INTEGRATED MONITORING PLAN
RED HILL VALLEY PROJECT
COMPREHENSIVE 5-YEAR SUMMARY

CITY OF HAMILTON

FINAL REPORT

Submitted to:
City of Hamilton, Ontario

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1.0 INTRODUCTION

1.1 Project History

Numerous studies have been conducted over the past several decades in support of the Red Hill Valley Project. The idea of a highway through the Red Hill Valley was initially proposed by the City of Hamilton in the 1950s. The project (encompassing both a north-south section through the Red Hill Valley, and an east-west section above the Niagara Escarpment) was subsequently approved by a Provincial Joint Hearing Board in 1985, with subsidy funding for the project approved by the Provincial cabinet in 1987. Funding for the north-south section (through the Red Hill Valley) was ultimately suspended by the Province in 1990; as such, the focus for the City then shifted to the east-west portion (to later become the Lincoln Alexander Parkway). Funding for the north-south section was ultimately restored in 1997. A complete re-design and environmental review process was undertaken at that time, with a focus on lessening the environmental impacts associated with the project.

A principal background document from this recent era of the Red Hill Valley Project is the “Red Hill Creek Watershed Plan”, 1998. This document set out the planning framework, which supported an eco-system assessment of land use change on a watershed scale. The Red Hill Valley Project (RHVP) elements were all considered by the Watershed Plan, including the Parkway, creek management, stormwater management (SWM), combined sewer overflow (CSO) control and landscape enhancement. The Watershed Plan provided ‘high-level’ guidance for all subsequent planning and design initiatives.

Pursuant to the Watershed Plan, the City of Hamilton, through a process developed consultatively with lead agencies, stakeholders, partners, and the public, undertook an integrated assessment of the impacts of the RHVP and developed a design which comprehensively addressed each impact. This process, termed the “Impact Assessment and Design Process” (IADP), was completed for numerous discipline areas specific to this undertaking, including:

- Surface Water and Stormwater Quality
- Hydrogeology
- Fisheries
- Terrestrial Resources and Natural Heritage
- Natural Channel Design of Red Hill Creek
- Noise and Air Quality

Other related discipline areas covered by the IADP included human health, landscape management, transportation and land use planning.

These documents formed the cornerstone of the current roadway and associated management infrastructure. The resulting highway and supporting infrastructure reflects an integration of each of the discipline-specific recommendations related to the management of surface water and the area’s natural resources.

The Red Hill Valley Project ultimately became much "more than a road", constituting an environmentally integrated infrastructure project with numerous elements, including:

- 8 km, four-lane, controlled access freeway
- Re-alignment of 7 km of Red Hill Creek
- 14 Stormwater Management Facilities for water quality
- 3 Stormwater Management Facilities for flood control
- 2.9 km Combined Sewer Overflow Storage Pipe
- Landscape management plan

The final construction phase of the project ended in 2007, at which point, the City began a multi-year environmental monitoring program to confirm and technically demonstrate the effectiveness of the new infrastructure.

1.2 Permitting Requirements

Environmental compliance monitoring for the Red Hill Valley Project was required as outlined in the following documentation:

- MOE Exemption Order, 1997
- Red Hill Creek Watershed Plan, 1998
- Impact Assessment Design Process, 2003
- Master Permit Application, 2004
- Various Permitting Compliance Reports, 2004 to 2011
- Permits and Authorization specific to the respective contract phases

The City of Hamilton decided that rather than issue a series of individual monitoring reports for the various sub-disciplines and for the various governmental agencies, that environmental compliance monitoring requirements would be best addressed through an integrated monitoring plan, which would compile findings into a single, integrated report. The exception to this would be the Department of Fisheries and Oceans, which requested direct reporting for fisheries related monitoring work only, however for clarity this information was also retained in the overall documentation.

The purpose of the Integrated Monitoring Plan has been to:

1. Evaluate the performance of the Environmental Management System (i.e. design and mitigation techniques) constructed as part of the Red Hill Valley Project.
2. Provide the necessary information to adjust and/or optimize the plan recommendations through a process of Adaptive Management.

It has not been the purpose of the plan to monitor isolated management practices, rather it has been intended to identify the impacts associated with developing the whole of the Red Hill Valley Project on the natural environment, and thereby provide direction with respect to impact management.

1.3 Monitoring Scope

The general scope and duration of monitoring the impacts associated with the development of the Red Hill Valley Project varied depending on the discipline.

The following table presents the framework used for the different disciplines' frequencies and durations of monitoring:

Table 1.3: Monitoring Scope And Duration Summary

Component	Frequency	Reporting Years	Minimum Duration	Reference
Streamflow (in-stream)	Continuous: April 1 – November 30	All	Ongoing	N/A
Streamflow (SWM facilities)	Continuous: April 1 – November 30	All	5 Years	IADP
Water Quality (SWM facility)	3 times per year	All	2 Years per facility	IADP/PCR
Rainfall	Continuous: April 1 – November 30	All	Ongoing	IADP/PCR
Erosion / Stream Morphology	Annual	All	5 Years	IADP/PCR
Groundwater	Water levels spring/fall Chemistry bi-annual	All 1,3,5,7,9	10 Years	N/A
Vegetation 1.Regulatory Acceptance (DFO) 2. Habitat Creation & Enhancement 3. IADP Ecosystem Monitoring	Twice annually to 2012 Annually to 2012 Once every 5 years	2008, 2010, 2012 2007- 2012 2009+(?)	5 years 5 years 20 years	IADP
Breeding Birds IADP Ecosystem Monitoring	Once every 5 years	2010+	20 Years	IADP
Amphibians IADP Ecosystem Monitoring	Once every 5 years	2010+	20 Years	IADP
Special Terrestrial Monitoring Studies (Turtles, Flying Squirrel)	Varies depending on focus	2010+	? Years	IADP
Fish Communities and Populations (Red Hill Creek)	Annual	All	5 years post-construction	IADP/PCR
Assessment of Fish Passage (Red Hill Creek)	Spring freshet and low flow period	As appropriate	1 year post diversion	IADP/PCR
Benthic Invertebrates (Red Hill Creek)	Annual	All	5 years post-construction	IADP/PCR
Water Temperature (Red Hill Creek)	Continuous	All	5 years post-construction	IADP/PCR
Final Post-construction Habitat Assessment (Red Hill Creek)	Once	5 (2012)	N/A	IADP/PCR
Fish movement into Compensation Area 1	Annually	1, 3, 5 post-construction	5 years	Authorization/ PCR
Fish utilization of Compensation Areas 1 and 2 and Enhancement Area 5	Annually	1, 3, 5 post-construction	5 years	Authorization/ PCR

As evident from Table 1.3, the majority of the required environmental monitoring components have involved a 5-year post-construction timeframe (the exception being groundwater, as well as IADP requirements for vegetation and breeding birds/amphibian monitoring). These requirements were largely addressed in the 5-year period between 2008 and 2012 inclusive. Due to operational issues, water quality monitoring requirements were extended beyond this time frame, necessitating a further annual report in 2013, to summarize the results of the final water quality sampling conducted in 2014. This is discussed in greater detail in Section 2.3 of the current report.

As per the approved Integrated Monitoring Plan (2007), a series of annual integrated monitoring reports have been prepared, with a cumulative summary/milestone report at the conclusion of major monitoring activities (the current document). All reporting for the Integrated Monitoring Plan has been submitted to the City of Hamilton, who has disseminated this information to members of the Government Agency Committee (GAC). The GAC has been comprised of representatives from all the City of Hamilton (City), Hamilton Conservation Authority (HCA), Department of Fisheries and Oceans (DFO), Ministry of Natural Resources and Forestry (MNRF), Ministry of Transportation (MTO), Niagara Escarpment Commission (NEC) and Ministry of the Environment and Climate Change (MOECC). The role of the GAC has been to review annual and milestone monitoring reports and provide comments and feedback to the Integrated Monitoring team. Annual reports were first submitted following the first year of monitoring in 2008. Based on feedback received from the GAC at that time, it was determined that annual meetings would not be conducted; rather GAC members would continue to receive and review the annual reports, but would await the findings of the Comprehensive 5-year Summary report (the current document) before providing final comments.

2.0 DISCIPLINE SPECIFIC MONITORING

2.1 Groundwater

2.1.1 Brief Background

A hydrogeological inventory and impact assessment of the Red Hill Creek watershed was carried out in 1997-1998. That study identified the geological and hydrogeological setting for the watershed and identified potential linkages between watershed hydrogeology and hydrology including aquatic and terrestrial aspects (i.e. baseflow and wetland linkages). Within the Red Hill Creek watershed, much of the surficial overburden consists of clay material which typically is of a low permeability which does not infiltrate or transmit water readily. There are limited deposits of permeable sands and gravels within the valley below the escarpment which allow for greater infiltration and transmittal of groundwater on a more local scale. Below the escarpment the underlying bedrock is a low permeable shale which has a reduced potential for transmitting water.

Extensive drilling within the Red Hill Creek corridor indicated the existing and realigned creek was situated on low permeability clay deposits and that the potential connection to the groundwater flow system was very low. Spot baseflow measurements, carried out during the watershed study, confirmed the lack of groundwater/surface water connection.

A groundwater discharge area was noted in the Montgomery Creek subwatershed approximately 50 metres below the creek outfall at Mt. Albion Road and Mud Street. This location is in the vicinity of the viaduct (the bridge structure where the RHVP descends the Niagara Escarpment). It was presented in the watershed study that the source of this groundwater discharge was from a more regional groundwater flow system.

The potential impacts to local groundwater recharge resulting from expressway construction were therefore assessed to be minor, particularly as it relates to groundwater discharge potential to Red Hill Creek.

A groundwater monitoring program has been carried out focusing on groundwater level trends in order to assess any potential changes to the recharge.

2.1.2 Major Findings

The water level monitoring results indicate there has been very little change since 1997 (Figure 2.1.1, Figure 2.1.2). There continues to be a consistent downward hydraulic gradient in the Mud Street wells on top of the escarpment (BH96-3). The wells adjacent to King’s Forest Golf Course (BH96-1) continue to show a shallow horizontal gradient towards Red Hill Creek, as well as a component of downward gradient to the intermediate and deep wells. There is little vertical hydraulic gradient between the intermediate and deep wells.

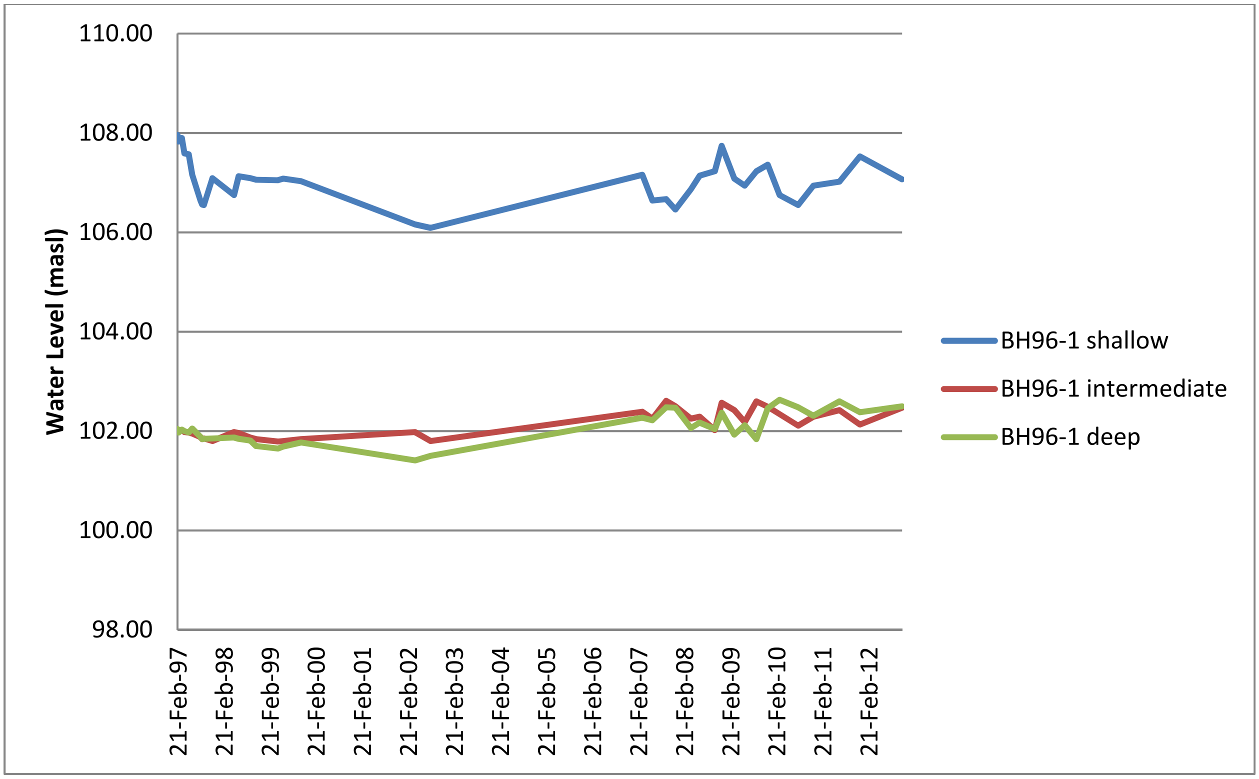

Figure 2.1.1: Recorded Groundwater Levels at Mud Street

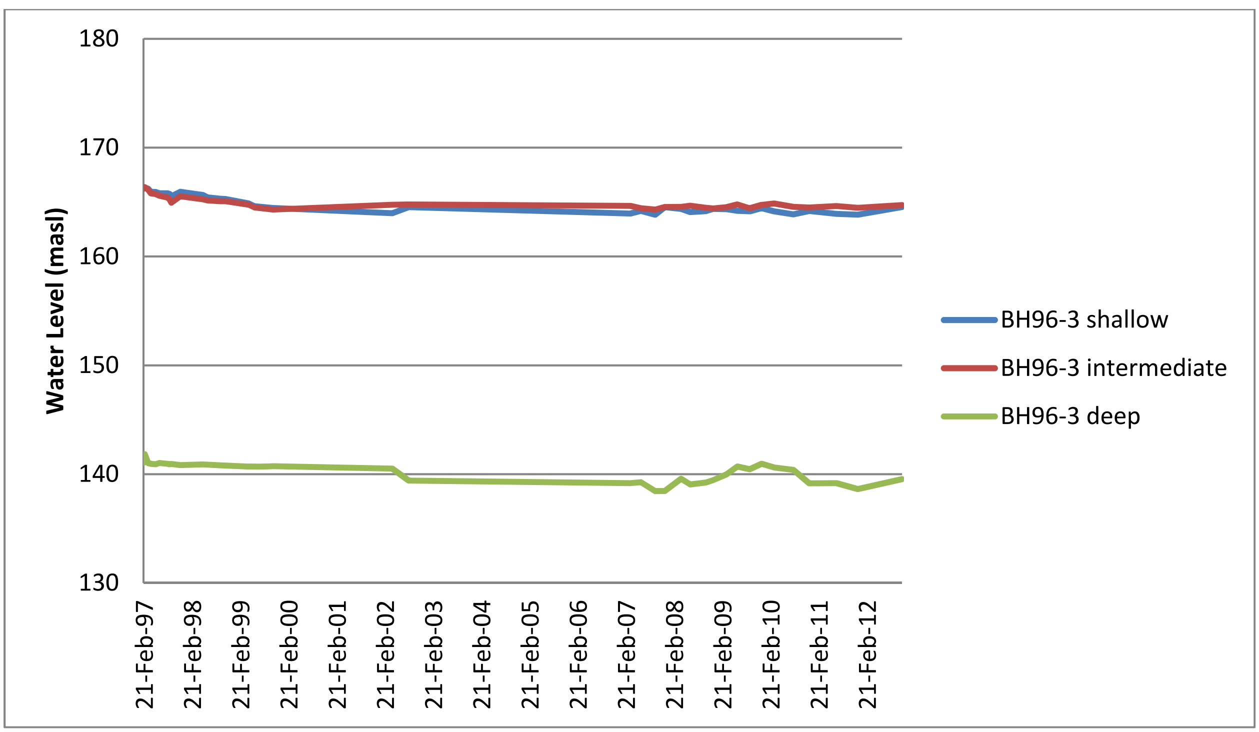

Figure 2.1.2: Recorded Groundwater Levels at King's Forest

Groundwater discharge in the vicinity of the viaduct remains consistent with discharge noted in the watershed study.

A comparison of the 2012 groundwater quality to the 1997 analysis in BH96-1 (intermediate depth) shows an increase in chloride and sulphate. The results for the remainder of the dissolved species are consistent between 1997 and 2012. A comparison of the results for BH96-1 (deep depth) shows no significant change in the dissolved species. The conductivity for both 2012 samples show a significant decrease which appears to be anomalistic compared to the dissolved concentrations. The increase in chloride and sulphate is consistent with a trend over the past 3 years in slight upward gradients between the deep and intermediate wells which could give rise to a mixing of the deeper groundwater, which has higher concentrations of chloride and sulphate, with the intermediate groundwater. Although there is a strong downward gradient between the shallow and intermediate wells, it is not expected that potential lower quality groundwater has migrated from the shallow system given the existence a 13 metre thick fine grained silt/clay layer. In addition high sulphate levels would not be expected to be associated with potential near surface groundwater quality degradation in the local setting.

2.1.3 Recommendations and Lessons Learned

Given the consistency in the various monitoring results over an extended period of time, it is recommended that the groundwater monitoring program be discontinued. Extending the monitoring program to the originally specified 10-year time frame is not considered warranted. It is however recommended to keep the existing monitoring wells for any future, more regional monitoring programs; this may require coordination with HCA and MOECC.

2.2 Surface Water and Flood Control Facilities

2.2.1 Brief Background

<u>Streamflow Monitoring, Major Storms, and the RHVP</u>

As per the Red Hill Valley Project Integrated Monitoring Plan (RHVP IMP), managing streamflow was a key aspect of the project, and monitoring the effectiveness of the measures which were implemented, is an important element of the IMP. Flow monitoring has been conducted for the overall Red Hill Creek system, to further assess watershed flows and the effectiveness of the flood control facilities, and watershed flows and system performance under major storm events.

A permanent flow monitoring station was re-established following construction of the RHVP by Water Survey of Canada at Melvin Avenue/Barton Street (Red Hill Creek at Hamilton – station ID 02HA014) which is slightly downstream from its pre-construction location at Queenston Road. A secondary gauge, previously in operation by Water Survey of Canada (Red Hill Creek at Albion Falls –station ID 02HA023) was ultimately not re-instated following construction.

These observed flow data were complemented by the network of rainfall gauges operated by both the City of Hamilton and the Hamilton Conservation Authority. As shown in previous annual monitoring reports, the gauge network for the Red Hill Creek watershed is extensive, and the data collected from this system have been applied in the assessment of collected streamflow data.

For major storm events within the watershed (where observed peak flows would be well beyond the limits of developed rating curves), alternative methods of assessment have been employed. The previously developed (and calibrated) HSP-F hydrologic model for the Red Hill Creek has been employed in these cases to assess peak flows, using available radar-generated rainfall data in some cases, as well as point gauge data from the previously noted network of rainfall gauges within the watershed. Additional data, such as field reconnaissance and photographs, and high water marks have also been used were available and relevant.

Flood Control Facilities

The Red Hill Valley Project includes three major flood control facilities, namely: Dartnall Road, Greenhill, and Davis Creek (refer to Drawing 1 for locations). These systems have been designed to protect the Red Hill Valley Parkway (RHVP) and Queen Elizabeth Way (QEW) from major flooding (100 year level of service +/-). In order to verify the performance of these critical systems, it was considered necessary to include flow monitoring as part of the Integrated Monitoring Plan to confirm the attenuative function of these features (i.e. that they provide the designed peak flow reduction).

Temporary flow monitors were established by Amec Foster Wheeler Environment & Infrastructure (Amec Foster Wheeler) specifically for the purpose of verifying the performance of these quantity control facilities. These gauges were installed for the duration of the surface water monitoring program (5 years: 2008-2012) during non-winter periods (April to November approximately).

The temporary gauges are self-contained sensors, which continuously record total pressure at set increments (15 minutes). An additional barometric sensor located within the Red Hill Valley was used to correct the data to represent actual water levels. At gauge locations, channel sections were surveyed, in order to assess channel width and flow area at varying depths. In stream velocity measurements were made at periods of both low and high flow, in order to calculate observed flows at known water levels. This information was used to develop rating curves for flow monitoring sites, which enabled the conversion of collected water level data into more useful flow data. These flow data were then used to more directly evaluate watershed flows and the attenuative function of the designed flood control facilities.

Given the magnitude of the peak flows throughout the Red Hill Creek watershed (and the corresponding depths and velocities), it was not possible to safely collect in-stream velocity measurements at higher flows. While developed rating curves were adjusted to fit to observed points at lower water levels and flows, the lack of field verified data at higher flows meant that the curve was approximate. However, all rating curves were estimated and fit using hydraulic modelling (rather than a simple trendline), which lent a higher degree of confidence to the interpretation of the results. Data checks and analyses were also conducted to ensure that flow estimates were reasonable, however as noted there is necessarily a degree of uncertainty in the estimated values.

Dartnall Road Flood Control Facility

The Dartnall Road facility is located at the upstream limits of Red Hill Creek above the escarpment. The quantity control component of the Dartnall Road facility involves a deliberately undersized culvert outlet between Hannon Creek and the Main branch of Red Hill Creek beneath the RHVP northbound on-ramp from Dartnall Road. This results in flood flows from Hannon Creek being impounded within the wide upstream valley system, and reduces contributing peak flows to Red Hill Creek.

In order to monitor facility performance, a gauge was placed directly on the upstream side of the culvert control. An additional gauge was placed on the downstream side (within Red Hill Creek) to assess the impact of tailwater levels on discharges due to the actual head differential across the outlet (2010 onwards). An additional gauge was placed at the upstream limits of Hannon Creek, in order to attempt to assess inflow rates to the facility. Refer to Drawing 1 for all gauge locations.

A key limitation associated with flow monitoring at this location is the extent of the backwater associated with the facility. Under even moderate storm events, backwater from the facility culvert control (or storage within the facility) extended to the upper reaches of Hannon Creek, rendering development of a rating curve for inflows impossible. Accordingly, the performance of the Dartnall Road facility has been largely evaluated on the basis of recorded peak operating levels within the facility and estimated peak discharges (using the measured head differential across the outlet) in comparison to hydrologic modelling data, where available.

