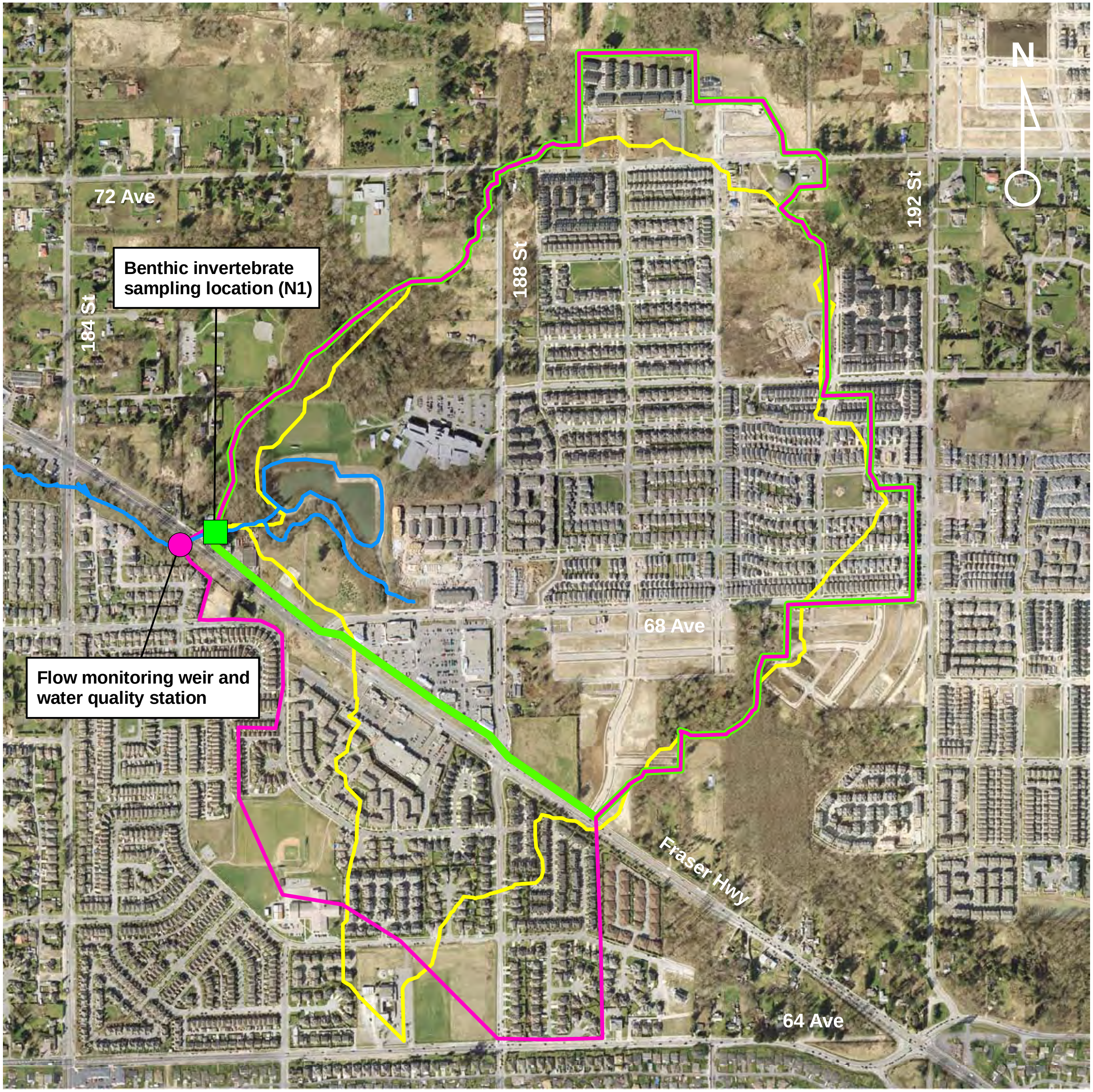
Appendices



Assessment of Hydrology, Water Quality, and Benthic Community Change in North Creek (1999–2009)

City of Surrey

Legend

- Flow + water quality catchment
- Benthic monitoring catchment (N1)
- Pre-development catchment (N1)
- North Creek and tributaries