Greenhill Flood Control Facility

The Greenhill facility is located along the main branch of Red Hill Creek, just downstream of King's Forest Golf Course (within Greenhill Bowl Park). The key component of the facility is a flood control berm, located along the east side of the channel. When water levels within the creek exceed the 2-year storm event, flows spill over the berm and into the remnant Red Hill Creek channel and valley system (refer to Drawing 1). Flood flows are then impounded within this channel and valley system, and then conveyed across the RHVP and into the Online (Retrofit) facility, where flows are further impounded before being directed back into the main channel of Red Hill Creek. In addition to creek flows, the remnant channel also receives periodic combined sewer overflow (CSO) discharges from the two CSO tanks located within Greenhill Bowl Park.

In order to monitor facility performance, a gauge was placed within the main branch of Red Hill Creek, upstream of the Greenhill flood control berm. A second gauge was placed along the main branch of Red Hill Creek, downstream of the flood control berm, in order to assess the reduction in peak flows provided by the berm. A third gauge was placed at the downstream limits of the remnant channel (upstream face of culvert crossing of the RHVP), in order to assess the amount of berm overflow in combination with CSO discharge. Recorded CSO discharges from the Greenhill CSO have been provided by City of Hamilton staff in order to better assess observed peak flows and volumes within the remnant channel, and separate creek overflows from CSO flows.

There were several limitations associated with flow monitoring at this location. First, given the magnitude of the creek flows at this location, it was not possible to safely obtain in-stream velocity measurements at higher flows. Rating curves at higher flows were therefore extrapolated based on hydraulic modelling, and associated peak flows estimated accordingly. Second, channel instabilities have made the establishment of a consistent rating curve extremely difficult, particularly at the upstream location, where channel grades are steeper. Channel sections at the monitoring gauge locations have been significantly altered multiple times due to major storm events over the monitoring period. Several gauge relocations were attempted to try and address this issue with minimal success. Third, several gauges were lost over the monitoring period, having been assumed to have been dislodged by high flows during major storm events. Accordingly, the uncertainty associated with the estimated observed flows should be taken into account as part of the associated facility performance assessment.

Davis Creek Flood Control Facility

The Davis Creek flood control facility is the third major flood control facility designed as part of the overall Red Hill Valley Project. The facility includes a permanent water level sensor and sluice gate (constructed on the upstream side of the RHVP Northbound on-ramp from King Street), which closes automatically at a pre-set water level (25-year or greater estimated return period). Flood waters are then impounded on the upstream side within the Davis Creek valley system, attenuating peak flows from the Davis Creek (largest subwatershed of the Red Hill Creek Watershed) to downstream reaches of Red Hill Creek.

Construction of the facility was completed in late 2012, with additional channel works undertaken in 2013. Although the facility is constructed, the flood control gate is not yet in operation, due to a combination of operational and regulatory issues. Given the delay in the construction and implementation of the Davis Creek Flood Control facility, it was not possible to include the surface water monitoring requirements for this facility as part of the current overall IMP reporting. The 5-year monitoring requirements will instead be undertaken and reported separately; the first year of monitoring was undertaken in 2014 (and the second year of monitoring underway in 2015), with the anticipation that the flood control gate will be fully operational shortly.

A gauge was installed within Davis Creek downstream of the flood control facility over the course of 2008 and 2009, with the intention of developing a rating curve ahead of facility construction. This gauge was ultimately not re-installed in 2010 due to the beginning of construction. However, the gauge provided useful data for some of the major storm events in 2008 and 2009.

Additional Facility Assessments

Although not a flood control facility, water level monitoring was conducted for Facility J over the 2011-2012 period (refer to Drawing 1 for location). Stormwater from this facility specifically flooded the RHVP on two occasions (July 7 and 9, 2010); accordingly, water level monitoring was recommended as part of the 2010 annual monitoring report in order to further assess facility performance with respect to major storm events. Gauges were installed both within the facility itself, as well as within the downstream ponding area, in order to quantify the impact of tailwater levels from both Red Hill Creek and the remnant channel area upstream.

In addition, water level monitoring was conducted at the compensation wetland located at the RHVP/QEW interchange, also referred to as COMP 2 (refer to Drawing 1 for location). This was a recommendation of the 2008 annual monitoring report, in order to better understand the influence of backwater from the Harbour and assess facility performance.

2.2.2 Major Findings

<u>Streamflow Monitoring, Major Storms, and the RHVP</u>

In general, the 2008-2012 period is considered to have been wetter than normal. A comparison of monthly and annual (April-November) precipitation totals has been included in past annual monitoring reports based on Environment Canada's Hamilton Airport gauge station. This information has been compiled and compared against 1981-2010 climate normals; the results are presented in Table 2.2.1.

Table 2.2.1: Comparison of Annual Precipitation (April-November) to Climate Normals (mm)

Year	Annual Percent Difference from Normal	Minimum Monthly Percent Difference from Normal	Maximum Monthly Percent Difference from Normal
2008	+11%	-30%	+48%
2009	+21%	-65%	+116%
2010	+16%	-37%	+85%
2011	+21%	-49%	+103%
2012	-17%	-80%	+107%

As evident, 2008-2011 were all well above normal annual precipitation totals. 2012 was a drier year overall; however even within that year, one month (July) had a precipitation total 107% (or more than double) the monthly normal precipitation. Other years displayed similar trends, with months well below normal precipitation totals, and other monthly well above (near or above 100% in many cases).

As documented in previous annual monitoring reports, a number of major storm events occurred over the 2008 to 2012 period. An above average number of events were found to be greater than bankfull conditions (for the 2009-2011 period in particular), as discussed in greater detail in Section 2.4 with respect to stream morphology. With respect to the most formative recorded events (or those that resulted in some degree of flooding along the RHVP), there are four storms of particular interest:

- July 26, 2009
- July 7, 2010
- July 9, 2010
- July 22, 2012

All of the foregoing storms appear to have been convective-type thunderstorm events, all of which occurred within the month of July. Each of the storms has been discussed in detail within previous annual monitoring reports; however the major findings from these reports are summarized herein.

It should be noted that other formative storms were also identified within the monitoring period, August 29, 2009 in particular. However, this storm was of a comparatively lower magnitude and was not known to have resulted in any flooding along the RHVP, and thus had not been included in this discussion. Details of this storm event can be found in the 2009 Annual Monitoring report.

July 26, 2009 Storm Event

By far the most formative storm event observed during the monitoring period was the July 26, 2009 storm event. The storm event was a high intensity convective type storm event which tracked directly along the Red Hill Creek watershed from headwater to outlet, based on available radar imagery for the storm. Based on available rainfall data alone, the storm was well in excess of a 100 year event. The storm also occurred after a week of heavy rainfall, resulting in already saturated soils and minimal capacity for infiltration. The storm event resulted in widespread flooding and damage along the Red Hill Creek Valley system, and the closure of both the RHVP and also a section of the QEW. The event was listed as one of Environment Canada's Top Ten Weather Stories for 2009 (#8).

A supplemental hydrologic assessment was undertaken for this storm using the approved/calibrated HSP-F model for the Red Hill Creek watershed. Resolute radar-generated rainfall data for the watershed (ref. Kije Sipi Ltd., September 2009) was applied; the results indicated that the storm event was approximately equal to a 100-year storm event for the upper watershed (i.e. upstream of Davis Creek), with peak flows downstream of Davis Creek found to be approximately 1.5 times the expected 100-year values due to the large inflows from Davis Creek (estimated to be almost double the expected 100-year value). A post-storm event survey of high water levels further confirmed that the storm event was well in excess of the 100-year storm event.

As would be expected, given that the storm event was in excess of the design standard for the RHVP (100 year storm event), widespread flooding occurred. Direct creek flooding occurred primarily for downstream sections of the RHVP (in the vicinity of Barton Street and the CNR), as well as the QEW. Some direct creek flooding also appears to have occurred further upstream, near the confluence of Davis Creek and Red Hill Creek. Based on the results of the field reconnaissance post-storm, surface flooding was also noted at the upstream limits of the RHVP (near the Mud Street facility), adjacent to the Online (Retrofit Facility) and Facility D, as well as the King Street off-ramp from the RHVP north-bound.

July 7, 2010 Storm Event

In comparison to July 26, 2009, the July 7, 2010 storm event was not a particularly significant storm event; it was estimated to be in the range of a 2 to 5 year storm event based on available rainfall data. However, the storm resulted in the closure of a portion of the RHVP in both directions.

Based on reporting within the Hamilton Spectator, it appears that the closure was related only to flooding at Facility J (a SWM quality control facility located within the Barton Street/RHVP Northbound on-ramp). It is understood that the box culvert outlet of Facility J was covered with a fine mesh grill at the time of the storm event. This grill is not shown on the original design drawings for the facility, and may have been added at a later date to help reduce the amount of debris entering Red Hill Creek, or possibly for safety reasons. While the grill would have served to achieve this purpose, it would also lead to potential outlet blockage, which would raise water levels within the Facility and direct overflow towards the RHVP, given that there is no defined overflow spillway for the facility.

The flooding of the RHVP caused by the July 7, 2010 storm event is therefore considered to be an isolated incident, due to the installation of an inappropriate grate on the outlet of Facility J. This issue has since been remediated.

July 9, 2010 Storm Event

Shortly after the storm event of July 7, 2010, a much more formative storm event was recorded on July 9, 2010. According to the Hamilton Spectator, this storm event resulted in 15 directly related vehicle accidents along the RHVP. Flooding for this storm event appears to have been more widespread than for the July 7, 2010 storm event, with flooding observed at multiple locations, including Facility J, the Online (Retrofit) facility and Facility D, and at the King Street off-ramp for the RHVP northbound (refer to Drawing 1 for locations). As with the July 7, 2010 storm event, the parkway was closed by City staff and police part way through the storm.

Based on available rainfall statistics, the July 9, 2010 storm event ranged from 5 to 10 year storm event based on volume, up to a 25 year storm based on peak rainfall intensity in some areas; much higher than the “one in two year” return period initially assigned to the storm by Environment Canada staff (as reported within the Hamilton Spectator). This does not account for the likely near-saturated antecedent moisture conditions within the watershed, due to the preceding storm event on July 7, 2010.

Similar to the July 7, 2010 storm event, the flooding of Facility J was again considered attributable to the blockage of the outlet grill. There were no reports of the grill being cleaned prior to the July 9, 2010 storm event. Based on reporting within the Hamilton Spectator, the outlet grill was not removed by City staff until sometime in August 2010.

Reported flooding at other locations (Online (Retrofit) facility and Facility D, as well as the King Street off-ramp) is consistent with observations from the more formative July 26, 2009 storm event, suggesting that these locations may be more flood susceptible than expected (i.e. flood for less than a 100 year storm event).

July 22, 2012 Storm Event

A significant storm event occurred on the afternoon of July 22, 2012, which was of relatively short duration and high-intensity. The storm event was highly spatially variable, with the majority of the storm focused in the upper sections of the Red Hill Creek watershed. Rain gauges in this area and radar data clearly characterized the storm event as being in excess of a 100 year storm event; while gauges in the lower reaches of Red Hill Creek characterized it as being a 2 year storm or less.

Similar to other formative storm events, a forensic assessment was conducted using the approved/calibrated HSP-F model for the watershed and available point rainfall data. The results of that assessment reflected the previously observed rainfall patterns. Peak flows above the Niagara Escarpment were estimated to be approximately 1.5 times the 100-year storm event, and approximately equal to the 100 year storm event within lower sections upstream of Davis Creek. Significant peak flows were estimated to have resulted from Davis Creek, well in excess of the estimated 100 year storm value. Likewise, peak flows within the Red Hill Creek downstream of Davis Creek were also considered to be equal, or in excess of, the 100 year storm event. Simulated results were also in approximate agreement with field observations near the peak of the storm event, which noted water levels approaching the edge of roadway between Barton Street and the CNR (where the channel was designed with a 100 year capacity with nominal freeboard).

The storm did not result in any known instances of flooding along the RHVP, and the RHVP remained open during the entirety of the storm event. The storm event caused extensive flooding of other areas within the City of Hamilton where the storm was focused, in particular within the community of Binbrook and areas of Hamilton and Stoney Creek Mountain.

Potential Remedial Actions

Based on the foregoing, over the 5 year plus monitoring period the RHVP itself experienced flooding on three occasions (July 26, 2009, July 7, 2010 and July 9, 2010). Although equal to, or in excess of, a 100-year storm event, the July 22, 2012 storm event did not result any reported flooding along the RHVP; this is considered attributable to the spatial distribution of the storm event, which was focused on the headwater areas of the watershed than the RHVP directly, as well as improved local drainage infrastructure (i.e. grill with fire mesh replaced with more appropriate system.

Of the three storm events in question, only the July 9, 2010 storm event resulted in some localized flooding which does not appear to be consistent with the approved design of the RHVP (less than 100 year standard) or not explained by external factors (the improper grate on the outlet of Facility J). Notwithstanding, as part of the 2010 annual monitoring report, a summary of locations which appeared to be more susceptible to localized flooding (rather than widespread creek flooding) was generated. The identified locations included:

- Mud Street area (observed water, debris and aggregate being washed onto the parkway under high flows)
- Online (Retrofit) Facility (flooding onto parkway, particularly from section closer to rail overpass)
- King Street off-ramp from RHVP northbound (ponding/flooding)
- Facility J (flooding onto parkway)

The 2010 annual monitoring report included a list of potential remedial measures for the above, with the exception of Facility J, where additional monitoring was recommended and subsequently conducted. Based on the results of that monitoring (2011-2012), it is considered that the most likely remedial measures in this case would be an improved overflow relief beneath the Barton Street overpass (either through re-grading or a new pipe/storm sewer), or secondary relief culverts/ditch inlets to ensure full equalization between Facility J, the downstream ponding area, Red Hill Creek, and the remnant channel area.

More detailed site specific assessment would be required to confirm the appropriateness of any of the previously referenced measures.

Climate Change

The potential impacts to the drainage systems along the RHVP (both the creek system and the various quantity and quality control SWM facilities) stemming from climate change were not assessed as part of the original assessment design works, largely due to the lack of available information and the state of the practice at that time.

Given the advances in climate change assessment techniques since that time, and the number of significant storm events which have been monitored within the Red Hill Creek watershed and surrounding areas, a climate change sensitivity analysis may be warranted. Such an assessment could take several different forms, including repeating the previously completed continuous simulation assessment with a shifted dataset (historic rainfall data increased by a set factor based on expected increases from climate change modelling simulations), or a more simplified sensitivity analysis using design storm type events. The results of such an assessment would assist in identifying potential changes in drainage system performance due to climate change, as well as confirming or verifying the most vulnerable/sensitive locations. Such an analysis could be used to complement an assessment of potential remedial actions as previously discussed.

<u>Flood Control Facilities</u>

Dartnall Road Flood Control Facility

As discussed previously, the assessment of the attenuative function of the Dartnall Road Facility is limited by the inability to accurately measure inflows to the facility under major storm events. Backwater from storage within the facility is so extensive that it affects the upstream reaches of Hannon Creek (and all attempted gauge locations) under even moderate storm events. It was considered both impractical to attempt to locate gauges sufficiently upstream in order to avoid all facility backwater; further, this would not account for sources of inflow between these locations and the outlet itself.

Accordingly, the performance of the facility has been assessed on the basis of the recorded peak operating level, the associated approximate storage volume (based on the facility stage-storage-discharge rating curve within the approved/calibrated HSP-F hydrologic model for the watershed), and the estimated peak facility discharge (based on the observed maximum head differential across the outlet and the outlet dimensions). This information has been in turn compared against available data from forensic hydrologic assessments conducted using the approved/calibrated HSP-F hydrologic model for the watershed, as documented in previous annual monitoring reports. Results are presented in Table 2.2.2 for the largest recorded operating levels within the Dartnall Road Facility over the 5-year monitoring period.

Table 2.2.2: Summary of Major Storm Events Monitored for the Dartnall Road Facility

Date	Monitoring Data			Hydrologic Simulation Data (HSP-F)		
	Peak Operating Level (m)	Approximate Storage Volume[1] (m^3)	Estimated Actual Peak Facility Discharge[2] (m^3/s)	Peak Operating Level (m)	Storage Volume (m^3)	Peak Facility Discharge (m^3/s)
7/26/2009	185.63	336,000	NA	185.78	359,000	7.8
8/29/2009	184.05	126,000	NA	183.27	72,000	5.4
6/6/2010	184.09	133,000	5.2	NA	NA	NA
7/9/2010	183.47	85,000	4.6	184.00	120,000	6.2
9/28/2010	183.46	84,000	4.3	183.91	114,000	6.1
4/20/2011	183.73	102,000	5.3	NA	NA	NA
10/20/2011	183.96	117,000	5.3	NA	NA	NA
11/29/2011	184.26	150,000	5.7	NA	NA	NA
7/22/2012	185.62	334,000	6.8	187.13	630,000	9.4

1. Based on maximum observed water level and stage-storage-discharge rating curve within the approved HSP-F hydrologic model
2. Based on head differential across culvert (data from two monitoring gauges) and orifice equation
3. NA = Data is not available (gauge loss or unavailable with respect to monitoring data, event not modeled with respect to hydrologic simulation using HSP-F).

As evident from Table 2.2.2, for those storm events where a comparison is possible, the results are mixed. Peak operating levels and storage volumes for the July 26, 2009 storm event are generally very close between observed and simulated data; this is considered attributable to the high resolution radar-generated rainfall data employed for the simulation in this case. For the August 29, 2009 storm event, the monitoring data show a much greater operating level and storage than simulated; this is considered attributable to the high spatial variability of that storm event and the difficulty in obtaining representative rainfall data for modelling purposes. By contrast, for the other three storm events were a direct comparison is possible (July 9 and September 28, 2010, and July 22, 2012), the monitoring data show a lower operating level and storage than simulated. This may again be attributable to the spatial variability of the available rainfall data, as well as other potential factors.

It should be noted that although mixed results are indicated with respect to peak operating levels and storages, observed peak discharges are consistently below simulated values (where data are available). While this is considered partially attributable to the differences noted previously, actual facility discharges also appear to be limited by tailwater from Red Hill Creek. Monitoring results suggest that actual peak discharges are in fact some 10% lower on average when tailwater levels are taken into account than when based on the peak facility operating level alone (which was likely the approach applied in the original hydrologic modelling development).

Greenhill Flood Control Facility

The attenuative function of the Greenhill Facility has been assessed based on data from the three temporary monitoring gauges at this location (refer to Drawing 1), in combination with recorded discharge data from the Greenhill CSO as provided by the City of Hamilton. A summary of storm events for which the Greenhill Facility berm appears to have been active is provided in Table 2.2.3. These events have been identified based both on the magnitude and difference in peak flows, as well as observed volumes within the remnant channel (which as noted previously, is due to a varying combination of CSO discharge and flood overflows across the berm).

Table 2.2.3: Monitored Operation Summary for the Greenhill Facility

Date	Monitored Peak Flow (m^3/s)			Monitored Volume (m^3)		
	Greenhill 3 (Upstream)	Greenhill 2 (Downstream)	Greenhill 1 (Flood Overflow+CSO)	Greenhill 1 (Overflow + CSO)	Recorded CSO Discharge Volume	Estimated Flood Overflow Volume
6/25/2009	38.9	32.5	3.6	8,759	0	8,759
7/26/2009	NA	166.6	NA	NA	180,558	NA
8/29/2009	70.3	55.8	13.2	232,666	109,818	122,848
7/9/2010	60.6	48.6	12.8	274,386	138,582	135,804
9/28/2010	59.4	46.5	12.6	175,263	73,572	101,691
6/8/2011	NA	33.6	5.3	28,864	NA	NA
10/20/2011[1]	17	20.6	12.0	480,118	254,736	225,382
7/22/2012	NA	42.7	11.8	102,470	9,780	92,690

1. Uncertain whether this storm event did in fact results in a overflow
2. NA = Data is not available (loss of gauge, etcetera)

The operation of the flood control berm appears to be consistent with the originally approved design; overflows are designed to begin when creek flows are above the 2-year storm event, approximately 26.5 – 30 m^3/s (based on the original Permitting Compliance Report). All storm events presented in Table 2.2.3 are above this threshold with the exception of the October 20, 2011 storm event. This storm event has been included on the basis of the significant discrepancy in overflow volumes which would suggest an overflow; however it is possible that gauge data at the Greenhill 1 location were impacted by a debris blockage (or that there is a discrepancy in the recorded CSO discharge data). A clear peak flow reduction is also evident in the monitoring data, with observed peak flows reduced by 20% on average due to the flood control berm.

The results presented in Table 2.2.3 also indicate the substantial volumes associated with not only the flood control berm overflows, but also CSO discharges. CSO discharges are equal to the flood control berm overflows for many storm events. Clearly CSO discharges from the Greenhill facility would therefore have an impact on available flood control storage volumes, in addition to negative impacts to downstream water quality.

As documented in previous annual monitoring reports, a large number of CSO events have been recorded over the monitoring period from the Greenhill CSO. A summary is presented in Table 2.2.4. Note that discharges to Red Hill Creek from other former CSOs (Lawrence Avenue, Queenston Road, and Melvin Avenue) have not been assessed; these former CSOs now outlet to the Red Hill CSO storage pipe (as of December 2011).

Table 2.2.4: Recorded CSO discharges from the Greenhill CSO

Year	Number of Recorded Overflows		Total Overflow Volume (m^3)	
	Calendar Year (January – December)	Monitoring Year (April – October)	Calendar Year (January – December)	Monitoring Year (April – October)
2008	10	3	1,553,244	284,988
2009	16	7	1,510,470	428,449
2010	11	7	1,621,827	524,383
2011	26	17	3,265,854	1,590,030
2012	2	2	269,996	269,996
TOTAL	**65**	**36**	**8,221,391**	**3,097,846**

As evident from Table 2.2.4, the number of recorded overflows from the Greenhill CSO over the monitoring period is significant. The City of Hamilton was ultimately required to undertake a review of the Greenhill CSO in late 2010 at the request of the MOECC, given concerns that the facility was not achieving the target of 1.7 CSO discharge events per year. The resulting report (Hamilton Greenhill CSO Tank Overflow Review, Hatch Mott MacDonald), indicated that the high number of overflows was in part due to the high number of significant storm events over the preceding several years. The report also noted a number of potential measures for improvement, including the implementation of a real-time control (RTC) system to better optimize storage, including co-ordination with the Red Hill Creek CSO storage pipe (i.e. release discharges from the storage pipe instead of the Greenhill facility, given that the storage pipe outlet is located much further downstream past Barton Street). It is understood that the City of Hamilton is continuing in its efforts to minimize CSO discharges, which as noted should benefit not only flood control volumes, but also clearly water quality within Red Hill Creek.

Davis Creek Flood Control Facility

Due to the timing of the construction of the facility, detailed monitoring analyses could not be included as part of the current summary. A separate 5-year monitoring program is currently underway for the Davis Creek Flood Control Facility.

Based on the details of the facility's operation, the gate would be expected to open once upstream water levels reach 90.45 m (21.2 m^3/s), which is slightly below the simulated 20 year return period peak flow of 23.1 m^3/s. Monitoring results from the 2008-2009 period suggest that the facility would have been expected to operate for the July 26, 2009 storm event, which was estimated to be in excess of a 100-year storm event at the outlet of Davis Creek. The July 26, 2009 storm event was used in the design/verification of the facility's operating parameters (rating curve).

There are limited available data to confirm whether or not the facility would have been expected to operate for any other storm event over the monitoring period. The exception would be for the July 22, 2012 storm event, which based on the previously noted hydrologic modelling, would have resulted in a peak flow well in excess of a 100-year storm event at the outlet of Davis Creek; the flood control facility would therefore have been expected to have been in operation for this storm event, if it had been in full service.

Additional Facility Assessments – Facility J

Water level monitoring of Facility J was completed over the 2011-2012 period for the reasons noted previously; detailed results are presented in the associated annual monitoring reports. The outlet grate (identified previously as a primary cause of flooding) was removed prior to the establishment of the additional monitoring, thus monitoring was intended to assess whether there were any residual concerns with respect to normal facility operation.

The average recorded permanent pool level over the 2011-2012 monitoring period was approximately 78.80 m +\- due to a blockage of the low flow (water quality) outlet pipe identified by Amec Foster Wheeler as part of the annual SWM facility inspection process (discussed in Section 2.3). Once this issue was repaired in November of 2012, the permanent pool dropped significantly, likely approaching the design permanent pool elevation of 78.30 m, and restoring a significant amount of available quantity control storage within the facility. However, given the timing of the repair, the available monitoring data do not represent the normal operating range of the facility.

Notwithstanding, the initial monitoring results indicate that based on the 2011 monitoring, tailwater levels were a frequent factor which impacted discharge from Facility J. Tailwater levels in 2011 were above the sill of the outlet culvert some 8 times in 2011, including a number of storms which were not considered to be particularly significant. In addition, water levels within Facility J were found to be correspondingly above tailwater levels for all storm events, by approximately 1 m for larger storm events. Peak facility operating levels during in 2011 were still some 1-1.5 m below the edge of roadway, however given that the elevated water levels were caused by relatively minor storm events, this was noted as a concern. Minimal results were noted from the 2012 monitoring data, given the lack of major storm events (with the exception of the July 22, 2012 storm, however this storm was focused mainly on headwater areas of the watershed).

As noted in the 2012 annual monitoring report, although the low flow pipe repairs were successful in restoring a significant amount of storage volume, modelling was considered as a potential option to better quantify the flood risk for the facility, given some of the results of the conducted monitoring (2011 in particular). This would also assist in further assessing the previously noted potential mitigation measures in this area.

Additional Facility Assessments – Compensation Wetland

Water level monitoring was also conducted for the compensation wetland located at the RHVP/QEW interchange (COMP 2) over the 2009-2012 period (refer to Drawing 1 for location). This was a recommendation of the 2008 annual monitoring report, in order to better assess facility performance. Summary results are presented in Table 2.2.5 along with recorded water levels within Lake Ontario (at Water Survey Canada's nearby Burlington monitoring site – 02HB017). All data presented are for the monitoring period (i.e. April to November).

Table 2.2.5: Summary of Observed Water Levels within the Compensation Wetland (COMP 2)

Year	Compensation Wetland			Lake Ontario at Burlington (02HB017)	
	Minimum Dry Weather Water Level (m)	Maximum Dry Weather Water Level (m)	Maximum Wet Weather (Storm Event) Water Level (m)	Minimum Monthly Lake Level (m)	Maximum Monthly Lake Level (m)
2009[1]	74.61	74.88	77.87	74.55	75.24
2010	74.49	74.92	76.32	74.63	74.99
2011	74.51	75.39	75.98	74.61	75.37
2012[1]	74.61	74.88	76.12	74.32	74.93
AVERAGE	**74.56**	**75.02**	**76.58**	**74.53**	**75.13**

1. Incomplete period of record; missing gauge data (gauge ran dry or was damaged for some portion of time)

The monitoring results presented in Table 2.2.5 suggest that dry weather water levels within the compensation wetland are generally correlated to water levels within Lake Ontario; minimum and maximum dry weather water levels within the compensation wetland are consistent with those observed within Lake Ontario.

The results presented in Table 2.2.5 also indicate a significant variation in water level within the compensation wetland during significant storm events, on the order of 1.5 m up to 3 m for the storm event of July 26, 2009. Although not intended as a formal flood control facility, given the significant surface area of this feature, it clearly provides a significant amount of informal flood storage volume for Red Hill Creek during major storms.

2.2.3 Recommendations and Lessons Learned

Recommendations

1. Surface water monitoring associated with the Davis Creek Flood Control facility was begun in 2014 and continues in 2015; this work should carry on for the originally specified 5-year timeframe to confirm that the facility is operating as intended (although it is noted that the outlet control system has not yet been activated). It should be noted however given that the system is intended to operate for storm events in excess of a 20 year return period, it is possible that the gate may not operate during the 5-year monitoring timeframe.
2. No further temporary flow monitoring is recommended for the balance of the RHVP system. The results of the monitoring work to-date suggest that the RHVP as a whole is largely operating as per the approved design.

3. Notwithstanding, the City of Hamilton may wish to consider further assessing the localized flooding locations previously noted, as well as the preliminary list of remedial measures. The City of Hamilton (and the MTO) may also wish to consider undertaking a climate change assessment in order to better understand the expected changes in drainage system performance over time and the most vulnerable/sensitive areas, and from this establish a plan to build in resiliency.
4. The City of Hamilton should continue its efforts to minimize CSO discharges to Red Hill Creek given the overall impacts to water quality and flood flows. CSO discharges at the Greenhill location should be targeted in particular given the impacts to flood storage volumes; the implementation of real-time control systems and the RHVP CSO super pipe storage system, should assist in this regard.

<u>Lessons Learned</u>

1. Gauge loss occurred numerous times within the Red Hill Creek system; this is considered primarily attributable to the significant flows and velocities. Any future monitoring should consider a more permanent installation to ensure gauge stability; at a minimum temporary gauges should be anchored within the creek bed to depths of 1 m or greater, or a more permanent gauge setup (such as at a bridge, or weir structure) should be considered.
2. Likewise, obtaining reliable water level and flow monitoring data from the steeper sections of Red Hill Creek was found to be extremely problematic given not only the higher velocities but the high degree of associated channel movement, particularly after formative storm events. This should be taken into account in any future monitoring efforts in similar circumstances; a more permanent gauge setup and channel form (i.e. a weir or otherwise) may be warranted depending on the location and circumstances.
3. In-stream velocity measurements cannot be safely obtained in larger creek systems such as Red Hill Creek at higher flows given the expected velocities and depths. Observed data points should be included to the extent possible, however the extrapolation of higher rating curve ordinates is considered to best addressed by fitting using a representative hydraulic model rather than a simple trendline (as has been done in this study). Reasonableness checks (such as runoff volume and comparison against hydrologic modelling) are a good way to ensure reasonably representative data.
4. A versatile, fully calibrated hydrologic model is an invaluable resource in assessing major storm events and expected system performance. The approved HSP-F model for the Red Hill Creek watershed has been applied numerous times over the course of the integrated monitoring program and has been found to be extremely useful and reliable.
5. Likewise, a resolute network of point rainfall gauges is an extremely useful resource in fully assessing major storm events. Radar-generated rainfall data are also a very useful tool in visualizing the spatial variability of storm events, and better understanding drainage system responses.

2.3 Water Quality and Sediment Quality/Quantity

2.3.1 Brief Background

Water Quality

A major component of the Red Hill Valley Project involved the construction of the stormwater management (SWM) system for the Red Hill Valley Parkway to address the expected increase in contaminant loading associated with the increase in impervious coverage and change in land use. End-of-pipe measures (extended detention wet ponds) were all originally designed based on MOECC "Enhanced" (Level 1) criteria, namely 80% average overall removal of total suspended solids (TSS). Monitoring of these facilities was a requirement of the original MOECC Certificates of Approval (C of A) in order to ensure that the SWM facilities function as designed.

A total of fourteen (14) SWM quality facilities were ultimately constructed as part of the RHVP, and have thus been included in the Integrated Monitoring Plan. The locations of these facilities are shown in Drawing 1; they included 11 City-owned facilities along the RHVP, and 3 MTO-owned facilities along the QEW corridor. Although these SWM facilities were primarily constructed and designed to address stormwater quality for the RHVP, several of the SWM facilities were also designed as retrofits to provide water quality treatment for previously untreated storm sewer outfalls in combination with providing treatment for the RHVP. The retrofit facilities include the Online (Retrofit) facility, Facility H, and Facility J (refer to Drawing 1 for locations).

Water sampling has been conducted in accordance with the protocol outlined in Section 7.4.1 of the Red Hill Valley Project Integrated Monitoring Plan (RHVP IMP, December 2007). In order to facilitate sampling, the 14 SWM facilities were divided into four separate groupings (2 groups of 4 facilities, 2 groups of 3 facilities), based on common location and inter-connectivity (where applicable). In general, it was considered practical to sample two separate groups of facilities in any given year, with three samples per year (generally representative of spring, summer, and fall conditions). Two separate years of sampling were required for each facility, resulting in 6 sampling sets for each facility.

Grab samples were collected from both SWM facility inlets during the onset of larger (typically > 15 mm) rainfall events. Approximately 12 hours after the onset of the rainfall event, grab samples were collected from the stormwater facility outlets (approximately representative of the average effluent concentration based on a 24-hour drawdown time). As was stated in the 2008 Monitoring Report, a single sample was to be collected from the inlet and outlet respectively. In the case of facilities with multiple inlets, either the major inlet was sampled only, or inlet concentrations were mixed, depending on the characteristics of the SWM facility in question.

Beginning in 2009, in-stream water quality monitoring was also conducted, coincident with facility inlet sampling. The intent of this additional sampling was to gain a more fulsome understanding of baseline/background stormwater quality within the watershed, as well as to compare in-creek contaminant concentrations to SWM facility effluent contaminant concentrations. Two in-creek sampling locations were ultimately selected; at Mount Albion Road and at Barton Street (the approximate upstream and downstream limits of the Red Hill Valley system). Both locations are shown on Drawing 1.

All water quality grab samples were analyzed by an accredited laboratory for the parameters specified in the original monitoring plan. This included typical contaminants of interest, such as TSS, nutrients (Biochemical Oxygen Demand, Nitrogen and Phosphorous species), metals (Aluminum, Copper, Lead, Zinc, etcetera), faecal coliforms, as well as numerous other parameters. The full suite of sampling parameters and associated results are included in previous annual monitoring reports.

Water quality sampling for SWM facilities was originally intended to take place within the specified 5-year project timeframe (2008-2012). However, as documented in previous annual monitoring reports, a number of operational issues were noted with several SWM facilities starting in 2009 (MTO-owned facilities) and 2011 (City-owned facilities). It was considered appropriate to delay sampling of these facilities until such time as the issues could be addressed, in order to ensure stormwater quality sampling was conducted with the SWM facilities operating as intended. Given the delay in addressing these issues, no water quality sampling was conducted for MTO-owned facilities until 2013; given the requirement for 2 years of sampling data, water quality sampling necessarily extended into 2014. The results of the 2014 water quality sampling program have been incorporated into the current 5-year summary, rather than issue a separate stand-alone report. Operational issues for City-owned facilities were not addressed until late 2012 (and early 2013), accordingly the second year of sampling for many City-owned facilities was not collected until 2013. Stormwater quality sampling data therefore reflects the periods of 2008-2010 and 2013-2014 (i.e. no sampling was conducted in either 2011 or 2012).

Sediment Quality

The accumulation of fine sediments in the secondary collection areas of stormwater management facilities (i.e. after forebay treatment) can, if sufficiently contaminated pose a risk to resident biota, wildlife and downstream water quality if flushed. Accordingly, sediment quality testing was also included within the scope of the IMP.

As per the IMP, sampling was specified to be conducted every 3 years; given the 5-year monitoring time frame, sampling was conducted once over this period. Main cell sediment samples were collected from the 11 City-owned facilities in 2010; owing to ongoing operational issues and repair works, main cell sediment samples were collected from the 3 MTO-owned facilities in 2011. In addition to the main cells, sediment sampling was also conducted for forebay areas, in order to provide a better overall characterization of sediment contaminant levels.

In all cases, two samples were collected from each location (consistent with the IMP) in order to ensure a representative overall characterization. Owing to the significant pool depths, sediment samples were collected using a boat, along with a Wildco Standard Ekman sampler.

Sediment samples were then analyzed by an accredited laboratory for the parameters specified in the original monitoring plan. This included typical contaminants of interest, such as metals

(Copper, Lead, Zinc, etcetera), polyaromatic hydrocarbons (PAHs), herbicides and pesticides, and total organic carbon (TOC) which assisted in applying sediment quality criteria developed by the MOE (1993).

The full suite of sampling parameters and associated results is included in previous annual monitoring reports.

SWM Facility Bathymetry

Although not included within the scope of the original (2007) IMP, as per the recommendations of the 2008 and 2009 Annual Monitoring Reports, a bathymetric survey was undertaken for the water quality SWM facilities along the RHVP (i.e. survey of the base elevation of the pools within the facilities/top of sediment). It was considered worthwhile to gather this information for a number of reasons, including synergy with sediment sampling efforts (i.e. the need to use a boat to access those areas), and in order to confirm that as-built facility depths were consistent with design grades. This additional work was undertaken for City-owned SWM facilities only.

An initial bathymetric survey was undertaken in 2010, in parallel with main cell sediment sampling efforts. A subsequent bathymetric survey was undertaken in 2012, with the intention to better evaluate annual sediment accumulation rates, and forecast clean-out frequencies accordingly. This was considered important, as it was unclear from the 2010 bathymetric data alone how much of the measured sediment accumulation was due to construction activities as opposed to normal post-construction operation.

Detailed bathymetric survey results are included in the 2010 and 2012 annual monitoring reports.

SWM Facility Inspections

Although not included within the scope of the original (2007) IMP, as per the recommendations of the 2009 annual monitoring report, an inspection of all 14 water quality SWM facilities was undertaken in 2010. The original intent of the annual inspection was to verify whether or not any of the facilities had sustained damage from the major storm events in 2009, and to confirm whether or not there were any operational issues which could impact upon the treatment performance of any of the facilities. It was subsequently concluded that there was significant value in continuing the inspection on an annual basis; inspections were therefore undertaken annually since 2010.

Annual inspections have produced a summary table indicating all identified issues, and classifying them depending on the relative priority. A photographic inventory has also been produced annually in order to document facility condition. Based on the results of these annual inspections (as well as the previous bathymetric surveys), a number of priority works were identified (those which would be expected to have an impact on SWM facility performance). The priority items identified as part of the 2011 inspection (repairs to the Mud Street Facility, Facility C, Facility J, and Facility M) were ultimately undertaken in late 2012 and early 2013, which delayed the completion of the water quality sampling program within the original 5-year timeframe, as noted previously.

A number of additional maintenance items were subsequently identified as part of the 2012 SWM facility inspection. The design and permitting for these additional repair works (to Facility B, Facility D, Facility F/G, Facility I, and Facility J) are currently ongoing, with construction anticipated for 2015. The documentation for these works will be included with the 2014 Annual Report (which documents the final year of required water quality sampling).

Detailed photographic inventories and facility inspection summaries can be found within all annual monitoring reports from 2010 onwards.

2.3.2 Major Findings

<u>Water Quality</u>

The water quality performance of SWM facilities is typically measured by comparing water quality before and after treatment by the facility (i.e. influent and effluent). The difference in contaminant concentrations between the inlet and outlet of the facility can be used to develop an approximate removal rate as a measure of the effectiveness of the facility in meeting water quality targets. As noted, all of the water quality facilities constructed as part of the RHVP were designed based on MOECC “Enhanced” (Level 1) criteria, namely 80% average overall removal of total suspended solids (TSS), which is the key measure for assessing SWM facility performance.

Removal rates for key contaminants (including TSS) have been presented in previous annual monitoring reports for individual sampling events. These results have been averaged, in order to assess the mean removal rates for each of the 14 facilities. Table 2.3.1 summarizes the average overall removal rates for each facility for key contaminants of interest.

It should be noted that consistent with the approach taken in previous annual monitoring reports, where an individual contaminant was not detected (i.e. below the laboratory’s reportable detection limit or RDL) concentration has been assumed to be equal to the RDL value for the purposes of calculating removal efficiencies. Values given in red represent negative removal efficiencies (i.e. on average contaminants concentrations are higher within the facility effluent than the influent).

Table 2.3.1: Average Calculated Removal Rates For Key Contaminants (all samples)								
Facility (City ID)	Number of Samples	Contaminant Removal Rate (%)						
		TSS[3]	TKN[4]	Total P[5]	Aluminum	Copper	Lead	Zinc
Mud Street Facility (116)	6	83%	27%	37%	59%	56%	72%	59%
Escarpment Facility (117)	6	54%	-25%	-1%	67%	55%	78%	44%
Facility B (108)	6	54%	52%	61%	41%	70%	73%	76%
Facility C (109)	5[1]	79%	40%	74%	74%	70%	80%	74%
Facility D (110)	6	16%	-29%	-258%[6]	35%	72%	45%	68%
Online (Retrofit) Facility (110)	6	79%	4%	44%	85%	71%	71%	64%
Facility F/G (111)	6	33%	33%	52%	-2%	73%	21%	32%
Facility H (112)	6	21%	-28%	-27%	-24%	60%	40%	50%
Facility I (113)	5[1]	19%	-21%	-5%	24%	62%	59%	67%
Facility J (114)	6	28%	-2%	1%	25%	29%	36%	28%
Facility K/L (115)	6	-41%	9%	48%	-82%	26%	-32%	-34%
Centennial Facility (MTO Facility 8)	5[2]	69%	28%	60%	69%	61%	69%	63%
Facility M (MTO Facility 7)	5[2]	92%	28%	88%	89%	80%	90%	87%
Facility O (MTO Facility 4)	5[2]	-70%	9%	35%	1%	66%	21%	57%

1. For the June 13, 2008 sampling event, an outlet sample could not be collected for either Facility C or Facility I (SWM facility had already drawn down). Accordingly, a removal efficiency cannot be calculated for this event.
2. 2014 is the final year of water quality sampling for the MTO-owned facilities; to-date 2 or the 3 required annual samples have been collected, thus data is only available from 5/6 sampling sets overall.
3. TSS = Total Suspended Solids
4. TKN = Total Kjedahl Nitrogen (sum of organic Nitrogen, Ammonia, and Ammonium)
5. Total P = Total Phosphorous
6. Values are skewed by an excessively negative removal rate for the June 22, 2010 sampling event.

The results presented in Table 2.3.1 indicate that only 4 of the 14 SWM facilities approximately meet or exceed the original design criteria for 80% TSS removal (Mud Street Facility, Facility M, and Facility C and the Online (Retrofit) facility, the latter of which have average removal rates of 79%, which is considered approximately equal to 80%). Half (7) of the facilities have average TSS removal rates below 50%, and 2 of those have negative removal rates (Facility K/L and Facility O). Negative removal rates are also noted for a number of facilities for nutrients (nitrogen as TKN, and total phosphorous), as well as some metals (aluminum in particular). Overall however, metals removal rates are generally in line with literature reported values for wet ponds (60% +\-); note that no criteria are specified by the MOECC specifically for metals removal.

Low and negative removal rates have been discussed in previous annual monitoring reports. Based on a review of the water quality sampling data, it is considered that the primary reason for these results relates to comparatively low contaminant concentrations in the sampled influent. When influent concentrations are below expected values (TSS concentrations of approximately 50 to 100 mg/L on average for uncontrolled urban areas based on available literature), 80% removal rates cannot practically be achieved.

Low influent concentrations can be the result of numerous factors; the primary reasons are considered to be the inter-event period and sample timing. The inter-event period represents the dry weather period prior to the sampling event; an extended inter-event period means a higher surface contaminant build-up and wash-off (and higher resulting influent contaminant concentrations), while a shorter period typically results in lower contaminant levels. Sample timing refers to the point at which the influent sample is collected; whether the initial most contaminated "first flush' is measured, or whether more dilute concentrations later into the storm event are measured. Both factors are inherent limitations of grab sampling methodology. It is not possible to sample under "ideal" conditions through this methodology (i.e. grab sampling); sampling is therefore inherently limited by the timing of storm events, the accuracy of weather forecasts, the ability to quickly move between sites, and numerous other factors.

In order to further validate the hypothesis that removal rates are significantly affected by influent contaminant concentrations, the results presented in Table 2.3.1 have been further assessed. Sample results where the TSS influent concentration is below 50 mg/L have been removed from the calculation of the average removal rate; results are presented in Table 2.3.2.

Table 2.3.2: Average Calculated Removal Rates For Key Contaminants (with Data Screening)

Facility (City ID)	Number of Samples	Contaminant Removal Rate (%)						
		TSS[3]	TKN[4]	Total P[5]	Aluminum	Copper	Lead	Zinc
Mud Street Facility (116)	6/6	83%	27%	37%	59%	56%	72%	59%
Escarpment Facility (117)	2/6	82%	-50%	-16%	87%	81%	79%	88%
Facility B (108)	5/6	88%	69%	73%	72%	87%	90%	90%
Facility C (109)	4/5[1]	88%	45%	79%	82%	73%	85%	78%
Facility D (110)	2/6	86%	10%	40%	89%	77%	82%	73%
Online (Retrofit) Facility (110)	5/6	86%	9%	48%	92%	78%	86%	77%
Facility F/G (111)	3/6	36%	49%	59%	-39%	59%	-16%	-24%
Facility H (112)	1/6	75%	-5%	37%	67%	77%	69%	66%
Facility I (113)	2/5[1]	79%	-43%	-34%	53%	76%	84%	87%
Facility J (114)	1/6	84%	-35%	-18%	41%	20%	54%	27%
Facility K/L (115)	1/6	96%	73%	87%	94%	87%	95%	92%
Centennial Facility (MTO Facility 8)	5/5[2]	69%	28%	60%	69%	61%	69%	63%
Facility M (MTO Facility 7)	4/5[2]	91%	25%	90%	90%	81%	90%	88%
Facility O (MTO Facility 4)	1/5[2]	90%	48%	79%	65%	85%	71%	90%

1. For the June 13, 2008 sampling event, an outlet sample could not be collected for either Facility C or Facility I (SWM facility had already drawn down). Accordingly, a removal efficiency cannot be calculated for this event.
2. 2014 is the final year of water quality sampling for the MTO-owned facilities; to-date 2 or the 3 required annual samples have been collected, thus data is only available from 5/6 sampling sets overall.
3. TSS = Total Suspended Solids
4. TKN = Total Kjedahl Nitrogen (sum of organic Nitrogen, Ammonia, and Ammonium)
5. Total P = Total Phosphorous

As evident from the results presented in Table 2.3.2, once samples with lower influent concentrations are screened, overall removal rates are significantly improved. In particular, all but 3 of the SWM facilities approximately meet or exceed the designed TSS removal rate of 80%. The 3 SWM facilities include Facility F/G (36%), Facility H (75%), and the Centennial Facility (69%). With respect to Facility F/G, it is considered that the low TSS removal rates may be partially attributable to the large amount of filling within the forebay area [samples were taken in 2008 and 2010; results from the 2010 bathymetric survey indicate the forebay was 78% full at that time]. The forebay of Facility F/G is proposed to be dredged and expanded as part of the forthcoming SWM repair works (2015); this should assist in improving removal rates for Facility F/G. With respect to Facility H, with data screening included, the calculated rate is based on a single dataset, and is considered to be reasonably close to the design removal rate of 80%. With respect to the Centennial Facility, it is considered that the slightly lower removal rate of 69% is attributable to the facility outlet orientation. The outlet in this case is typically submerged by water levels within the receiving watercourse; as such the outlet sample is a mix of the facility effluent and the watercourse rather than the facility effluent alone.