0 100 200 300 400 Meters

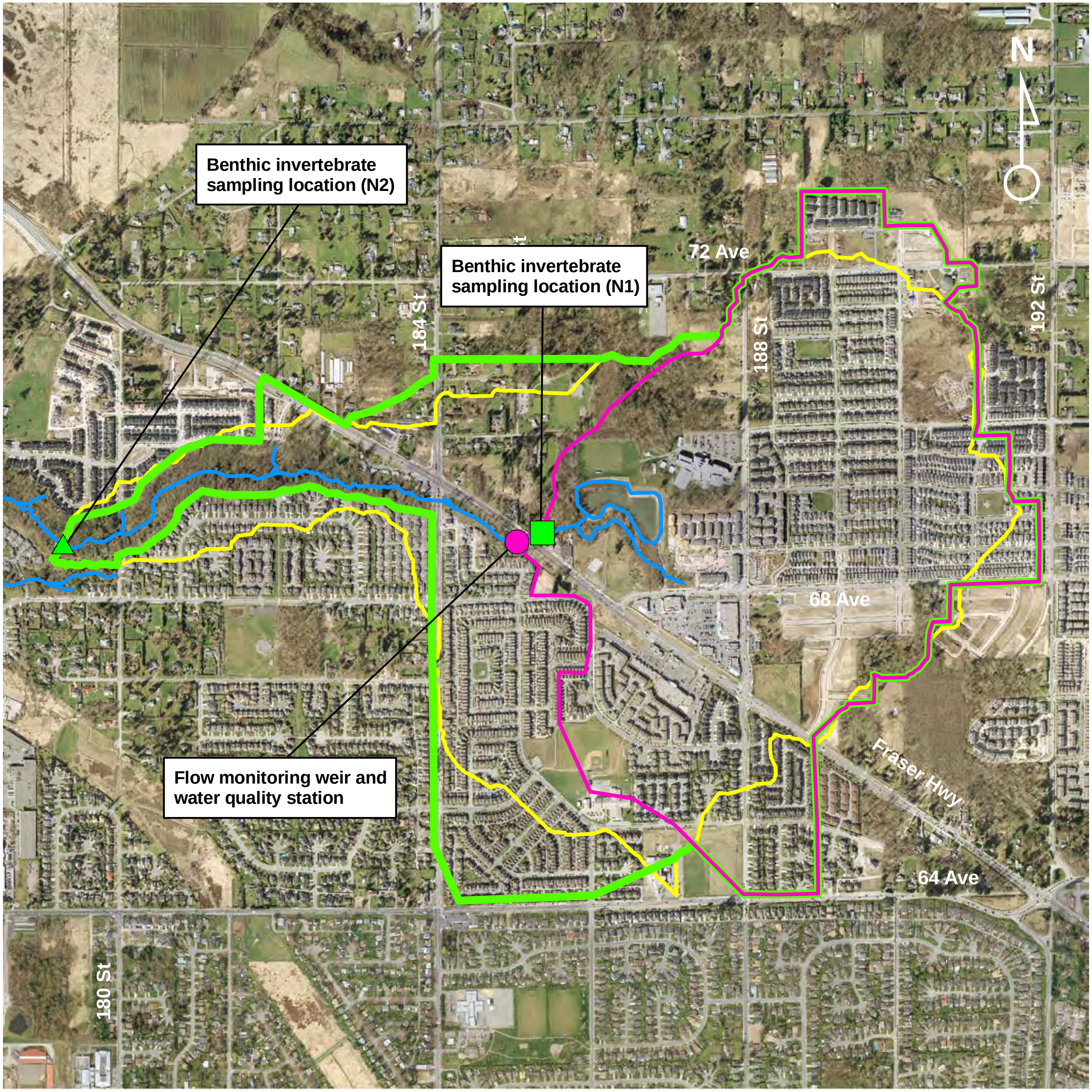
2008 orthophoto provided by City of Surrey

Raincoast Applied Ecology

Project No.	Drawn by:
09-263	P. Lilley

May 2010

MAP 1
Pre-development and post-development catchment boundaries for N1



Assessment of Hydrology, Water Quality, and Benthic Community Change in North Creek (1999–2009)

City of Surrey

Legend

- Flow + water quality catchment
- Benthic monitoring catchment (N2)
- Pre-development catchment (N2)
- North Creek and tributaries