Based on the foregoing, the results suggest that the water quality SWM facilities are generally meeting or achieving their intended design function. In addition to TSS removal rates, nutrient removal rates (TKN and Total P) are generally equal to, or above, literature reported values for wet ponds (30-50% +\-); where lower or negative removal rates are indicated in Table 2.3.2, the results are generally based on a limited number (1-3) of samples. Metals removal rates are generally consistent with literature reported values for wet ponds (60% +\-), with the exception of Facility F/G (which as noted previously, may be due to a deficient forebay feature).

As a further comparison, average contaminant concentrations for all available samples have been compared between creek sampling locations and SWM facility effluent. The results are presented in Table 2.3.3, along with a comparison to MOECC guideline values (Provincial Water Quality Objectives, or PWQOs) where available.

Table 2.3.3: Average Contaminant Concentrations for Creek and SWM Facility Effluent Samples

Location/Facility (City ID)	Number of Samples	Contaminant Concentration (mg/L, CFU/100 mL for E. Coli)							
		TSS[3]	TKN[4]	Total P[5]	Aluminum	Copper	Lead	Zinc	E. Coli
PWQO Criteria	**NA**	**NA**	**NA**	**0.03**	**0.075**	**0.005**	**0.001**	**0.02**	**100**
RHC at Mount Albion	***8***	***180***	***1.24***	***0.315***	***3.70***	***0.020***	***0.013***	***0.195***	***42,500***
RHC at Barton Street	***10***	***370***	***1.88***	***0.465***	***4.66***	***0.018***	***0.015***	***0.174***	***51,370***
Mud Street Facility (116)	6	36	2.95	0.203	2.60	0.006	0.002	0.022	5,543
Escarpment Facility (117)	6	11	0.71	0.040	0.07	0.001	0.001	0.019	2,200
Facility B (108)	6	22	0.73	0.166	0.55	0.008	0.004	0.041	35,672
Facility C (109)	5[1]	26	1.01	0.066	1.13	0.006	0.002	0.017	43,340
Facility D (110)	6	20	1.37	0.262	0.45	0.004	0.002	0.015	5,022
Online (Retrofit) Facility (110)	6	32	1.73	0.218	0.64	0.007	0.003	0.027	11,567
Facility F/G (111)	6	51	2.75	0.172	2.17	0.006	0.006	0.051	5,548
Facility H (112)	6	14	2.53	0.298	0.35	0.006	0.002	0.018	23,000
Facility I (113)	5[1]	18	2.06	0.276	0.65	0.005	0.002	0.017	17,800
Facility J (114)	6	13	1.26	0.119	0.32	0.007	0.003	0.033	109,333
Facility K/L (115)	6	22	1.22	0.097	0.96	0.009	0.005	0.038	38,488
Centennial Facility (MTO Facility 8)	5[2]	26	0.96	0.057	0.82	0.008	0.004	0.043	14,000
Facility M (MTO Facility 7)	5[2]	12	0.63	0.018	0.33	0.003	0.001	0.007	9,040
Facility O (MTO Facility 4)	5[2]	43	1.13	0.088	0.96	0.006	0.006	0.031	6,096

1. For the June 13, 2008 sampling event, an outlet sample could not be collected for either Facility C or Facility I (SWM facility had already drawn down). Accordingly, a removal efficiency cannot be calculated for this event.
2. Only 2 of the 3 required annual samples could be collected for the MTO-owned facilities in 2014 (last year of sampling), thus data is only available from 5/6 sampling sets overall.
3. TSS = Total Suspended Solids
4. TKN = Total Kjedahl Nitrogen (sum of organic Nitrogen, Ammonia, and Ammonium)
5. Total P = Total Phosphorous

The results indicate that, as would be expected, contaminant levels within Red Hill Creek are significantly higher than SWM facility effluent (by an order of magnitude or greater in many cases). The average SWM facility effluent TSS concentration is 25 mg/L, which is considered fairly low (there is no PWQO criteria for comparison purposes). Metals concentrations (Copper, Lead, and Zinc) are generally near, or below, PWQO criteria for SWM facility effluent, concentrations for Aluminum are significantly above PWQO criteria, however these can be affected by naturally occurring levels within soils in some cases. Effluent results for nutrients are variable, with concentrations of Total Phosphorous typically well above PWQO criteria. Likewise, effluent E. Coli concentrations are significantly above PWQO criteria (as are those within Red Hill Creek itself), however SWM facilities do not provide effective treatment of bacteriological contaminants.

Overall, once low contaminant concentrations within influent samples are accounted for, the results indicate that the water quality SWM facilities are largely performing as per the approved design criteria with respect to contaminant removal rates. While some PWQO exceedances have been noted with respect to SWM facility effluent, concentrations are well below levels within the receiving watercourse (an order of magnitude or greater in many cases). It should also be noted that PWQO criteria are guidelines only, and given that expected removal rates are being met, achieving those targets for SWM facility effluent is likely impractical.

<u>Sediment Quality</u>

Sediment quality sampling results are typically compared against the MOECC's Guidelines for Sediment Quality (1993). The guidelines distinguish between the *No Effect, Lowest Effect*, and *Severe Effect* levels of contaminant concentration:

- A *No Effect Level* (NEL) indicates that no toxic effects have been observed on aquatic organisms. This is the level at which no bio-magnification through the food chain is expected. Other water quality and use guidelines will also be met at this level.
- A *Lowest Effect Level* (LEL) indicates a level of sediment contamination that can be tolerated by the majority of benthic organisms.
- A *Severe Effect Level* (SEL) indicates the level at which pronounced disturbance of the sediment-dwelling community can be expected. This is the sediment concentration of a compound that would be detrimental to the majority of benthic species (MOE, 1993).

The results from main cell sediment sampling (2010 for City-owned facilities, 2011 for MTO-owned facilities) are presented in Table 2.3.4. As noted, forebay sampling was also conducted (2009 for City-owned facilities, 2011 for MTO-owned facilities), however the focus of the IMP has been upon main cell contaminants; in addition, contaminant concentrations and patterns are generally consistent between forebay and main cell sampling results. Complete results can be found in previous annual monitoring reports.

Table 2.3.4: Comparison of Average Main Cell Sediment Contaminant Concentration for Key Parameters									
Location	Contaminant Concentration (µg/g or ppm)								
	Cadmium	Chromium	Copper	Lead	Nickel	Zinc	p,p-DDE[1]	Total PCB[2]	Total PAH[3]
Lowest Effect Level Guideline	**0.6**	**26**	**16**	**31**	**16**	**120**	**0.005**	**0.07**	**4**
Severe Effect Level Guideline	**10**	**110**	**110**	**250**	**75**	**820**	**NA[4]**	**NA[4]**	**NA[4]**
Mud Street Facility (116)[6]	0.1	24.5	30	21	25.5	115	ND[5]	ND[5]	ND[5]
Escarpment Facility (117)	1.05	18	31.5	77.5	22.5	350	ND[5]	ND[5]	1.25
Facility B (108)	0.95	35.5	49	51.5	22.5	325	ND[5]	ND[5]	0.85
Facility C (109)	0.6	33.5	40.5	40	22.5	230	0.042	ND[5]	0.65
Facility D (110)[6]	0.95	19.5	41.5	65.5	21.5	310	ND[5]	ND[5]	2.53
Online (Retrofit) Facility (110)	0.9	26	52	62	29	400	ND[5]	ND[5]	2.87
Facility F/G (111)	1	18	30.5	56.5	21.5	300	0.017	ND[5]	1.43
Facility H (112)	0.9	30	67.5	60	24.5	365	0.037	ND[5]	15.0
Facility I (113)	0.8	24	33	40.5	26.5	235	0.009	ND[5]	0.43
Facility J (114)	2	62	105	108	20	627	ND[5]	ND[5]	39.5
Facility K/L (115)	0.85	34.5	56.5	60	23	365	ND[5]	ND[5]	5.21
Centennial Facility (MTO Facility 8)	0.9	49.5	101	97.5	27	600	ND	ND	8.92
Facility M (MTO Facility 7)[6]	0.2	16.5	25.5	19	16.5	76.5	0.07	ND	1.09
Facility O (MTO Facility 4)	0.55	31.5	51	73.5	24.5	325	0.01	0.08	2.65

1. p.p-DDE = dichlorodiphenyldichloroethylene, a common breakdown product of DDT (a well-known pesticide/insecticide)
2. PCB = polychlorinated biphenyls (known toxic carcinogen used widely in past electrical products)
3. Total PAH (polyaromatic hydrocarbons) has been calculated as the sum of individual average concentrations of each tested PAH. Where value was not detected, concentration equal to zero given variability in laboratory detection limits.
4. NA = Not applicable (Severe Effect Level is variable depending on the amount of Total Organic Carbon per sample)
5. ND = Not detected (below the laboratory's detection threshold).
6. Main cell of SWM facility was dredged after sampling, thus results may no longer be representative of in-situ contaminant concentrations

The results generally indicate that metals exceedances of the LEL are common, however there are no reported exceedances of the SEL. Exceedances are far less common for pesticides and PCBs, with only a few facilities showing any measured concentration above the laboratory detection limit. Based on the detailed results in previous annual monitoring reports, where those values are detected above the LEL, they are still typically an order of magnitude or greater below the SEL. PAHs were generally found in all facilities, but at concentrations typically below the LEL. Total PAH concentrations were the highest within Facility H, and in particular Facility J, which had PAH concentrations of an order of magnitude or greater than other SWM facilities. In both cases, the higher PAH concentrations are considered attributable to the facility type; both are retrofit facilities which receive runoff predominantly from adjacent residential/commercial/industrial land uses. The particularly high PAH concentrations within Facility J may be attributable to a large proportion of contributing commercial/industrial land use. In both cases, measured concentrations were still typically an order of magnitude less than the SEL.

Overall, the sediment contaminant concentrations presented in Table 2.3.4 appear reasonably consistent, with the previously noted exceptions. There are limited literature sources to provide meaningful comparatives of expected concentrations. The results presented in Table 2.3.4 may be useful in assessing likely disposal options for future clean-outs. In general, it is considered that the potential for re-suspension and downstream flushing of settled main cell sediments is low, given the typical pool depths within SWM facilities. Detailed site-specific hydraulic modelling would be needed to assess the risk in further detail. In general, it is considered that the risk of sediment flushing can be best addressed through regular inspection and maintenance to avoid excessive sediment build-up, which would likely be a major contributor to flushing risk.

SWM Facility Bathymetry

Given that the bathymetric surveys of City-owned SWM facilities were not part of the scope of the original IMP, detailed results are not included herein. Detailed results can be found in previous annual monitoring reports, in particular the 2012 report (which includes the results of both the 2010 and 2012 surveys).

In general, the bathymetric surveys were extremely useful in identifying infilling within SWM facilities, and targeting those which required immediate dredging to restore design treatment volumes. It should be noted that where dredging has been subsequently completed (or is planned), the results presented in previous reports are clearly no longer valid.

The 2012 annual monitoring report also attempted to better evaluate annual sediment accumulation rates under “normal” operating conditions (based on the differences between the 2010 and 2012 surveys), and forecast clean-out frequencies accordingly. The results of this effort were largely inconclusive. In many cases sediment accumulations were found to be minimal, or in some cases negative. This may be in part attributable to unavoidable differences in the collected data points from the bathymetric survey (points in different locations, thus different sediment depths). Notwithstanding the lack of sediment accumulation over the two year period remains counterintuitive. This may be the result of weather conditions (dryer than average) or potentially lower than expected sediment concentrations in contributing drainage areas, however the precise reason remains unknown. The latter would be consistent with the observations with respect to water quality sampling (lower than expected TSS concentrations within SWM facility influent).

Based on the foregoing, the high sediment accumulations in certain SWM facilities (those which have been, or will be targeted for dredging and clean-out) would appear to be the direct result of original construction activities. SWM facilities were not surveyed prior to assumption by the City of Hamilton (or MTO). Alternatively, some of the higher sediment accumulations could be due to instabilities post-construction, or deposition from the major storm events of 2009.

SWM Facility Inspections

As noted, annual SWM facility inspections were not part of the scope of the original IMP, and as such, detailed results are not included herein. Detailed results can be found in previous annual monitoring reports from 2010 onwards.

In general, the facility inspections were extremely useful in identifying maintenance issues which could impact upon facility operation and treatment capacity, which could in turn impact upon water quality sampling results. The results of the annual inspections have resulted in a number of works by both the City and the MTO, primarily related to facility dredging and erosion repairs (re-grading, additional rip-rap stone, etcetera). Regular inspection and maintenance is key to ensuring the proper operation and stability of all SWM facilities.

2.3.3 Recommendations and Lessons Learned

Recommendations

1. Although some low and negative removal efficiencies have been noted with respect to SWM facility water quality sampling, additional sampling is not considered warranted. As noted, the results are considered primarily attributable to low contaminant concentrations within sampled influent; once these results were screened, SWM facility removal rates are generally consistent with design values. Selected water quality sampling may be considered in the future if there is a particular concern with a SWM facility, however it is not considered warranted at this time. Should the City or other regulatory agencies wish to assess SWM facility water quality in greater detail, a further alternative would be to consider implementing continuous water quality monitoring at one specific trial location, either through the use of an auto-sampler, or a continuous water quality gauge in combination with grab sampling. This would serve to validate the previously noted conclusions regarding the water quality performance of the SWM facilities along the RHVP.
2. By contrast, additional water quality sampling within the overall Red Hill Creek system may be warranted. Based on the in-stream water quality sampling conducted, water quality within Red Hill Creek continues to be heavily degraded, likely owing to the large proportion of the watershed without stormwater quality controls. Targeted water quality sampling could be beneficial in assessing the most degraded areas and likely locations for future remediation, where feasible.
3. Although not directly assessed as part of the IMP, CSO discharges to Red Hill Creek clearly have a negative impact on water quality. The City of Hamilton should continue its effort to minimize overflows, through ongoing monitoring, system optimization, additional storage, sanitary sewer disconnection, and other such measures. The Red Hill CSO “superpipe” constructed as part of the RHVP should assist in this regard; it is understood that this feature has been active as of December 2011, and limits CSO discharges from three former CSO points at Lawrence Avenue, Queenston Road, and Melvin Avenue. The Red Hill CSO does not however collect overflows from the two CSO tanks at Greenhill.
4. The sediment quality sampling conducted to-date should be considered as informative only; additional sampling should be conducted prior to any dredging or excavation work so that

appropriate disposal and health and safety precautions are taken into account. Particular attention should be given to retrofit facilities and those where higher contaminant levels were noted (Facility J in particular).

5. The City of Hamilton and the MTO should consider repeating a bathymetric survey of all SWM facilities sometime in the next 5-10 years, in order to assess the need for SWM facility clean-outs and ideally better establish sediment accumulation rates in comparison to the 2010 and 2012 bathymetric survey results.
6. The City of Hamilton and the MTO should consider continuing annual SWM facility inspections in order to proactively assess SWM facility condition and respond to potential maintenance issues. The Operations and Maintenance Manual for the RHVP SWM Facilities should also assist in this regard.

<u>Lessons Learned</u>

1. The limitations associated with water quality grab sampling should be clearly understood. While grab sampling is still considered useful to provide an indication of water quality, it should be understood that it represents data at a single point in time, which depending on timing, may not be representative of overall patterns. Likewise, grab samples are impacted by a number of factors, including antecedent conditions and storm characteristics; it is never possible to consistently sample under the same “ideal” conditions applied in design. Accordingly, water quality sampling results should always be interpreted with caution and careful thought.
2. Based on sampling results, municipal storm sewers (residential/commercial/industrial land uses) appear to generate much higher contaminant levels than those from the Red Hill Valley Parkway itself. Commercial and industrial land uses in particular seem to be significantly higher. In some cases, the lower loading levels associated with the Red Hill Valley Parkway may be due to the pre-treatment provided by grassed swales in the medians, which are not directly accounted for in design calculations. Such pre-treatment may also explain some of the frequent low influent concentrations. This should be interpreted and recognized as a positive.
3. An as-constructed/as-built bathymetric survey should be mandatory prior to assuming any SWM facility. This ensures that the constructed facility is consistent with the approved design, and that the ultimate owner (City/MTO) is not responsible for dredging sediment associated with construction rather than the intended operation.
4. Regular inspection of SWM facilities is clearly the best way to ensure efficient operation and to proactively address maintenance requirements.

2.4 Creek Morphology

2.4.1 Brief Background

An approximate 7,200 m reach of Red Hill Creek between the confluence of the Butternut Falls tributary (upstream of King's Forest Golf Course) and north of the CNR railway was re-aligned during the period June 2004 - April 2007 using natural channel design (NCD) principles. Channel re-alignment was undertaken to accommodate the expressway corridor while minimizing interactions between the roadway and the creek alignment. Additional efforts were undertaken to rectify approximately 60 years of adverse impacts to the creek corridor from urbanization and various historical channelization methods.

The design was based upon site investigations of Red Hill Creek during the period 1996 – 2004, assessments of comparable watercourses in similar geology and slopes, and using the current state of knowledge in both theoretical research and practice (WRIS 2002). Post-construction monitoring methods and metrics used to evaluate channel dynamics were consistent with the methods employed during the investigation period prior to construction which included surveys of: channel cross sections, longitudinal profile, and substrate in addition to visual inventories.

2.4.2 Major Findings

Analyses were based upon the bankfull channel characteristics which coincide with the morphological channel forming flow. This flow regime has been shown to maintain the channel form and bed material transport over a long period of time which is well document in literature (Leopold et al., 1964; Schumm et al., 1984; Annable et al., 2012). The rate of channel change is based upon the frequency and duration of flows exceeding bankfull discharge where it is also widely accepted that large magnitude low frequency discharge events (severe floods) may cause significant channel alterations that disrupt the ongoing trends of the bankfull flows (Leopold et al., 1964).

Prior to 2004, discharge analyses used in assessing channel erosion and change were based upon two Environment Canada gauge stations along Red Hill Creek at Queenston Ave. (02HA014) and Mount Albion Falls (02HA023) for their respective periods of records. Prior to roadway construction, the Mount Albion Falls station was discontinued. After channel construction was completed, the Queenston Ave. gauge was moved to Barton St. to capture a larger portion of the catchment area. The adopted hydrologic analysis is based upon the Barton St. gauge as it has maintained the longest period of record (and captures the largest proportion of the watershed). Forensic hydrology modelling results undertaken by Amec Foster Wheeler were also used for the high magnitude low frequency flood events observed on July 26, 2009 and July 22, 2012.

Over the period of record of the Barton St. gauge (02HA014) since 1978, a median of 10 annual events exceed bankfull discharge (flows begin to access the floodplain) with minimum and maximum annual ranges of 1 and 19 events respectively; where the 25th and 75 percentile are 6 and 13 events respectively (Figure 2.4.1). These findings are consistent with those observed prior to creek construction (WRIS, 2002). Ready access of flood waters to the adjacent floodplain was, and is, a key element in the proper functioning of the creek system. Between 2009 and 2011 an increased number of convective storms occurred resulting in an increased frequency in bankfull events (all exceeding the 84th percentile). Only four discharge events exceeded bankfull discharge in 2012 – falling below the 20th percentile in discharge frequency observations. Based exclusively upon the increased frequency of bankfull discharge (between 2009 and 2011), higher than average channel erosion and migration rates would be anticipated during the same time frame (discussed further).

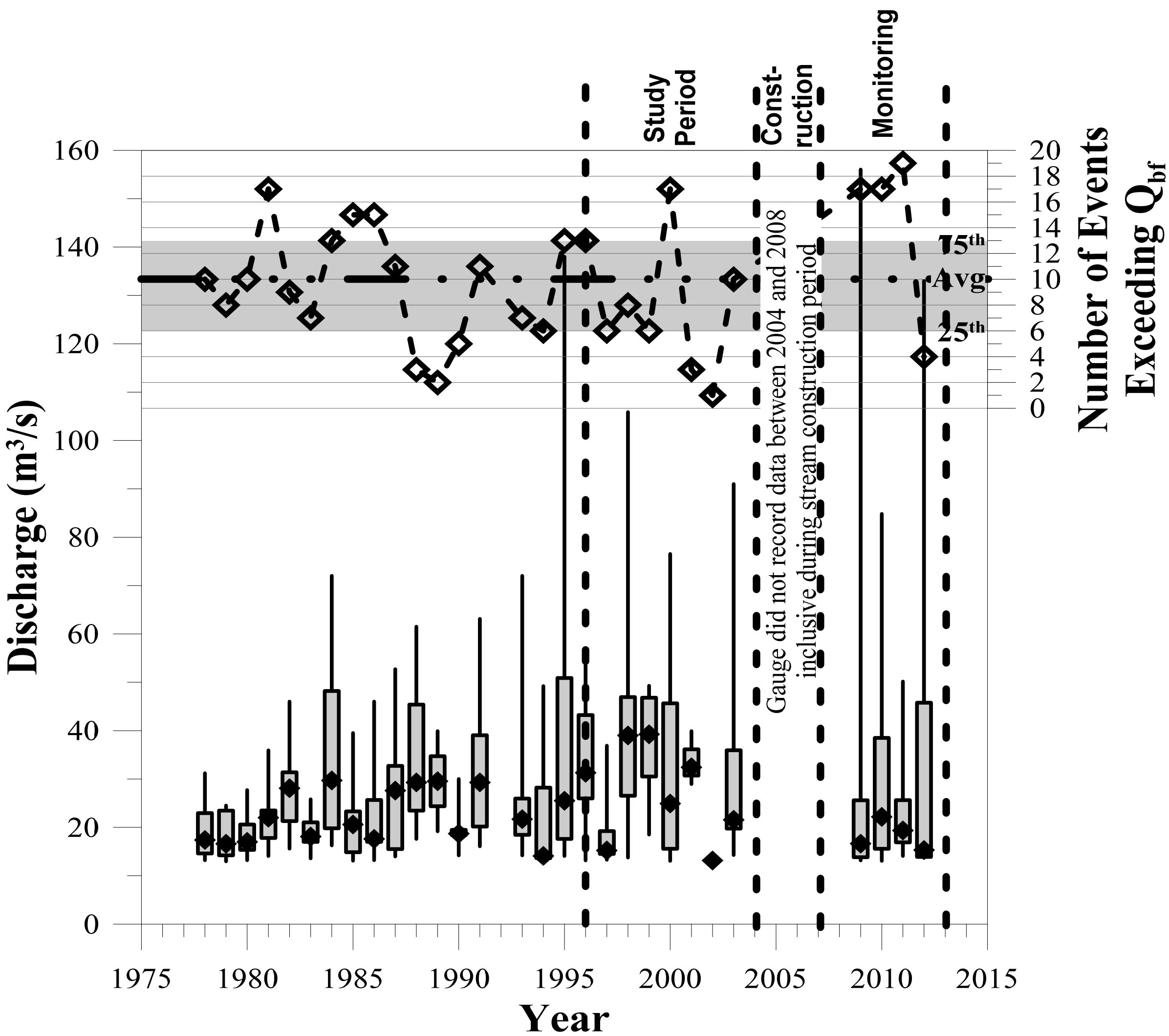

Figure 2.4.1 Box-and-whisker plot of annual range in flows exceeding bankfull discharge and annual frequency of events exceeding bankfull discharge (Barton ST. gauge 02HA014)

As noted, two rare low frequency high magnitude discharge events occurred subsequent to the creek construction on July 26, 2009 and July 22, 2012. The 2009 event represents the largest flood for the period of discharge record which exceeded the 100-year return period through the Red Hill Creek valley corridor. The flood on July 22, 2012 was lower in magnitude yet also exceeded the 100-year return period upstream of Davis Creek (as forensically assessed by Amec

Foster Wheeler). The stream channel responded in a fashion consistent with the response to high magnitude low frequency events where significantly larger rates of in-stream channel erosion and deposition were observed (relatively to bankfull flows). Common in such flood flows are observations that the planometric location of channels can significantly change (by several channel widths), existing channel locations may be abandoned and new channel alignments and/or significant vertical erosion observed. This was not the case along the rehabilitated reach of the Red Hill Creek where the alignment stayed within the design corridor.

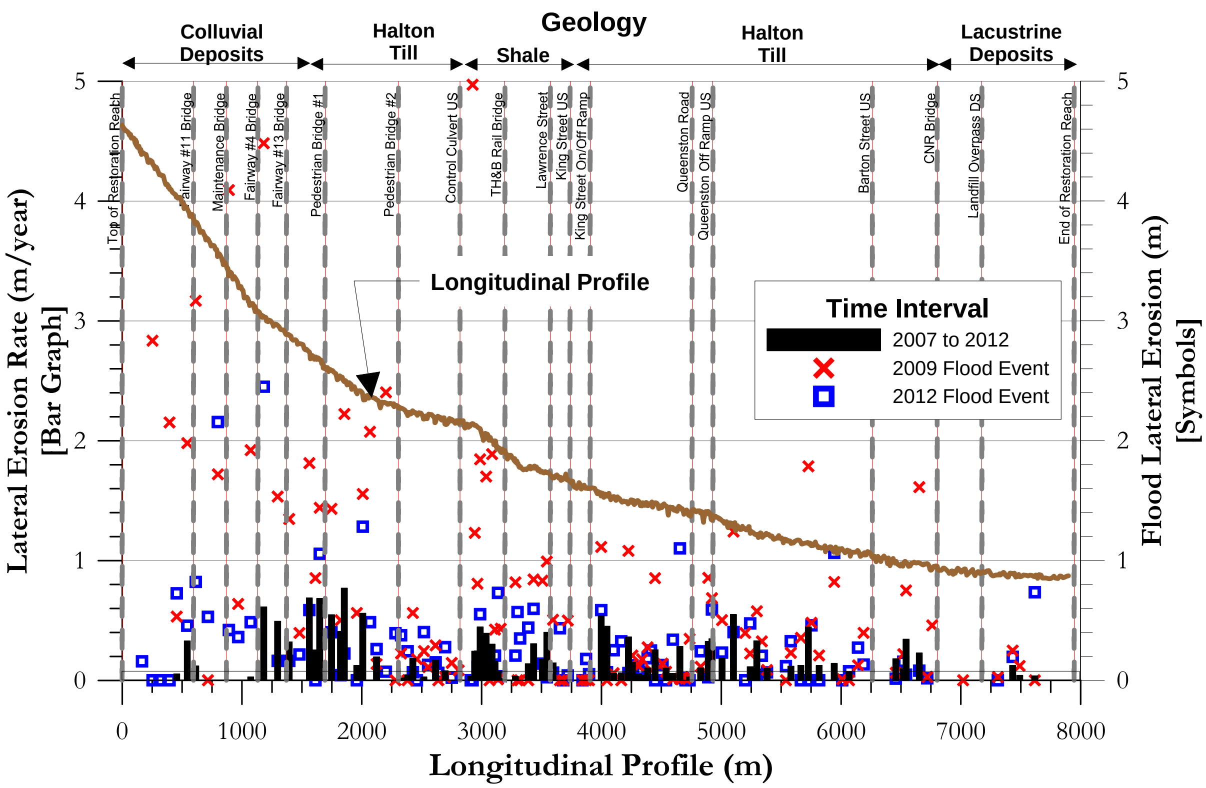

Figure 2.4.2 Bankfull channel annual lateral erosion rate (monitoring period 2007 – 2012) and net erosion for major flood events. Note: vertical axis of longitudinal profile not shown.

The assessment of bankfull channel erosion rates, changes in cross sectional area and centerline meander migration rates were based upon annual field surveys of 118 permanently benchmarked cross sections laid out at approximately equal intervals along the rehabilitated reach. During the July 26, 2009 event, 58 cross sections observed lateral erosion exceeding 0.3m which predominantly occurred upstream of the TH&B railway where the channel slope is the steepest or the channel flows directly over shale (Figure 2.4.2). The maximum amount of lateral scour that was observed occurred within King's Forest Golf Course where on one particular bend (where the greatest amounts of lateral erosion would be anticipated) 4.1m and 4.3m of lateral erosion resulted at two cross sections. Correspondingly, 34 of the cross sections observed net lateral erosion of less than 0.05m (measurement error) during the same flood event. There is notably one scour location that was observed downstream of the stormwater control culvert which resulted in 4.9m of lateral scour, however, this location was related to culvert expansion scour rather than river mechanics processes. The average annual observed lateral erosion rate over the monitoring period (2007 – 2012) was calculated to be 0.17 m/year which includes the episodic results from the July 2009 and July 2012 storms. The amount and extent of lateral erosion that occurred from the 2009 flood is considered relatively minor for the magnitude of the discharge event.

The flood event of 2009 also initiated an erosion cycle in the creek between the toe of Mount Albion Falls and the confluence with the Buttermilk Falls tributary (just upstream of the rehabilitated site). Based upon field evidence and comparisons with previous surveys of the creek (Annable, 1996), the bankfull channel doubled in width at some sections and vertically incised by in excess of a meter. This channel reach had previously demonstrated no signs of instability and based upon field indicators, had maintained a relatively stable channel form for several decades to possibly centuries. The response of this previously stable section further demonstrated the severity of the July 2009 storm but also raised concern for the rehabilitated reach downstream. The recently destabilized reach has been (since July 2009) generating notable quantities of cobble-sized bed material which are being transported and deposited through the upper portion of the rehabilitated reach. The constructed channel was never designed to handle/receive the increased volume of bed material transport (as the reaches upstream of Mount Albion Falls are dominantly fine-grained material). The response of the rehabilitated channel receiving the coarse bed material through the King's Forest Golf Course and above, during flood flows, has been increased rates in in-channel deposition leading to infilling of the bankfull channel or flanking of in-stream structures. This response is expected to persist into the near future (likely decades) requiring in-stream maintenance until the upstream reach erosion is either mitigated or the erosional cycle diminishes.

The July 2009 flood also presented limitations in the creek corridor design as a result of some design choices. The creek design by WRIS (2002) identified that the minimum bridge spans to maintain channel stability should be no less than 32m throughout the creek corridor. This design recommendation was followed through the valley corridor with the exception of golf cart bridge crossings along the King's Forest Golf Course. In these locations, a constraint was placed upon the creek design to minimize nuisance flooding to the golf course and limited the golf cart bridge spans to 22 m. The July 2009 flood demonstrated limitations in these constraints where the greatest rates of both lateral (Figure 2.4.2) and vertical scour were observed downstream of the cart bridges of anywhere along the 7.2 km rehabilitated reach. At these locations flow contraction scour occurred leading to accelerated rates of channel scour and the failure of in-stream structures. The design constraints remained in place after the July 2009 flood (with the exception of the golf course maintenance bridge which was increased to a 38 m span) and alterations were made to the in-stream structures in attempts to further mitigate the limited bridge spans and floodplain corridor. Scour and erosion was further exacerbated along the golf course reach as a result of the increased cobble material transport and deposition originating from the erosion source downstream of Mount Albion Falls and corresponding limited growth of herbaceous size vegetation along the creek margins.

The erosion assessment following the July 2012 flood event identified 30 cross sections with observed lateral erosion exceeding 0.3 m and 35 cross sections with net lateral erosion less than 0.05 m (measurement error) during the same flood event. Similar to the July 2009 event, the highest lateral erosion was observed upstream of the TH&B railway where the channel slopes are the steepest. The decreased number of monitoring cross sections observing erosion in excess of 0.3 m is a combined result of the lower magnitude event, relative to the July 2009 event, enhancements made to many of the in-stream structures further mitigating channel erosion (discussed further), and the increased density in riparian vegetation downstream of King's Forest Golf Course. Subsequent to observing the channel responses from the July 2012 storm and based upon continued monitoring and adaptive management, the initial design constraints of limited floodplain width and golf cart bridge spans, narrower that those recommended and constructed for the remainder of the rehabilitated reach, were re-addressed. In the spring of 2014, golf cart bridge spans were increased to 38 m and installed. In the winter and summer of 2015, increased floodplain connectivity by widening the existing creek floodplain corridor and the re-construction of the in-stream structures with further enhancements are currently underway (Figure 2.4.3).

Figure 2.4.3 2015 channel works through King's Forest Golf course which shows increased golf cart bridge spans, floodplain benches and modified in-stream structures.

Net erosion rates, as calculated in Figure 2.4.2, do not account for any deposition which may occur in portions of the bankfull channel at any given cross section (Figure 4.2.4). To assess a dynamically stable channel, as designed in this project using NCD techniques, requires that both erosion and deposition be accounted for. This approach recognizes that in a dynamically stable channel, the channel is allowed to move and adjust and does so at a relatively slow rate consistent with the frequency and duration of channel forming flows observed. The quasi-stable criteria and NCD approach allows for movement, however, the long-term change in average cross sectional area along the entire rehabilitation reach, should remain relatively close to zero.

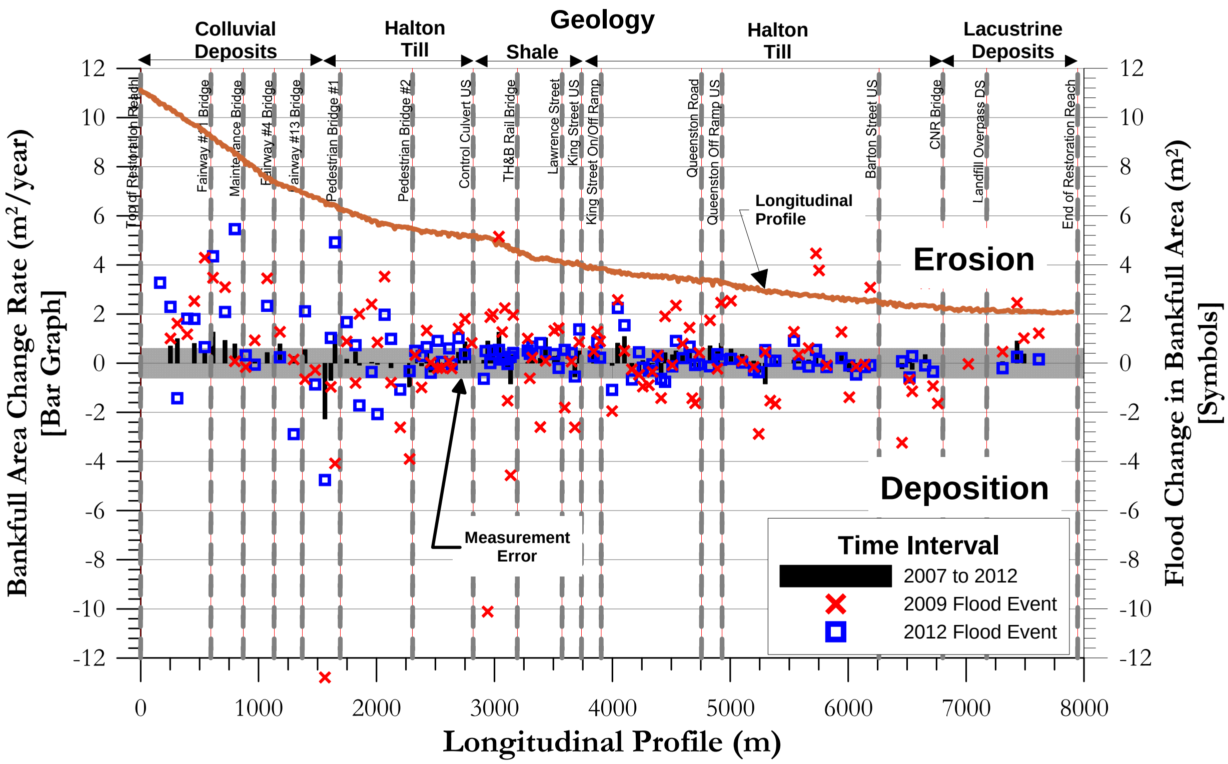

Figure 2.4.4 Bankfull channel annual cross sectional area change rate (monitoring period 2007 – 2012) and net cross sectional area change for major flood events. Note: vertical axis of longitudinal profile not shown.

The change in bankfull cross sectional area from the July 2009 flood resulted in 40 sections having net increases in cross sectional area greater than 1.0 m^2 (standard measurement error) whereas 21 cross sections decreased in cross sectional area by greater than 1.0 m^2 (Figure 2.4.4). The analysis of the July 2012 storm identified 18 and 6 cross sections where increased and decreased cross sectional area occurred in excess of $\pm$1.0 m^2 respectively. The average change in cross sectional area for all cross sections along the rehabilitated reach was calculated to be +0.21 m^2/year which is within the standard measurement error. Larger volumes of both erosion and deposition are observed within and above King's Forest Golf Course where the channel slopes are steepest, contraction scour was occurring downstream of golf cart bridges and the channel was attempting to transport the increased coarse-grained bed material originating upstream of the rehabilitated reach.

The bankfull channel centerline, meander migration rate is the most representative metric to evaluate planform change in the river corridor which accounts for both the erosion and deposition that may be occurring in any given cross section. This is also the method employed by WRIS (2002) in assessing the long-term quasi-equilibrium channel migration rates prior to creek rehabilitation. The analysis of the pre- and post-flood cross sectional surveys from the 2009 event identified net channel centerline migrations exceeding 0.3 m at 33 of the cross sections and net migrations less than 0.05 m (measurement error) at 70 cross sections (Figure 2.4.5). The July 2012 flood identified 10 and 67 cross sections experiencing lateral migration in excess of 0.3 m and below 0.05 m respectively. Similar to previous observations, the decrease in observed larger migration adjustments from the July 2009 to the July 2012 floods at monitoring sections, is a result of the lower magnitude flood event, improvements made to in-stream structures and increased vegetation along the riparian corridor downstream of King's Forest Golf Course.

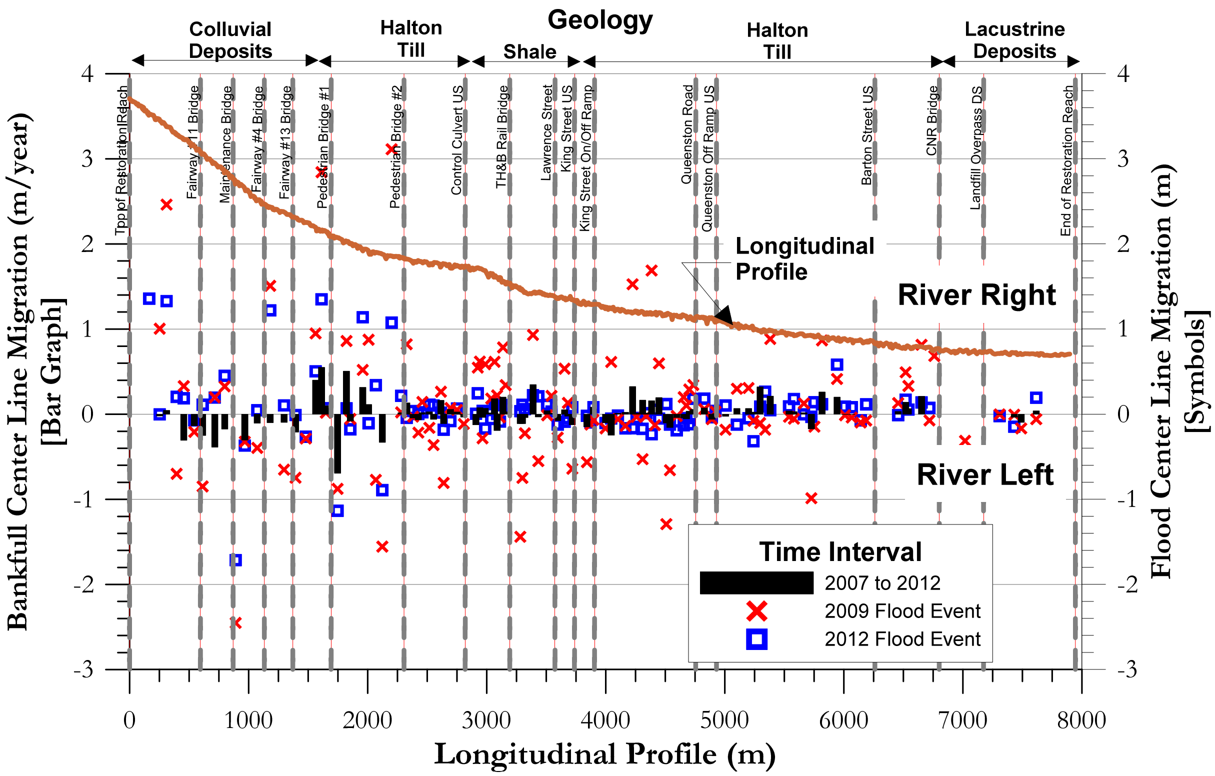

Figure 2.4.5 Bankfull channel centerline migration rate (monitoring period 2007 – 2012) and net channel centerline migration for major flood events. Note: vertical axis of longitudinal profile not shown.

The average meander migration rate for the entire rehabilitated reach over the monitoring period (2007 – 2012) was calculated to be 0.10 m/year. WRIS (2002) identified from field observations along Red Hill Creek in the Halton Till that the natural meander migration rates for a series of similar cross sections (where no in-stream structures existed) was, on average, 0.07 m/year. The 0.07 m/year was used as a design target for the long-term morphological forming flow migration rate employed in the NCD procedure. If post-construction monitoring cross sections along the rehabilitated reach where Halton Till dominates the channel boundaries are exclusively considered, the average channel centerline migration rate was found to be 0.11 m/year. A higher average annual rate for the coarser colluvial deposits within, and above the King's Forest Golf Course reach of 0.13 m/year, was calculated.

The channel centerline meander migration rates are notably biased as a result of the 2009 and 2012 flood events and the ensuing reconstruction of many of the in-stream structures (particularly in the upper 2.2 km of the rehabilitated reach). Higher lateral migrations were observed in many of the cross sections subsequent to the 2009 and 2012 flood events as illustrated in Figure 2.4.5. However, the re-construction of many of the in-stream structures in 2010 and those that are occurring in 2015 also re-establish the creek banks which are used in the erosion assessment. The only way to further refine the rates of channel change and to remove the current 2009 and 2012 flood biases would be through continued channel monitoring after 2015 channel works.

It is common practice in channel rehabilitation to employ a series of in-stream structures to maintain grade control (mitigate the channel from vertical erosion) and planform location (mitigate the channel from laterally migrating). Final structure locations and structure configurations occur during the construction process to address field issues and properly field-fit each structure to the local conditions, as occurred on the Red Hill Creek project. Alterations to structures commonly occur post-construction after the structures are exposed to flood flow forces above bankfull discharge, where they begin to adjust to the local forces of discharge events and scour. Such alterations typically decrease with time until in-frequent adjustments or reconstruction are required (Figure 2.4.6 up to the pre-2009 flood period).

The July 2009 flood, however, demonstrated both resiliency and limitations in the channel design under the extreme flood flow conditions. Although many structures experienced undermining, flanking around structures or failure, the channel remained in its design alignment thus demonstrating the robustness of the design and the ability of the in-stream structures to absorb change (as evidenced by the low bankfull channel centerline migration rates similar to the design targets). This is particularly important in urban or urbanizing watersheds where there is significant infrastructure either crossing or in in close proximity to the river corridor. Such storm events do not exclude the requirement for in-stream structures to be re-constructed or altered which is akin to man-made infrastructure that requires infrequent maintenance from rare events beyond the design envelope.

Many of the in-stream structures did not experience any adverse effects from the July 2009 storm (in particular through the Greenhill area and between Queenston Ave. and Barton St.), many others though were undermined, flanked or failed (in particular though the steepest channel reach in and upstream of the King’s Forest Golf Course where design constraints were imposed). A total of 128 modifications to 99 of the 192 in-stream structures were required after the 2009 flood (Figure 2.4.5). Many of the post-flood design modifications along the entire watercourse added sills into the floodplain of existing structures to mitigate flanking. Sills were not part of the initial design process (only where they were deemed critical to maintain lateral constraints).