0 100 200 300 400 500 600 Meters

2008 orthophoto provided by City of Surrey

Raincoast Applied Ecology

Project No.	Drawn by:
09-263	P. Lilley

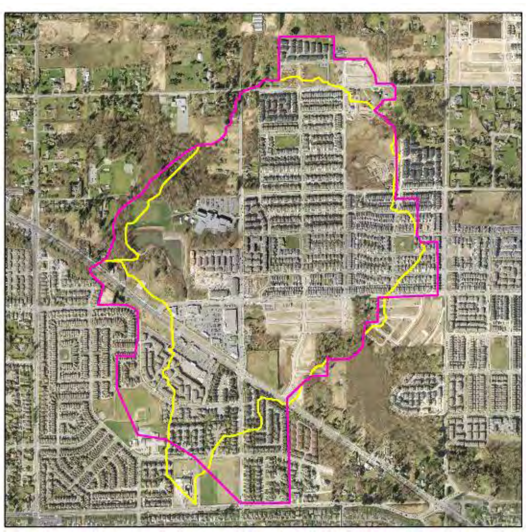
May 2010

MAP 2
Pre-development and post-development catchment boundaries for N2

Appendix A3. Land cover change in the North Creek – East Clayton catchment: 2001-2008

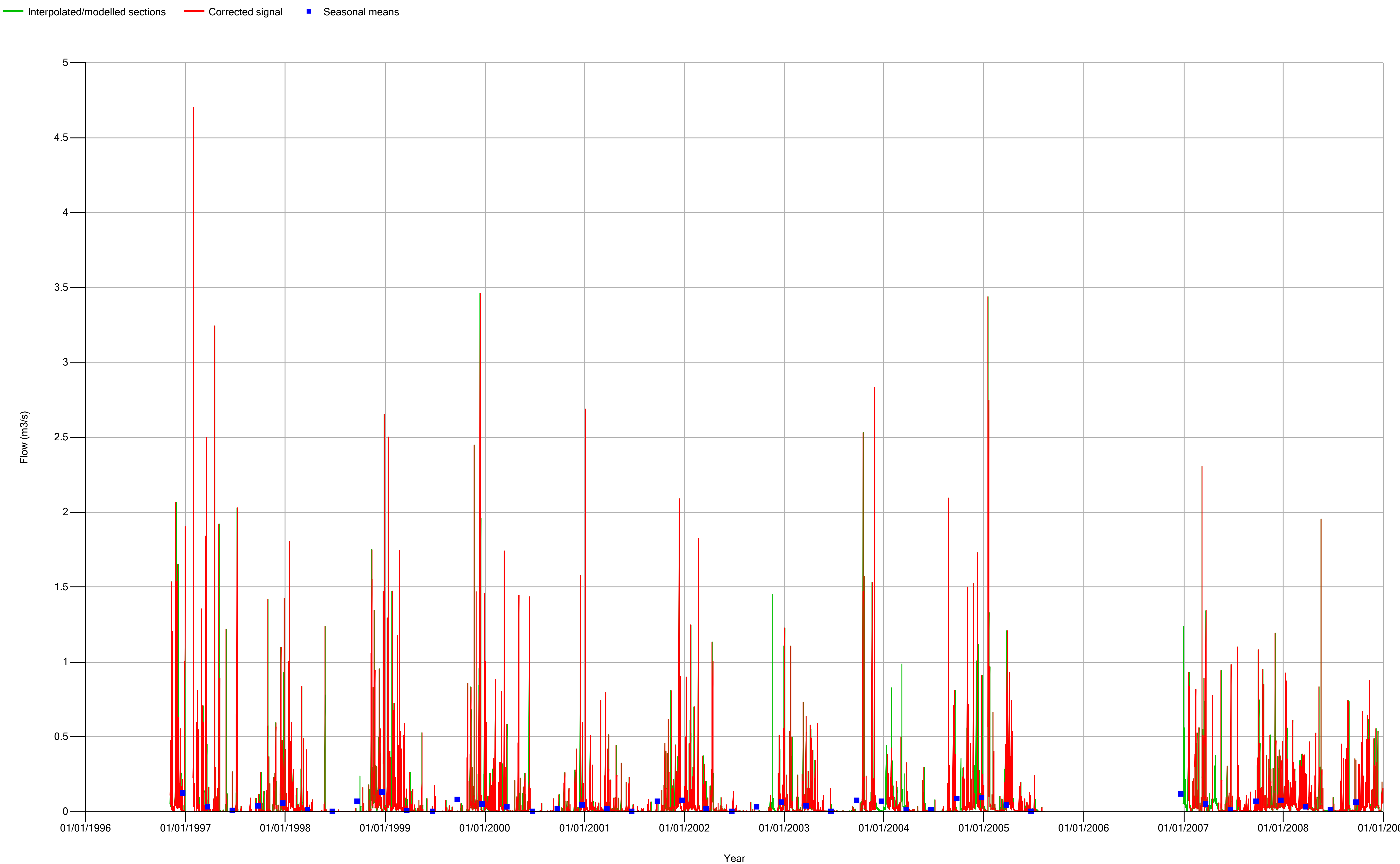
2001 land cover in North Creek – East Clayton catchment

2005 land cover in North Creek – East Clayton catchment



2008 land cover in North Creek – East Clayton catchment

Appendix B1. Streamflow in North Creek (at Fraser Highway), 1996-2008



Appendix C1. Summary of Newcombe's Impact Assessment Model for turbidity effects on clear water fishes (excerpted from Bull 2008).

Visual clarity of water (turbidity): Secchi depth (m)	Turbidity (NTU)	Impact Assessment Model for Clear Water Fishes Exposed to Conditions of Reduced Water Clarity (adapted from Newcombe, 2001, 2003)										
		Severity-of-ill-effect Scores (SEV) - Potential										
		$SEV = -4.49 + 0.92[\ln(h)] - 2.59[\ln(yBD)]$										
0.01	1100	7	8	9	10	11	12	13	14			
0.03	400	$_P6^{\pi}$	7	7	8	9	10	11	12	13	14	
0.07	150	3	$_P4^{\pi}$	$_P5^{\pi}$	6	7	8	9	10	11	12	13
0.15	55	$_P1^{\pi}$	2	3	4	5	6	7	8	9	10	10
0.34	20	0	$_P0^{\pi}$	$_P1^{\pi}$	2	3	4	5	6	7	8	8
0.77	7	0	$_P0^{\pi}$	0	0	1	2	3	4	4	5	6
1.53	3	0	$_P0^{\pi}$	0	0	0	0	1	2	3	4	5
3.68	1	$^P0_{\pi}$	$^P0_{\pi}$	$^P0_{\pi}$	0	0	0	0	0	0	1	2
		1	3	7	1	2	6	2	7	4	11	30
		Hours			Days			Weeks		Months		

NTU (nephelometric turbidity units): measure of light scattering by suspended clay particles (0.2 to 5μm diameter)
yBD (black disk sighting range (m): horizontal measurement in water of any depth (reciprocal of beam attenuation).
SEV scale: $0 \le$ nil < 0.5; $0.5 \le$ minor < 3.5; $3.5 \le$ moderate < 8.5; $8.5 \le$ severe < 14.5
Impact assessment is based on *net* duration (less clear-water intervals) and weighted-average visual clarity data.

Equation for converting NTU to yBD: $\ln(yBD) = 5.572012 - 0.80137\ln(NTU)$**, yBD in cm**

***Ideal (0)*.** Best for adult fishes that must live in a clear water environment most of the time.
***Slightly impaired (1-3)*.** Feeding and other behaviours begin to change: severity of effect increases with duration.
***Significantly impaired (4-8)*.** Marked increase in water cloudiness could reduce fish growth rate, habitat size, or bot
***Severely impaired (9-14)*.** Profound increases in water cloudiness could cause poor 'condition' or habitat alienation.
Areas with least supporting data (1 day to 11 months), or least likelihood of problems (30 months), or both.
$^P0_{\pi}$ Some predatory fish (P) catch more prey fish (π) in clear water ($^P{}_{\pi}$) than they do in cloudy water.
$_P1^{\pi}$ Survival of some fishes (e.g. young juvenile Pacific salmon) is enhanced ($^P{}_{\pi}$) by natural, seasonal, cloudiness.
$_P5^{\pi}$ Data sources: predatory-prey dynamics, see Newcombe, 2000.
8 Data sources: severity of hill effects (any SEV with underscore), see Newcombe, 2000.

Reference:

Bull, J. 2008. Stormwater quality in Whistler Creek in October 2007, Technical Memorandum (May 29, 2008), BC Ministry of Environment. Prepared for Whistler-Blackcomb, Vancouver Olympic Organizing Committee, and the Resort Municipality of Whistler. 32 pp.