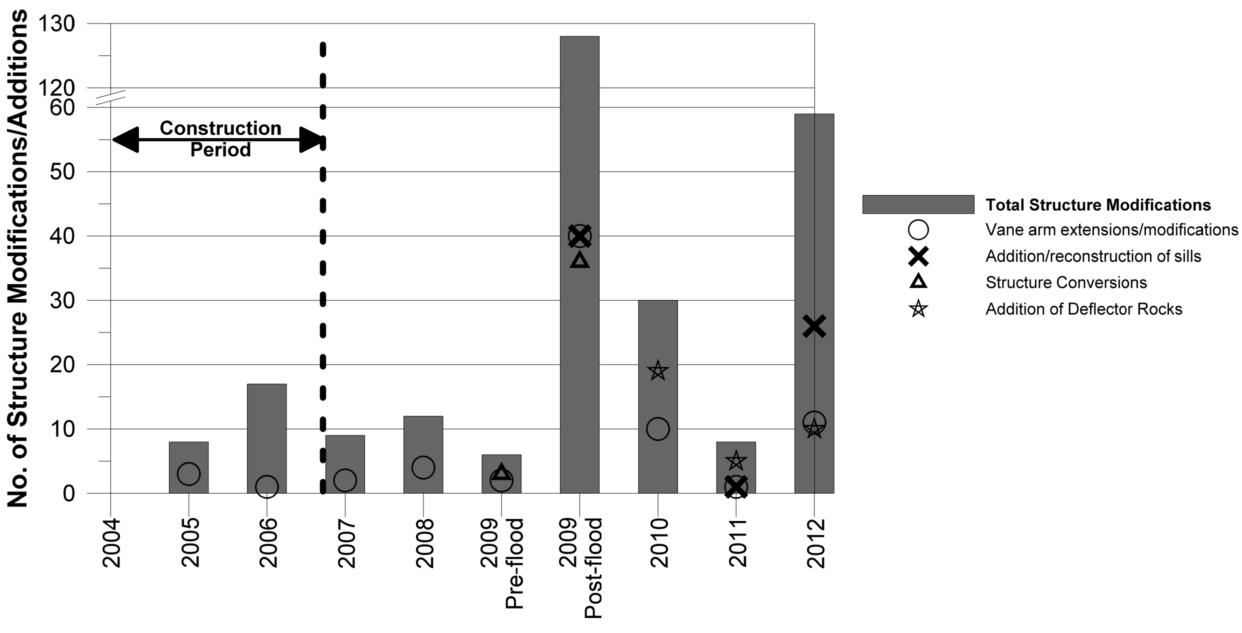

Figure 2.4.6 Annual in-stream structure inventories requiring modification or maintenance. Note: bar graph illustrates the net number of in-stream structures requiring modification where many structures were accounted more than once to identify separate structure components requiring modification. Symbols show the major structure revisions included in the total inventory.

The majority of structure conversions and the addition of deflector rocks to mitigate localized downstream structure scour occurred along the reach in, and above, the King's Forest Golf Course. This section maintains the steepest channel slopes, is the most vulnerable to scour and erosion, has had to accommodate the limited bridge span and floodplain design constraints (up to 2014), is transporting the coarse-grained bed material sourced from the newly eroding reach upstream of the Buttermilk Falls tributary and has developed limited rooting density of floodplain vegetation to mitigate bank scour. The alterations to the in-stream structures within this section were undertaken to accommodate all of the competing channel degradation challenges identified above.

Re-construction of in-stream structures occurred during the winter of 2010 and similar to the initial construction phase, the number of post-construction modifications began to decrease until the flood of July 2012 (Figure 2.4.6). In this flood, all in-stream structure flankings, underminings and failures were limited to the channel section within, and above the King's Forest Golf Course. In-stream structures in the remaining 5 km of the rehabilitated reach did not experience any adverse effects from the July 22, 2012 storm event.

2.4.3 Recommendations and Lessons Learned

Recommendations

Although the average bankfull meander migration rates are similar to the design target (0.07 m/year) for the entire rehabilitated reach (0.11 m/year), the inclusion of the 2009 and 2012 storms and the subsequent creek works in 2010 and those occurring during 2015 introduce significant bias in the long-term erosion and meander migration rates to assess channel performance. A stronger understanding of these rates can only be achieved by continued monitoring along the creek corridor (in particular for the upper 2.2 km of the rehabilitated reach).

Maintenance along the creek corridor will continue to be a future requirement. The creek corridor should be considered natural infrastructure and intermittent maintenance will be required to maintain its current alignment (particularly after large magnitude flood events). Anthropogenic material discarded into the creek remains a constant challenge which is common to most urban watersheds. Annual creek cleanup days should be organized to rid the channel of discarded materials (in particular shopping carts, water bottles, tires, etc.).

Removal of debris jams in-and-around culverts (particularly the Greenhill flood control facility culvert, TH&B railway, King St.) are key to maintaining channel function and for mitigating adverse flooding.

Addressing the channel erosion upstream of the Buttermilk Falls tributary (upstream of the rehabilitated site) to the toe of Mount Albion falls is of long-term importance for maintaining downstream channel stability. The rehabilitated channel reach was never designed to handle/receive the bed material load that is currently being generated by the upstream reach destabilized in the July 2009 flood. Measures should be taken to mitigate erosion in this reach and provide enhanced geotechnical slope stability. The extent and future duration of re-occurring impacts through this sub-reach is unpredictable, as the magnitude and frequency of significant future flood discharge events are unknown.

Channel works occurring over the winter and summer of 2015 in the upper 2.2 km in the King's Forest Golf Course reach, to offset previous design constraints, are recommended to be monitored for erosion for at least five years to verify that the design revisions are functioning properly and to more accurately assess the design bankfull channel centerline meander migration rates.

Lessons Learned

Many lessons were gained in the practice of NCD techniques from the July 2009 and July 2012 floods. In particular, limitations were identified in the scour patterns of in-stream structures constructed in relatively steep slopes (those that occur in and above the King's Forest Golf Course) which have never been identified on any other NCD in North America. No other known NCD projects of similar length and variation in slopes in an urban watershed has ever been exposed to the magnitude frequency in discharges events observed on July 26, 2009 and

July 22, 2012. Design alterations and knowledge gained from these events were integrated into post-flood in-stream structure modifications, and the findings from these analyses are also disseminated in scholarly works and river channel design presentations.

Sills along each structure should have been included in the initial channel design. The expense of installing these minor features during the initial construction phase may have reduced the number of in-stream structures requiring 2009 post flood modification in the lower reaches of the rehabilitated reach (downstream of the TH&B railway) and minimized subsequent disturbances to the riparian corridor.

Design constraints through the King's Forest Golf Course were discussed however due to economic reasons and other factors were not explicitly applied. However, as there are fewer case-studies of NCD projects on steeper slopes and in similar geology, the fate of the channel response to flood flow conditions was not and continues to be less certain. An adaptive management approach was exercised within this reach where the cart bridge and limited floodplain limit constraints were reassessed in 2014.

2.5 Fisheries

2.5.1 Brief Background

Monitoring of the fish and benthic invertebrate communities and water temperature began in 2004 in Red Hill Creek and in two reference sites, one in Indian Creek and one in Spencer Creek, prior to channel realignment, and was conducted annually until 2012. The abundance and biomass of each fish species present was estimated in representative sections of channel that included pool, riffle and run habitats, the King Street culvert and, prior to realignment, a portion of the concrete channel at Queenston Road. Each reach was characterized with respect to width, depth, water velocity, substrate and cover. Benthic invertebrate species composition and abundance was also assessed annually at representative locations. Samples were collected using a t-sampler and organisms were identified to lowest practical level. Beginning in the summer of 2003, and continuing until the autumn of 2012, water temperature was logged at 15 minute intervals using Hobo WaterTemp Pro® loggers (Onset Computer Corporation) at six (6) locations along the Red Hill Creek, at one location in Davis Creek, and at one location each in Indian Creek and Spencer Creek, used as reference locations. Air temperature was also logged at a shaded location near the base of the Niagara Escarpment within the Red Hill Creek valley. As sections of Red Hill Creek were realigned, monitoring was relocated to the new channel. The dates when sections of the creek were switched to their new alignment and the fish sampling locations are presented in Figure 2.5.1. The upstream extent of white sucker (*Catostomus commersonii*) and Pacific salmon (primarily Chinook, *Oncorhynchus tshawytscha*) spawning migrations has also been observed following re-alignment.

2.5.2 Major Findings

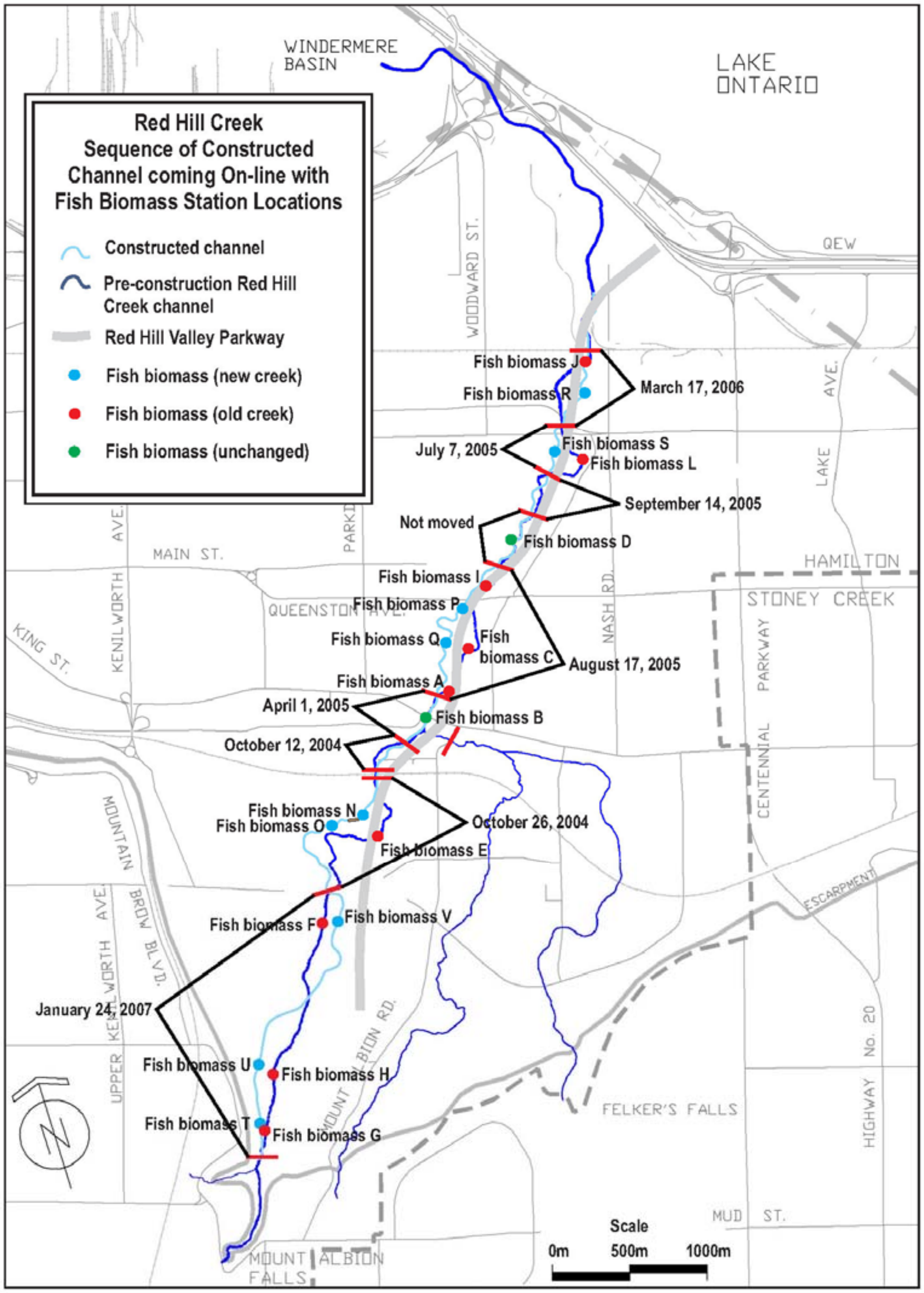

Figure 2.5.1: Sequence of channel realignment and sites where fish abundance and biomass were estimated in Red Hill Creek.

The habitat in Red Hill Creek was characterized in 1997, from a point near Brampton Street upstream to the north end of the King's Forest Golf Course, as was the habitat in lower Davis Creek. In 1998, Red Hill Creek was characterized through the King's Forest Golf Course, as the length of the proposed realignment was extended. This characterization was repeated in 2012 using the same methodology, to allow comparison of pre- and post-realignment conditions.

A number of events occurred during the course of the study that were not related to the realignment of Red Hill Creek but that affected, or had the potential to affect, the fish and benthic invertebrate communities. A fish kill was documented in the Red Hill Creek downstream from Queenston Road in September of 2004 due to a release of water containing chlorine into the creek via the storm sewer system. Another fish kill, the cause of which is unknown, occurred in the Davis Creek and in Red Hill Creek downstream from the confluence with Davis Creek in June of 2012. A fish kill also occurred in the Spencer Creek reference area in July of 2007 (after the annual sampling was conducted) as a result of douse water entering the creek from a fire at a pesticide packaging facility. The Indian Creek reference site was realigned during the course of the study. Weather-related events, most notably the large floods on July 26, 2009 and July 22, 2012, but also a drought during the summer of 2007, also had potential to affect the biological communities, although both floods occurred after the fish sampling for that year had been completed.

Fish Community

The fish community in Red Hill Creek, based on overall mean density (ref. Figure 2.5.2), is dominated by blacknose dace (*Rhinichthys atratulus*; 43%), longnose dace (*Rhinichthys cataractae*; 37%), and creek chub (*Semotilus atromaculatus*; 14%). This has not changed.

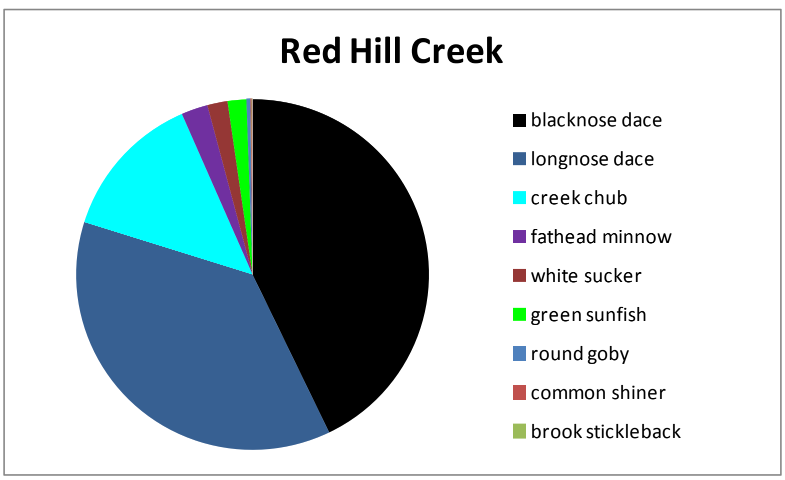

Figure 2.5.2: Dominant fish species in Red Hill Creek based on mean estimated densities for all reaches and years combined.

When the data for all reaches and years were combined, the mean density of fish (number of fish per m^2) and the mean biomass (number of grams of fish per m^2) was highest in Spencer Creek, lowest in Indian Creek, and intermediate in Red Hill Creek (Ref. Table 2.5.1). The difference in overall mean biomass between Spencer and Red Hill was much smaller than the difference in overall mean density, reflecting the presence of larger fish in Red Hill Creek. This is primarily because the fish community in Spencer Creek was dominated by small fish species, including several species of darter.

Table 2.5.1: The Estimated Number of Fish per m² and Estimated Number of Grams of Fish per m² for All Reaches Combined, by Year, for Each Creek.						
	Number of fish per m²			Grams of fish per m²		
Year	**Indian Creek**	**Red Hill Creek**	**Spencer Creek**	**Indian Creek**	**Red Hill Creek**	**Spencer Creek**
2004	0.11	0.91	1.84	0.48	4.58	7.84
2005	0.24	0.29	1.72	2.09	3.20	6.22
2006	0.29	1.22	1.38	2.74	8.54	5.24
2007	0.17	1.42	4.48	1.32	7.40	14.41
2008	0.30	1.09	0.80	3.00	5.02	3.07
2009	NA	1.11	1.64	NA	6.60	6.52
2010	0.23	1.20	0.66	1.31	8.00	2.06
2011	0.19	1.23	3.20	1.30	6.41	10.90
2012	0.17	1.35	3.37	0.93	7.81	9.52
all	0.21	1.10	2.12	1.65	6.42	7.31

In Red Hill Creek both mean fish density and mean fish biomass were lowest in 2005, with fish density being markedly lower than in any other year. This was not the case in either Spencer Creek or Indian Creek, indicating that the cause was specific to Red Hill Creek. The Red Hill Creek summary data are confounded somewhat by differences in the reaches sampled among years, but examination of the data on a reach by reach basis indicates that density and biomass were not lower in 2005 at locations F, G and H, located upstream from any of the realignments that had occurred prior to the 2005 sampling, and upstream of the fish kill that occurred downstream from Queenston Road in September 2004. Both the realignment and the fish kill may have contributed to the marked decline in abundance in the lower reaches in 2005. Regardless of the cause of lower fish density and biomass in Red Hill Creek in 2005, density and biomass rebounded in 2006 and has exceeded the 2004 (pre-realignment) levels every year since.

Abundance and biomass were more variable on an individual reach and habitat basis than the overall composite values suggest. The year-over year patterns were not consistent among reaches or even among habitats within the same reach, suggesting that factors operating at the local scale were more influential than factors acting at the reach or entire creek scale, such as year-to-year variation in flow. As an example, Site F was a natural pool-riffle channel prior to realignment. Realignment occurred in January of 2007. The corresponding Site V in the re-aligned channel was initially a series of step-pools that evolved into a series of pools and riffles. Sites F1 and F2 and sites V1 and V2 were contiguous. Fish abundance in the pool (pre-2007) or step-pool (2007-2012) habitat type was very low from 2007-2009 and then much higher than at any previous time in 2011 and 2012 (ref. Figure 2.5.3, FV1) due to increases in the numbers of all three dominant species (blacknose dace, longnose dace and creek chub). In the riffle habitat, fish abundance was highest in 2009 and lowest in 2011 (ref. Figure 2.5.3, FV2).

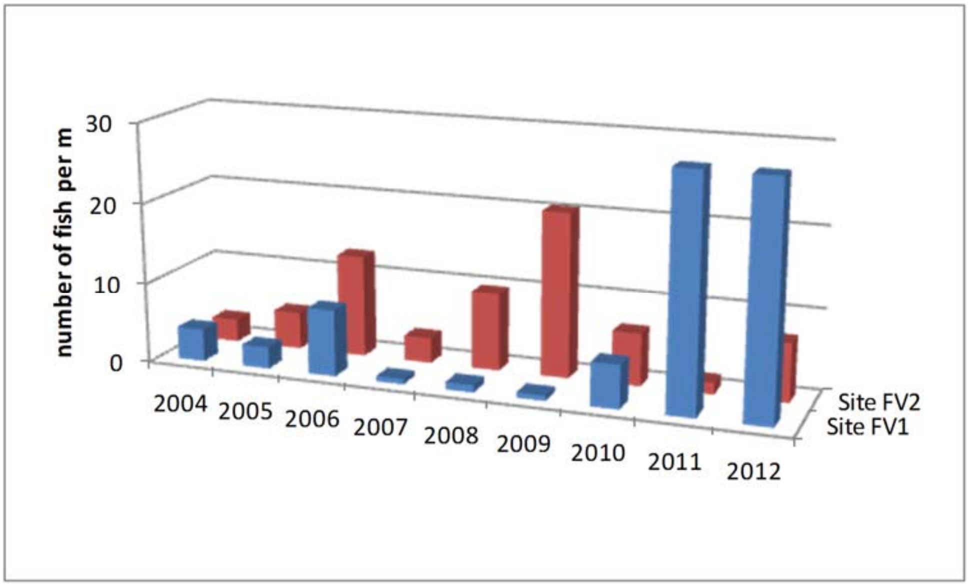

Figure 2.5.3: Number of fish per meter of creek length in Sites F (2004-2006) and V (2007-2012).

<u>Benthic Invertebrate Community</u>

When all years and stations were combined, the benthic invertebrate community was dominated by chironomid larvae, which comprised 59% of the organisms (ref. Figure 2.5.4). Individuals of the genus Cricotopus were the most abundant of the chironomids; they alone accounted for 36% of the benthic organisms. Oligochaete worms, primarily Nais elinguis, and immature tubificids without hairs, accounted for 18% of the benthic invertebrates and the isopod *Ceacidotea intermedius* accounted for 16%. Trichoptera (caddisflies) accounted for only 3% of all benthic invertebrates, with most either hydropsychids of the genus *Cheumatopsyche* or hydroptilids of the genus *Hydroptila.* Ephemeroptera (mayflies), which accounted for 1% of the total number of benthic orgamisms, were primarily (95%) *Baetis flavistriga*.

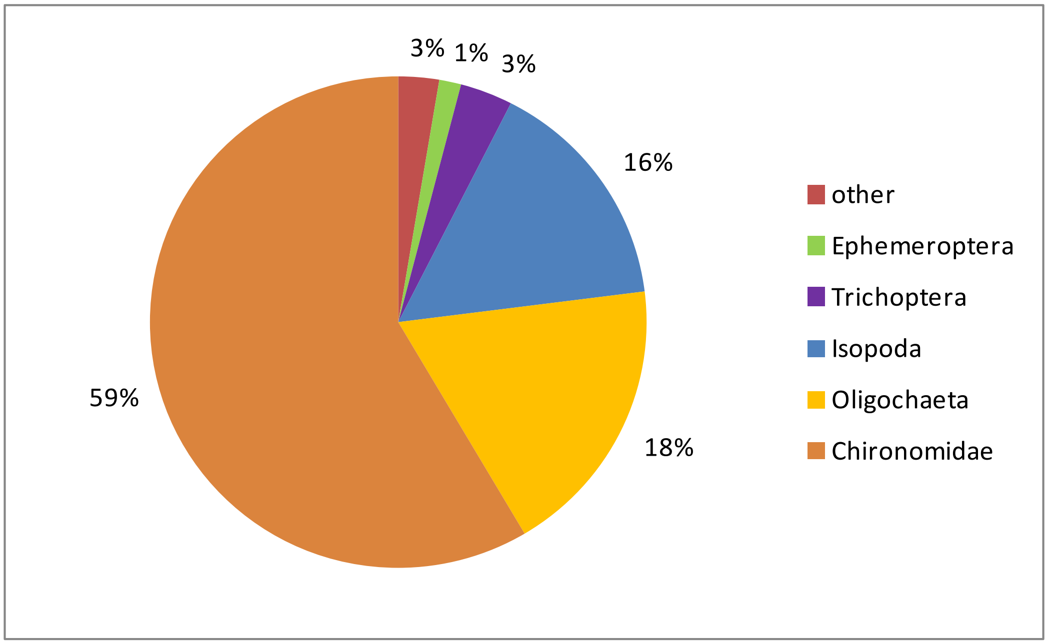

Figure 2.5.4: Dominant benthic invertebrate groups, expressed as a percentage of all samples combined.