Appendix D1. Summary of North Creek benthic invertebrate sampling (N1 + N2).

Code	Year	Period	Sample Date	BIBI N1	BIBI N2	Taxa N1	Taxa N2
99S N1	1999	spring	May 7, 1999	14.0	15.3	12	26
99F N1	1999	fall	November 15, 1999	14.0	15.3	8	13
00S N1	2000	spring	April 19, 2000	14.0	14.0	16	13
01S N1	2001	spring	April 25, 2001	14.0	14.7	17	19
01F N1	2001	fall	November 6, 2001	17.3	ns	24	ns
02S N1	2002	spring	May 3, 2002	16.0	15.3	24	27
02F N1	2002	fall	November 7, 2002	15.3	18.7	19	32
03S N1	2003	spring	May 1, 2003	16.7	19.3	21	33
03F N1	2003	fall	November 1, 2003	18.0	18.7	20	20
04S N1	2004	spring	May 6, 2004	19.3	18.7	21	30
04F N1	2004	fall	November 10, 2004	18.0	16.7	26	24
05S N1	2005	spring	April 21, 2005	17.3	15.3	27	21
05F N1	2005	fall	November 1, 2005	14.7	18.0	22	26
06S N1	2006	spring	May 1, 2006	16.0	14.0	24	17
06F N1	2006	fall	November 1, 2006	14.0	17.3	16	24
07S N1	2007	spring	May 10, 2007	14.7	14.0	19	18
07F N1	2007	fall	October 30, 2007	18.7	16.7	17	23
08S N1	2008	spring	May 1, 2008	16.0	14.7	22	22
08F N1	2008	fall	November 18, 2008	18.7	14.0	17	19
09S N1	2009	spring	May 13, 2009	17.3	14.7	17	23
09F N1	2009	fall	October 28, 2009	19.3	16.0	16	25

Appendix D2. Biological metrics for stream invertebrates, response to human disturbance, and scoring rules used to integrate into the 10-metric B-IBI.

Metric	Response	Scores*		
		1	3	5
Taxa richness and composition				
Total number of taxa	Decrease	[0, 15)	[15, 28]	> 28
Number of Ephemeroptera taxa	Decrease	[0, 4]	(4, 8]	> 8
Number of Plecoptera taxa	Decrease	[0, 3]	(3, 7]	> 7
Number of Trichoptera taxa	Decrease	[0, 5)	[5, 10)	≥ 10
Number of long-lived taxa	Decrease	[0, 2]	(2, 4]	> 4
Tolerance				
Number of intolerant taxa	Decrease	[0, 2]	(2, 3]	> 3
% of individuals in tolerant taxa	Increase	≥ 50	(19, 50)	[0, 19]
Feeding ecology				
% of predator individuals	Decrease	[0, 10)	[10, 20)	≥ 20
Number of clinger taxa	Decrease	[0, 8]	(8, 18]	> 18
Population attributes				
% dominance (3 taxa)	Increase	≥ 80	[60, 80)	[0, 60)

* Scores for LPTL taxonomy; square braces indicate the value next to the brace is included in the range; rounded parentheses indicate the value is *not* included.

Appendix D3. Mean B-IBI values[1], total number of taxa, and total number of EPT taxa in North Creek Stations N1 and N2 between 1999–2009.

Date	BIBI N1	BIBI N2	Taxa N1	Taxa N2	EPT Taxa N1	EPT Taxa N2
1999 S	14.0	15.3	12	26	3	10
1999 F	14.0	15.3	8	13	1	7
2000 S	14.0	14.0	16	13	5	7
2001 F	14.0	14.7	17	19	3	9
2001 F	17.3	ns	24	ns	5	ns
2002 S	16.0	15.3	24	27	6	10
2002 F	15.3	18.7	19	32	1	12
2003 S	16.7	19.3	21	33	8	14
2003 F	18.0	18.7	20	20	3	8
2004 S	19.3	18.7	21	30	5	14
2004 F	18.0	16.7	26	24	4	9
2005 S	17.3	15.3	27	21	5	9
2005 F	14.7	18.0	22	26	6	11
2006 S	16.0	14.0	24	17	6	9
2006 F	14.0	17.3	16	24	2	11
2007 S	14.7	14.0	19	18	4	8
2007 F	18.7	16.7	17	23	5	11
2008 S	16.0	14.7	22	22	3	6
2008 F	18.7	14.0	17	19	1	6
2009 S	17.3	14.7	17	23	2	6
2009 F	19.3	16.0	16	25	1	8

[1] Mean values refer to the mean of 3 replicates; total values refer to a composite of 3 replicates combined.