The mean Hilsenhoff Biotic Index (HBI) values for samples from riffles in each of the reaches do not indicate any major differences among locations or years (ref. Figure 2.5.5). The mean HBI scores (Hilsenhoff, 1987) were typically in the “fair” (5.51-6.50), “fairly poor” (6.51-7.5) or “poor” (7.51 – 8.5) ranges. There was no evidence of significant changes as a consequence of the channel realignment, which is not unexpected because the HBI index is designed to reflect changes in organic enrichment. Shannon-Weaver diversity (Shannon and Weaver, 1949) was more variable in both space and time than the HBI scores, and tended to increase in a downstream direction (ref. Figure 2.5.6). Most values were in the moderately polluted range (between 3 and 1). Diversity values in 2012 were among the highest observed during the study period at most sites.

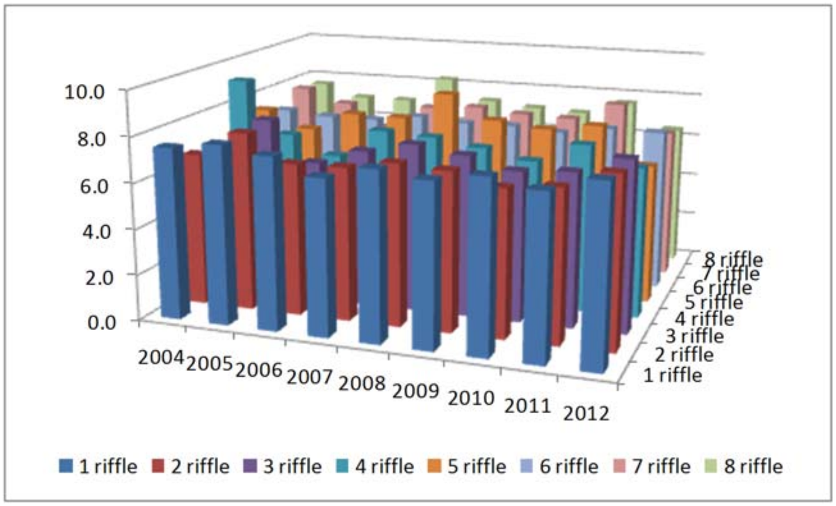

Figure 2.5.5: Mean Hilsenhoff biotic index of samples from riffles, by reach and year. Reach numbers increase in a downstream direction.

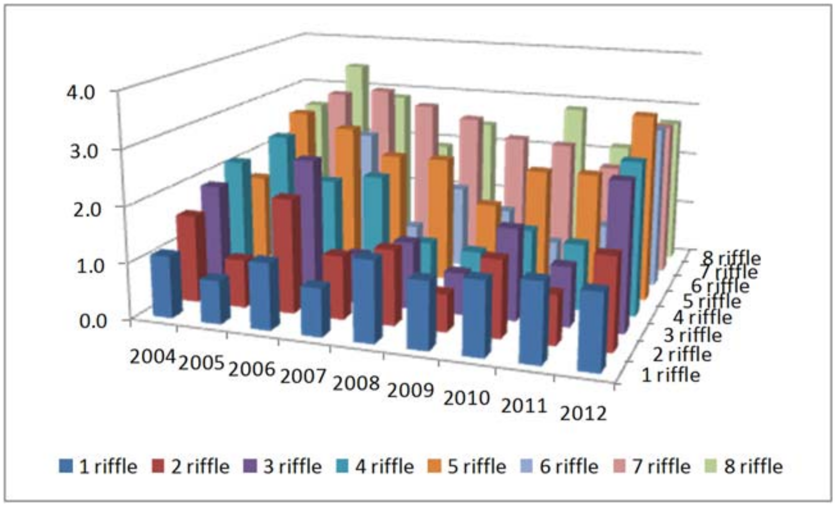

Figure 2.5.6: Mean taxa diversity of samples from riffles, by reach and year. Reach numbers increase in a downstream direction.

Water Temperature

Mean summer (July-August) water temperature at each monitoring location in Red Hill Creek was correlated with mean summer air temperature (ref. Figure 2.5.7), with temperatures increasing in an upstream to downstream direction. Any attempt to look for a post-realignment trend-through-time has also been complicated by the fact that 2011 and 2012 had the warmest July-August during the ten-year period. Comparing the mean July-August water temperatures in 2004 (pre-realignment) and 2009 (post-realignment), which had identical, cool July-August mean air temperatures suggests that the re-alignment has not had a major impact on mean July – August water temperature. Mean July-August water temperatures were slightly (0.2 C°) lower in 2009 at locations 3 and 5 and 0.5 C° higher at location 6.

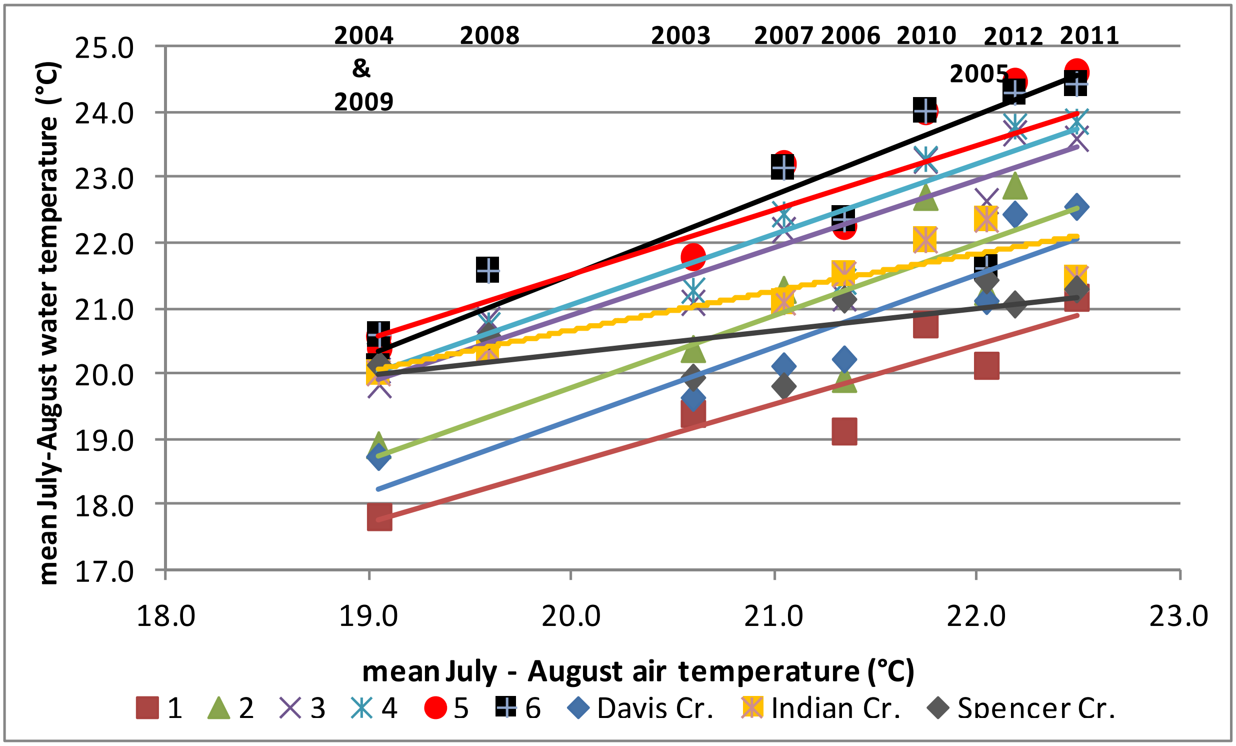

Figure 2.5.7: Mean July – August water temperature at each logging location versus mean July – August air temperature. The lines are derived from simple linear regressions. The year during which each set of data were collected are shown at the top. Logger locations are shown in Figures 2.5.1 and 2.5.2.

<u>Fish Passage</u>

Prior to the realignment of Red Hill Creek the long, shallow concrete channel at Queenston Road was a barrier to the upstream migration of Pacific salmon in the autumn and, in springs when flows were low, to the upstream spawning migration of white sucker. The King Street culvert was also an impediment to upstream migrations when flows were low and a concrete saddle upstream from King Street was the upstream limit of white sucker migration. There do not appear to be any barriers to upstream migration in the realigned channel, which has eliminated the concrete section at Queenston Road and all of the concrete saddles. During the spawning run, white sucker were observed to have migrated upstream at least as far Rosedale Park every year from 2006 through 2012. The King Street culvert continues to impede upstream migrations during periods of low flow. This is more often a factor during the autumn salmon migrations than during the spring white sucker migrations because low flows tend to occur more often during the fall.

Comparison of the Pre- and Post-Realignment Stream Habitat

Comparison of the measurements taken prior to realignment (in 1997-1998) and after realignment (2012), the total length of channel between a point near Brampton Street and the south end of the King's Forest golf course was reduced by 193 m which is 3% of the pre-realignment length (ref. Table 2.5.2). This is less than the length of the concrete channel at Queenston Road that was eliminated by the realignment. The sum of the increase in pool and run length exceeds the reduction in riffle length (ref. Table 2.5.2). The trends in the changes in wetted area were similar to those for length.

Table 2.5.2: The length and area of various types of habitat prior to the channel realignment and after realignment and the change in absolute terms and as a percentage of the pre-realignment condition.

Habitat Type	Length (m)				Wetted area (m^2)			
	1997-1998	2012	Change (m)	Change (%)	1997-1998	2012	Change (m^2)	Change (%)
Pool	1187	1299	+113	+9	10007	10795	+788	+8
Riffle	3299	2610	-688	-21	26962	20187	-6775	-25
Run	1989	2730	+741	+37	16090	23410	+7321	+45
Culvert	331	235	-97	-29	2674	1482	-1192	-45
Concrete Saddle	50	0	-50	-100	508	0	-508	-100
Concrete Channel	212	0	-212	-100	2328	0	-2328	-100
Total	7068	6875	-193	-3	58568	55875	-2694	-5

Comparing wetted area by substrate type prior to realignment (in 1997-1998) and after realignment (2012), confirms the large reduction in the area of concrete (ref. Table 2.5.3). In addition to the channel at Queenston Road, other concrete sections were eliminated at the Barton Street culvert (which was replaced by a bridge), immediately upstream and downstream from the King Street culvert (replaced by natural substrate), and at four concrete saddles that protected underlying sewers (replaced by natural substrate). The one new culvert has concrete baffles across the bottom that retain natural substrate. Bedrock, clay, cobble and gravel substrate increased in area, while boulder, sand and mud/silt substrate decreased.

Table 2.5.3: Wetted Area of Various Substrate Types Prior to the Channel Realignment and after Realignment and the Change in Absolute Terms and as a Percentage of the Pre-Realignment Condition

Substrate Type	Wetted Area (M^2)			
	1997-98	2012	Change (M^2)	Change (%)
Concrete	4945	439	-4506	-91
Bedrock	6940	7736	+796	+11
Clay	1725	3924	+2199	+127
Boulder	4817	3433	-1384	-29
Cobble	12637	13550	+913	+7
Gravel	18052	20194	+2142	+12
Sand	8656	6620	-2036	-24
Mud/Silt	583	0	-583	-100
Total	58355	55896	-2459	-4

Cover provided by undercut banks, tree roots and woody debris, and gabions was greatly reduced or eliminated as a result of the realignment (ref. Table 2.5.4). The total amount of cover more than doubled as a result of the large area of interstitial spaces between the armour stone used in the realigned channel. These estimates do not take into account the cover provided in spaces beneath substrate particles.

Table 2.5.4: Area of Cover (m^2), by Cover Type, Prior to the Channel Realignment and After Realignment and the Change in Absolute Terms and as a Percentage of the Pre-Realignment Condition. Cover Provided by Substrate is not Included.

Type Of Cover	1997-98	2012	Change (M^2)	Change (%)
Armour stone	101	3431	+3330	+3297
Gabions	567	0	-567	-100
Tree roots	302	29	-272	-90
Undercut banks	209	33	-176	-84
Rock ledge	8	0	-8	-100
Woody debris	371	12	-360	-97
Total	1557	3505	+1948	+125

<u>Summary</u>

The results indicate that the effect of the re-alignment of Red Hill Creek on the fish community may have been negative in some, but not all, locations in the first year following re-alignment, but that fish abundance and biomass rebounded quickly. This is not unexpected, given that the resident fish community is composed of short-lived, tolerant fish species, many of which first reproduce at one or two years of age. Similarly, the benthic invertebrate community appears to have rebounded quickly from any short-term effect of realignment.

There has been no substantial change in the composition of the resident fish community as a consequence of the channel realignment, nor was any expected. Red Hill Creek was, and still is, an urban watercourse with a simple fish community dominated by tolerant resident species and migratory species, primarily white sucker and the introduced Pacific salmons. The potential of other stream resident species to colonize Red Hill Creek is limited. They would have to travel a considerable distance from other streams with more diverse resident fish communities through habitats in Cootes' Paradise and/or Hamilton Harbour and/ or Lake Ontario that are generally unsuitable for them. If it is desired to establish a more diverse fish community in Red Hill Creek, then transplanting suitable native stream fishes from other area watercourses will likely be necessary.

Three "concrete habitats" were sampled during the study and the results confirmed that reaches consisting of bare concrete support no or very few fish. The number of fish present inside the King Street culvert tended to increase as the proportion of the bottom with rocks large enough for fish to hide under increased. Based on these results, the conversion of bare concrete habitat to natural substrate will improve fish habitat even if the natural substrate is on top of concrete. It was initially intended to reduce velocities through the King Street culvert by placing a structure downstream and creating a backwater condition. It was expected that this would increase depth and allow natural substrate to accumulate within the culvert. Unfortunately, attempts to achieve this were unsuccessful and the culvert continues to support few fish. The results of this study suggest that conversion of concrete habitat to habitat with natural substrate is a very effective method of increasing fish abundance and that a reduction in habitat area when that area is bare concrete would have little or no negative effect.

Both white sucker and Pacific salmon appear to move upstream through the natural channel design sections with little difficulty unless flows are very low. The King Street culvert continues to impede or block upstream progress of Pacific salmon at low flows. There is no evidence that the new culvert that was constructed with baffles to retain natural substrate and focus low flows into a narrower cross-section impedes upstream movement. This design appears to be a viable method of providing fish passage when it is not possible to construct a culvert with an open bottom.

The differences in year-to-year trends in fish density among reaches of Red Hill Creek, and even among contiguous sections of the same reach were surprising and indicate the need for monitoring programs to sample an adequate number of reaches and habitats. Preliminary results suggest that the number of hiding places under stones is one factor affecting the density of both longnose dace and blacknose dace, but other factors are clearly also at play. It is possible that the differences among reaches and habitats are due to transient conditions which the study did not measure. Flow influences many aspects of habitat and it would have been helpful if flow had been continuously monitored throughout the study (i.e. if flow monitoring had been maintained during the construction period).

2.5.3 Recommendations and Lessons Learned

<u>Recommendations</u>

If it is desired to establish a more diverse fish community in Red Hill Creek, then transplanting suitable native stream fishes from other area watercourses will likely be necessary. This should be discussed with regulatory agencies.

As noted in previous sections, the Red Hill CSO storage pipe was not fully functional until December 2011. This new system now eliminates three former CSO points at Laurence Avenue, Queenston Road, and Melvin Avenue. Given that only one of the five monitoring years (2012) reflects these conditions (i.e. with an expected reduced number of CSO discharges to the creek), and the pipe was only functional for approximately 6 months prior to the 2012 benthic invertebrate sampling, follow-up monitoring, particularly with respect to benthic invertebrates, should be considered in the future, potentially within the next 5 years +\-.

Although not directly assessed as part of the fisheries monitoring, consideration should be given to implementing carp control within the lower reaches of Red Hill Creek and associated wetland areas, as has been done in other areas such as Cootes' Paradise and the Windermere Basin. This is also consistent with the recommendations from terrestrial ecology monitoring (Section 2.6). Given the difficulties with implementing effective control over extended periods however, this may not be feasible. Further discussions with regulatory agencies would be required accordingly.

Lessons Learned

Given the observed differences in year-to-year trends in fish density among reaches of Red Hill Creek, and even among contiguous sections of the same reach, there is a clear need to ensure that future monitoring programs sample an adequate number of reaches and habitats.

The results of this study suggest that conversion of concrete habitat to habitat with natural substrate is a very effective method of increasing fish abundance, even when that natural substrate is placed over concrete. This should be considered in the design of hydraulic structures in the future where fish habitat and passage would be a factor.

Likewise, although open-bottomed culverts are considered preferable, a modified culvert design such as the one employed at King Street (with baffles to retain natural substrate, and graded to focus low flows into a narrower cross-section is a viable alternative method of providing fish passage.

2.6 Terrestrial Ecology

2.6.1 Brief Background

The Integrated Monitoring Plan (IMP) for the Red Hill Valley Project (RHVP) was developed to ensure environmental compliance required by the various agencies involved in the planning and approval process (Philips Engineering Ltd., 2007). The purpose of the IMP was to evaluate the performance of the Environmental Management System for the Red Hill Valley Project, and to provide adjustments to the plan recommendations through a process of adaptive management.

In so far as Terrestrial Ecology, the Red Hill Valley Project encompassed construction and landscaping activities related to the new Parkway, relocated Creek, and associated infrastructure (i.e. stormwater management facilities). It incorporated major habitat protection, creation, restoration and enhancement initiatives:

- RHVP Impact Assessment and Design Process (IADP) (1999-2003)
- RHVP Landscape Management Plan (Envision et al 2003),
- Detailed design for Parkway and QEW interchange works (2005-2007),
- RHVP Landscape Design and Habitat Enhancement Plan (D&A 2005)
- RHVP Ecological Restoration and Landscaping Project (SNEOG 2006),
- Rennie/Brampton St. Landfill Remediation (1999-2005), and
- East Hamilton Trail and Waterfront Link (2008-2011).

This section summarizes monitoring based on the Impact Assessment and Design Process (IADP) recommendations and agency approval conditions, profiled areas, and key lessons learned and challenges of terrestrial ecology-related aspects of the RHVP.

Monitoring of the natural heritage aspects within the Red Hill Valley Project study area focused on three levels to address agency requirements and planning objectives:

- ***DFO Conditions of Approval (DFOCOA)*** - ensure that slope, channel and wetland plantings will be dominated by indigenous riparian species.
- ***Landscape Management Plan (LMP)*** - ensure that habitat restoration and enhancement works achieve objectives.
- ***Impact Assessment and Design Process Ecosystem Monitoring* (*IADPEM)*** - assess ecosystem level diversity and functions in the longer term.

For detailed methods and results for each year of the terrestrial monitoring program, refer to the 2008-2012 annual reports.

2.6.1.1 Goals and Objectives

Objectives for the terrestrial ecology component of the Integrated Monitoring Plan were:

- Regulatory monitoring of riparian vegetation along the Creek (DFOCOA)
- Monitoring of vegetation within wetland compensation areas and within Stormwater Management (SWM) facilities (DFOCOA);
- Survey wildlife (i.e. breeding birds and amphibians) and vegetation long-term monitoring stations to collect baseline data (IADP);
- Watershed and valley-level Ecological Land Classification (ELC) updates and characterization (IADP);
- Monitor vegetation planted within the wetland enhancement areas (LMP);
- Determine the Free-to-Grow status of habitat restoration areas (LMP)
- Survey invasive exotic species within the riparian area of the Red Hill Creek.

Department of Fisheries and Oceans Conditions of Approval (DFOCOA)

Riparian Vegetation

Primary questions to be addressed for riparian vegetation monitoring were:

1) What is the structure and composition of riparian vegetation along the Red Hill Creek?
2) What spatial and temporal patterns occurred within the riparian vegetation community from 2008-2012?
3) Which species define the riparian vegetation community along the Red Hill Creek in terms of relative importance?

These questions were addressed with the following monitoring approaches:

- 38 permanent transects, each with 6 plots, spaced 250 m apart along 9.5 km of the Red Hill Creek and along Van Wagner’s Pond channel, sampled over a 5-year period;

- Annual photomonitoring of each transect;
- Quantitative sampling of all transects in 2008 and alternating even- and odd-numbered transects 2009-2012. Data included species presence, plant and bare soil cover, and species height values; Frequency, Average Cover, Relative Cover, Relative Frequency, Importance, and Relative Importance values were calculated;
- Findings were compared to historical conditions (from Goodban 2006).

Wetland Compensation and Stormwater Management Facility Vegetation

Primary questions to be addressed for monitoring stormwater management facilities and wetland compensation areas (referred to as 'ponds') were:

1) What is the structure and composition of vegetation within and surrounding the ponds,
2) What spatial and temporal patterns in vegetation occurred within and among ponds from 2009-2012.

These questions were addressed as follows:

- 8 of 14 ponds (including stormwater ponds and wetland creation sites) located along the Red Hill Valley Parkway and near the QEW interchange were sampled each August from 2009-2012.
- The Red Hill Marsh enhancement area (ENH5, Figure 1) was monitored in 2011 and 2012 using a similar approach.

<u>Impact Assessment Design Process (IADP)</u>

Ecological Land Classification

In 2010 GIS data compiled from existing sub-watershed studies were used to provide updated Ecological Land Classification (ELC) community mapping for the Red Hill Creek Watershed, to compare with 1997 estimates of vegetation cover. Key areas were visited in 2010 - 2012 to remap the ELC at Community Series level, to answer the following questions:

1) How did the land cover within the Red Hill Creek Watershed and Red Hill Valley change from 1997 to 2012, and;
2) Were wetland compensation targets achieved?

The changes in land cover across the watershed, and the Red Hill Valley Project Study Area are summarized in Section 4.3 of Appendix A.