Appendix D4. B-IBI metric scores for Station N1 (1999–2009). Metric are scored scored as a 5, 3, or 1 according to whether they are similar to values observed at reference sites (score = 5), deviate somewhat from expected values (3), or deviate substantially from expected values (1). It is noteworthy that only 4 metrics have affected total B-IBI value.

Year		Taxa Richness	Eph. Richness	Plec. Richness	Trich. Richness	Long-lived Richness	Int. Taxa Richness	% tolerant ind.	% predator ind.	Clinger Richness	% dominance (3)
1999	spring	1	1	1	1	1	1	5	1	1	1
1999	fall	1	1	1	1	1	1	5	1	1	1
2000	spring	1	1	1	1	1	1	5	1	1	1
2001	spring	1	1	1	1	1	1	5	1	1	1
2001	fall	3	1	1	1	1	1	5	1	1	3
2002	spring	3	1	1	1	1	1	5	1	1	1
2002	fall	1	1	1	1	1	1	5	1	1	3
2003	spring	3	1	1	1	1	1	5	1	1	1
2003	fall	1	1	1	1	1	1	5	1	1	5
2004	spring	3	1	1	1	1	1	5	3	1	5
2004	fall	3	1	1	1	1	1	5	1	1	3
2005	spring	3	1	1	1	1	1	5	1	1	3
2005	fall	1	1	1	1	1	1	5	1	1	1
2006	spring	3	1	1	1	1	1	5	1	1	1
2006	fall	1	1	1	1	1	1	5	1	1	1
2007	spring	1	1	1	1	1	1	5	1	1	1
2007	fall	1	1	1	1	1	1	3	5	1	3
2008	spring	1	1	1	1	1	1	3	1	1	3
2008	fall	1	1	1	1	1	1	5	5	1	1
2009	spring	1	1	1	1	1	1	5	3	1	3
2009	fall	1	1	1	1	1	1	5	5	1	1

Appendix D5. Changes in abundance in selected taxa at Sampling Station N1 (1999-2009). Taxa were selected because of substantial changes in presence of or abundance during the sampling period.

Taxon	Order	99 S	99 F	00 S	01 F	01 S	02 F	02 S	03 F	03 S	04 F	04 S	05 F	05 S	06 F	06 S	07 F	07 S	08 F	08 S	09 F	09 S
Malenka	Plecoptera								16	9			28			1		5		6		1
Ramellogammarus	Amphipoda	6		24	27	2	2	13			116	37		6								
Zapada	Plecoptera				9			3			11	11										
Helisoma	Basommatophora				24	3	13															
Planorbidae	Basommatophora		12					1	1	1	6	7	7	1	2	1						
Ceratopogoninae	Diptera								18	7			10		2	2		14	5	3	4	20
Hirudinea	Hirudinea		4	2	1	1		1	1		2	2	4	1								
Hydrozoa	Hydrozoa								1	1	2	137		2		18						
Paraleptophlebia	Ephemeroptera	13		65		2		9		22		24	2	2								
Probezzia	Diptera	5			63	14	54	22			9	3		6								
Rhyacophila	Trichoptera				5	2	8	5	2	3	2	1	4	2								
Turbellaria	Turbellaria			1	1		3		1				2				138	1	549	101	632	183
Caecidotea	Isopoda				2			2	7	1	21	60	197	43	11	45	177	147	12	194	39	160
Copepoda	Copepoda				6		37	1	2	30	33	108	2	52	60	35						
Corixidae	Amphipoda								16	11			445		2	12	44	16	11	30	19	3
Hyalella	Amphipoda														3		1	11		3	2	
Ostracoda	Ostracoda				38	1	14	2	3		29	42	66	5	2	4			2	1	1	1
Cyclopoida	Cyclopoida																	2	3		4	2
Baetis tricaudatus	Ephemeroptera			1	3	16		14		11	50	135	13	98		40	2	32	7	319		55