Permanent Vegetation Monitoring Plots

Permanent vegetation and wildlife monitoring stations was established in the Red Hill Creek Valley in 2010 according to biomonitoring protocols developed by Environment Canada's Ecological Monitoring and Assessment Network (EMAN 1996). The 2010 surveys determined baseline conditions of species richness and community composition for future comparison of changes within these areas over the long term.

Permanent Wildlife Monitoring Plots

Amphibian and breeding bird monitoring stations were established and monitored in April through June 2010 to cover the majority of breeding habitats and estimate species diversity and abundance in key areas (see Figure 1 in Appendix A). This included:

- 12 nocturnal amphibian call stations (*i.e.* frog and toad) according to the Marsh Monitoring Program (MMP) protocols (BSC 2003);
- 14 breeding bird monitoring stations according Ontario Breeding Bird Atlas protocols (OBBA 2001)

Data were compared to 2011 and 1012 data from the Urban-Rural Biomonitoring & Assessment Network (URBAN), a citizen-science program based at McMaster University in Hamilton, Ontario.

<u>Landscape Management Plan</u>

Ecological restoration works within the Red Hill Valley were undertaken under the direction of City staff by Kayanase, an ecological restoration contractor that employed science-based techniques and adaptive management, along with Haudenosaunee cultural values and ecological knowledge, to carry out this design-build restoration and enhancement project (2007-2012).

The overriding goals of the ecological restoration plan were to:

- Protect and conserve existing native plants and plant communities to the maximum extent possible;
- Restore degraded habitat areas through sustainable ecological restoration efforts; and,
- Increase the connectivity and size of natural habitat areas.

The Red Hill Valley Project Ecological Restoration and Landscaping Proposal (SNEOG 2006) and Red Hill Valley Ecological Restoration Detailed Design Plan Report (Kayanase 2006) provide summaries of approaches.

<u>Additional Terrestrial Monitoring</u>

Invasive Exotic Species (IES) Surveys (2009)

In 2009, the City of Hamilton requested more detailed mapping of the extent of invasive exotic species (IES) along the riparian zone, to assist in restoration planning. A field protocol supported by GIS mapping was developed and applied in the summer of 2009.

Free-to-grow Monitoring (2012)

In 2009 and 2011 Kayanase conducted plot-based surveys in-pre-selected restoration polygons to identify restoration areas that were 'free-to-grow' (i.e. areas that had a viable woody stem density/ha that met target densities outlined by Kayanase and the City of Hamilton). A 'free-to-grow' is capable of self-regeneration. In 2012, the City requested resampling of ten percent of the 'free-to-grow' plots sampled in 2011 (12 plots) to allow third-party verification of the results obtained in 2011 using the methodology employed in Kayanase surveys.

2.6.2 Major Findings

2.6.2.1 Department of Fisheries and Oceans Conditions of Approval (DFOCOA)

Riparian Vegetation

Photomonitoring - Photos taken annually of each vegetation transect demonstrated substantial growth and successional transitioning of vegetation along reaches of the creek, documenting substantive changes to woody and herbaceous structure and composition, and effects of channel dynamics.

Species Composition – 311 plant vascular plant species were observed in the immediate riparian zone between 2008 and 2012; 176 (56.6%) were native, and 135 (43.4%) were considered exotic (refer to Table 2 in Appendix A). The percentage of native species was comparable all years. New species observed increasing by approximately 25 species per year between 2009 and 2012, with the overall increase in the final year (2012) being primarily due to new records of native species. This finding suggests that species richness within the riparian zone was adequately captured by the timeframe and extent of sampling.

Historical Comparison - Goodban (1996) listed 287 species occurring within riverine, marsh, and deciduous floodplain woodland habitats within the Red Hill Valley from 1995 surveys and historic records. Although Goodban's list included 129 native species and 26 exotic species not observed during the monitoring for this study, 84 native species and 95 exotic species were observed that were not listed in Goodban. The two lists have 130 species in common, including 90 native and 40 exotic species. In terms of site-level floristic quality, the vascular plant list reported by Goodban (1996) had an FQI of 53.96, whereas the list value generated for this Study was 47.71.This 6 point difference was due to a higher richness of native species recorded in the Goodban study (221 vs. 176). However, the current monitoring was focused on the immediate riparian zone of the reconstructed channel which is in an early successional state, whereas Goodban's data encompassed more extensive habitat areas within the valley.

Relative Importance of Species - Change in relative importance of the species observed is a good gauge of changes in community composition, and can be more sensitive to community changes on shorter time-scales. It identifies which specific species are important, or are changing in importance through time. An increase in the cumulative importance of the top-20 ranked species was observed between 2008 and 2012, with a slight decline in the years 2010 and 2011, and a spike in 2012 due to an increase in the frequency and importance of exotic species, the highest for all of the monitoring years. The years 2009 and 2010 showed the highest incidence of top-ranked native species and the highest cumulative importance for native species.

Wetland Compensation and Stormwater Pond Vegetation

Species Composition - The total vascular flora observed in ponds and wetland compensation areas (2009- 2012) was 247 species plus 45 identified to genus. The percentage of native species observed was 57%, and was consistent in each year of monitoring (min= 56.0% in 2011, max = 58.3% in 2010). Species richness within ponds and wetlands was stable across 4 years of monitoring, with native species slightly dominant over exotic species. New species observed in annual surveys were 67 in 2010, to 44 in 2011, and 28 in 2012. Cumulative species richness across all features continued to increase each year through 2012. Average species richness within ponds increased annually to 2011, but dropped significantly in 2012 due primarily to fewer native species; exotic species also declined over the four monitoring years. Average FQI decreased from 2009 (4.07) to 2012 (3.40), though annual changes were insignificant.

2.6.2.2 Impact Assessment Design Process (IADP)

Ecological Land Classification (2010-2012)

Changes in Vegetation Cover - The most significant changes in the Red Hill Creek Watershed between 1997 and 2012 were the increase in aquatic ELC cover types, from approximately 4.62 ha to 34.08 ha (638% increase); shoreline communities also increased. Contributing areas included specific wetland creation projects (Comp1 and Comp2, and new wetland at the Escarpment Viaduct), construction of stormwater ponds within the Valley and in the upper watershed, and conversion of former creek sections to stormwater functions.

Agricultural and successional communities decreased in area within the watershed between 1997 and 2012 due to urban development above the Escarpment. Successional communities also decreased by 50 ha (-7% of 1997 area), explained in part by increases in anthropogenic woodlands (32.92 ha to 119.78 ha) and anthropogenic open space (481.37 ha to 572.36 ha). There was a slight net increase of natural woodlands and forest (0.34 ha; 0.09%) between 1997 and 2012. The distinction of successional communities under the ELC is also more refined than with pre-ELC mapping.

Prior to construction of the Parkway, in 2003 wetland vegetation communities were estimated at 13.28 ha of the Study Area, while aquatic communities occupied 19.02 ha. Snell (1987) estimated that there was 76.4% wetland loss in Hamilton-Wentworth since settlement; as of 1997 wetland cover constituted only 0.3% of the Red Hill Creek Watershed. The total estimated area of aquatic and wetland cover within the Red Hill Creek watershed as of 2012 was 61.05 hectares.

The Terrestrial Resources IADP Report (Dougan & Associates, 2003) predicted a 5.04 ha loss of wetlands (3.3 ha in Study Area 1, Mud Street Interchange to the CNR; and 1.74 ha in Study Area 2, CNR to the QEW). At detailed design in 2005, the estimated loss of wetlands within the project study area increased to 5.22 ha. Based on the recommended minimum 2:1 replaced ratio identified in the IADP, this would require the creation of 10.45 ha of new wetland through the construction of stormwater management facilities (wet ponds, wetlands, and grass swales), restored floodplain functions under natural channel processes, and conversion of the abandoned channel sections into wetlands.

Overall wetland cover in the Parkway Study Area increased from 20.32 ha pre construction, to 27.54 ha as of 2012. The gain of new, non-SWM wetland within the Parkway Study Area was 4.47 ha; functional enhancement works within the Red Hill Marsh added a further 3.23 ha, which was considered equivalent to a 50% gain (1.62 ha) based on the 2005 estimates. This is not included in the estimated total gain of wetland cover.

In a separate project, approximately 11 ha of wetland was created within Windermere Basin between 2010 and 2012, providing a restored estuarine ecosystem with wildlife habitat for species such as Common Tern, Northern Pike, Large Mouth Bass, and White Sucker. The Windermere Basin project included a barrier to Common Carp, an introduced fish species that has constrained the spread of emergent marsh cover in Comp1 and Comp2, as well as in Enh5. This feature, enhancement works in the Red Hill Marsh (Enh5), plus the Comp1/Comp2 wetland creation, provide a substantial increase in habitat for wildlife, improving connectivity of the riparian and wetland habitats along the lower Red Hill Creek, and to the Lake Ontario shoreline.

The overall increase in wetland area is 15.9 ha (including Windermere Basin, but excluding SWM facilities and Enh5 functional enhancement), exceeding the 10.45 ha targeted in 2005, and representing a 76.17% increase.

Ecological Monitoring and Assessment Network Plots (2010)

A total of 92 vascular plant species were detected within the permanent vegetation plots (refer to Figure 1 in Appendix A) sampled in 2010, including 8 specimens identified to genus level. Of the total, 57 (67.9%) are native species, and 27 (32.1%) are exotic. No species of conservation concern were recorded.

Wildlife

Surveys in 2010 detected forty-two (42) species of birds, 39 of which were considered possibly breeding or on territory. Great Blue Heron, Black-crowned Night-Heron and Turkey Vulture were detected flying over the study area, but were not considered breeding in the vicinity. Of the 39 breeding species, two are introduced (non-native): three are considered Special Concern (COSEWIC 2012 and/or CASSARO 2013). None are designated as Threatened or Endangered; most are considered common or abundant, and widespread, within the City of Hamilton (Curry 2003). However, Wood Duck, Green Heron and Belted Kingfisher, are considered uncommon and widespread within the City (Curry 2003). At a regional level, six species have been designated as priority land bird species by Partners in Flight in BCR 13 (Lower Great Lakes/St. Lawrence Plain) (OPIF 2006); BCR 13, the Lower Great Lakes – St. Lawrence Plain, corresponds roughly with the area south of the Canadian Shield.

Four species of amphibians were detected during RHVP monitoring surveys in 2010: all four species are considered abundant within the City of Hamilton (Lamond and Duncan 2003). Green Frog was the most widespread, while Northern Leopard Frog was the least widespread; Gray Treefrog and American Toad were also detected. Amphibian surveys in 2011 and 2012 by URBAN were competed at 3 of the same locations sampled as 2010 RHVP monitoring. All results are reported in Appendix A.

Two McMaster University undergraduate students undertook follow-up monitoring studies related to wildlife utilization of the Escarpment viaduct. Tentative observation of utilization of artificial tree structures (constructed by the City under the viaduct) by Southern Flying Squirrels (SFS) was photo-documented. Dr. Pat Chow-Fraser at McMaster indicated that apart from the work by URBAN, no further monitoring studies have been completed on the SFS or other wildlife.

2.6.2.3 Landscape Management Plan

<u>Restoration Activities</u>

No annual reporting of Kayanase restoration activities was provided by the City beyond the 2009 monitoring season. The Kayanase stock and planting records provided by the City have been reviewed to prepare a brief summary. Based on GIS data provided by the City, the total treatment area within the Red Hill Valley Project was 100 hectares, and involved 305 distinct restoration units with an average size of 0.33 ha. Areas restored extend from the Lincoln Alexander Parkway to the Lake Ontario Shoreline, and included early successional, thicket, and forested communities within escarpment, riparian, wetland, and shoreline environments. Table 6 in Appendix A provides a summary of restoration templates in terms of coverage and species richness. From 2007 to 2012, 242 locally sourced native species were seeded or planted by Kayanase in restoration areas within the Red Hill Creek Valley. During riparian vegetation monitoring, 75 of the 242 (31%) species planted were encountered.

<u>Invasive Exotic Species (IES) Surveys (2009)</u>

IES sub-units were mapped, along with species of particular concern, and accompanied the 2010 annual report. As of the 2009, most (88.7%) of the areas surveyed in the riparian zone of the Red Hill Creek had moderate to high levels of invasive exotic species. The most problematic species included Common Reed (*Phragmites australis*), Reed Canary Grass (*Phalaris arundinacea*), Crown Vetch (*Coronilla varia*), Sweet Clovers (Melilotus spp.), Manitoba Maple (*Acer negundo*), Tatarian Honeysuckle (*Lonicera tatarica*), Common Buckthorn (*Rhamnus cathartica*), Black Locust (*Robinia pseudo-acacia*), exotic Willows (Salix spp.), Garlic Mustard (*Alliaria petiolata*), and Dames Rocket (*Hesperis matronalis*). A complete list of problematic species, and mapping of the severity of infestation has been provided. Many of the most problematic species and areas were subsequently treated during restoration works by Kayanase. Many invasive species persist, in particular exotic grasses and shrubs.

Free-to-grow Monitoring (2012)

Resampling of a sub-set of Kayanase 'free-to-grow' plots was completed in May 2012. Of 12 plots resurveyed, 11 exceeded the Kayanase estimates for stem density (stems/m^2) taken in 2011; all plots qualified as 'free-to-grow' according to density criteria.

2.6.3 Recommendations and Lessons Learned

Recommendations

The following are key conclusions and recommendations:

1. High-disturbance areas of the Red Hill Creek (i.e. upper reaches) would benefit from further restoration work focused on enhanced riparian vegetation cover along the creek bank, which would aid in mitigating the effects of flooding and erosion.
2. Future monitoring at 5-10 year intervals is recommended to evaluate long-term changes within the riparian zone of the Red Hill Creek, and to better understand the success of the restoration efforts on a more ecologically meaningful time scale.
3. Invasive plant species that are prevalent in the Valley were documented during this monitoring project; some were targeted by specific management during the implementation of the Landscape Management Plan. In order to ensure the long-term ecological integrity of the Red Hill Valley, future monitoring and management of these species is warranted to eradicate these species or prevent their further spread.
4. The wetland enhancement area within Red Hill Marsh (ENH5) should be further monitored as only two years of monitoring have been completed to date. Particular focus should be on invasive species such as Reed Meadowgrass (*Glyceria maxima*), which currently occupies a substantial area within the marsh, and Common Reed (*Phragmites australis*).
5. Monitoring of created habitats and built initiatives (such as QEW culvert) is recommended to evaluate their effectiveness in supporting local wildlife populations and habitat functions.
6. No conclusive research has been conducted indicating the effectiveness of the escarpment viaduct as a wildlife movement corridor for the population of Southern Flying Squirrels (*Glaucomys volans*) that was documented between 1999 and 2001; this remains a key knowledge gap.
7. Turtle population status within the Red Hill Marsh and Van Wagner's Ponds, as well as habitat enhancement areas, should be updated.
8. Common Carp is prevalent within the lower Creek and connected aquatic habitats. Further measures to control Common Carp populations should be undertaken, as has been done in Windermere Basin and Cootes Paradise. As noted within Section 2.5 however, the implementation of such control is considered difficult and would require further discussion and assessment.
9. Permanent vegetation plots were established in 2010 to document native vegetation communities found within the Red Hill Creek Valley. Monitoring should be repeated at regular intervals.

10. Wetland cover has increased by 15 ha within the Red Hill Valley since 2003, primarily as a direct result of habitat enhancement and wetland works. ELC cover should be periodically updated, preferably as part of watershed updates or new project undertakings.
11. This section provides only a brief summary of ecological restoration work completed by Kayanase under the direction of City staff. A separate report would be valuable to address the full scope of this work.

Project Level Learning

The Red Hill Valley Project brought many innovations to the planning and implementation for a major regional highway project; these included:

- Completion of the 1997 Watershed study and comprehensive Action Plan from public and interdisciplinary consultations; resulted in significant design changes for the Parkway and associated infrastructure works;
- The IADP provided a detailed focus on ecological issues such as significant habitats and species, wildlife corridors, regional bird migration, road noise, road salt, and identification of ecological restoration opportunities; precedent-setting targets for wetland and general habitat compensation on a watershed basis; prescribed monitoring at project and watershed scales;
- The RHVP Landscape Management Plan paralleled the IADP process and effectively combined Parkway and creek construction with a range of landscape restoration initiatives that addressed Watershed Action Plan and mitigation principles and objectives, encompassing areas such as landfill re-use, trails, and wetland impact mitigation.
- Detailed Design of the Parkway and QEW works, CSO, stormwater management systems, landfill re-use and trail system works, all built upon previous experience and integrated IADP and LMP principles and objectives, allowing testing and improving a variety of innovative approaches.
- Assignment of Kayanase's ecological restoration role in the project was pivotal to the initiation of numerous site-specific and science-based approaches, with more than 300 polygons treated, representing the targeted 100 ha of works to compensate for Parkway and Creek relocation works.
- Separating the major terrestrial mitigation efforts from the Parkway construction was a success in allowing enough time (5 years) to implement and follow up on a variety of measures which will continue to provide benefits as the restored communities undergo succession and proliferation;
- The City's Environmental Coordinator enabled efficiencies, integration for synergies with other City projects, and follow-up between numerous construction and mitigation activities.

Terrestrial Monitoring Program Learning

The terrestrial monitoring work provided an opportunity to observe ecological changes within a naturalized urban system. Primary findings include:

- The riparian monitoring and underlying planting and restoration works achieved the terrestrial goals of the DFO Authorization. The Cumulative Relative Importance Values indicate that native (indigenous) species dominated the immediate riparian zone through to 2012.

- In terms of spatial patterns, an increased native species presence was observed, floristic quality, and ground cover from transect 1 (upper Red Hill Creek) to transect 37 (lower Red Hill Creek), but significant variation within and between transects. Diversity was relatively stable along the length of the creek, but decreased through specific reaches along the lower creek due to relatively stable conditions and resultant lower environmental heterogeneity.
- Minor temporal changes in the structure and composition of the riparian vegetation community were observed between 2008 and 2012. Variation between years likely reflects annual environmental variation as much as successional changes. The monitoring time frame was relatively short, and represents primarily early-successional stages of the various plant communities present. Literature indicates that declines in species richness in early successional communities may be expected ~5 years after disturbance due to establishment of long-lived perennials and competitive exclusion of early-colonizing species (Prach et al. 2007).
- Disturbances are important factors influencing establishment of vegetation and the stability of vegetation communities. Before the Parkway and creek construction, most of the valley had undergone significant disturbances since settlement. Flood events in 2009 and 2012 demonstrated the character of potential catastrophic flow events, and highlighted areas most sensitive to these events, primarily in the upper valley. Human impacts such as the creation of informal trails and disposal of garbage (e.g. shopping carts) may be compromising the function of the constructed channel and restoration works.
- Recurring flooding and creek bank erosion also posed technical challenges to monitoring, as vegetation transect markers were washed out.
- Stormwater management facilities were consistently native-dominant (57%) across the 4 years of monitoring, but varied from year-to-year in composition. Based on species accumulation, the estimate of site-level species richness is likely low.
- Kayanase restoration works created or enhanced approximately 100ha of upland, riparian, and wetland habitats within the Valley. This involved site preparation (i.e. soil amendments, invasive species removal, and enhancement of topography), planting and seeding, and free-to-grow monitoring.
- The targeted 2:1 wetland gain has been exceeded, including RHVP works and the Windermere Basin wetland creation; coverage within the Red Hill Valley is now ~35.78 ha (4.80%), compared to 20.31 ha (2.73%) in 1997, and watershed wetland cover is now ~39.59 ha (0.58%), compared to 22.83 ha in 1997.
- Wetland succession has been impeded by impacts from Common Carp. Exclusion of this introduced species was first attempted in Cootes Paradise and was very beneficial to wetland diversity. The wetland creation completed in Windermere Basin in 2011 has also applied a carp barrier. In the lower Red Hill Valley, key opportunities for carp exclusion exist in Comp1 and Comp2, new backwater channels created within ENH5 (Red Hill Marsh), and the north Van Wagner’s Pond along with connecting waterways.

3.0 INTEGRATED SUMMARY

3.1 Overall Performance Assessment

The Red Hill Valley Parkway Flood Management

The Red Hill Valley Parkway (RHVP) was designed to a 100-year storm event performance standard for flood protection. The parkway would be expected to flood for storm events in excess of a 100-year storm. The storm event of July 26, 2009 has been characterized as being well in excess of a 100-year storm event, particularly for the section of Red Hill Creek in the vicinity of and downstream of Davis Creek (King Street), where peak flows indicate a storm approximately 1.5 times greater than the 100-year event. The storm event of July 26, 2009 was also preceded by a week of heavy rainfall, which saturated soils and limited the infiltration ability of pervious areas of the watershed. The recorded flooding of the RHVP for the July 26, 2009 was therefore to be expected, and is consistent with the originally approved design.

No flooding of the RHVP was experienced for the July 22, 2012 storm event, which was characterized as being approximately 1.5 times a 100-year storm event for the upper reaches of the watershed. For lower sections of the watershed (downstream of Davis Creek), the storm event was approximately equal to a 100-year storm event, however no flooding was reported during this event.

Flooding of the RHVP was noted for two other storm periods during the monitoring period, July 7 and July 9, 2010. In both cases, the primary location of parkway flooding was Facility J, a stormwater management facility located within the RHVP northbound/Barton Street interchange. This flooding has been shown to have been the result of a fine-meshed grill placed over the outlet structure, which was not part of the original design. This grill resulted in an accumulation of debris leading to flow blockage and as would then be expected, excess ponding and flooding. This grill has since been removed; no flooding in this location has been noted since.

Localized flooding of the RHVP in other locations was noted for the July 9, 2010 storm event, as well as for more formative storms (July 26, 2009). These locations include the Mud Street area, the Online (Retrofit) SWM Facility, the King Street off-ramp from the RHVP northbound, and SWM Facility J. A detailed list of potential remedial measures for these areas was provided as part of the 2010 Annual Monitoring report. For Facility J, subsequent monitoring was conducted (2011-2012) and determined that improved overflow relief would be the most likely solution. The City of Hamilton should consider these measures as part of future works.

Red Hill Creek System

The reconstructed channel (Red Hill Creek) has been subjected to two major flooding events equal to or exceeding the 100 year storm event over the 5-year monitoring period (July 26, 2009 and July 22, 2012). In addition, it has been demonstrated that a particularly high number of flows above bankfull conditions were experienced over the 2009-2011 period. As such, higher than average rates of channel erosion would naturally be expected during the monitoring period. In general, average bankfull meander rates are still reasonably close to the design targets set for the reconstructed channel portion of Red Hill Creek. The channel alignment also stayed relatively consistent over the monitoring period, despite the high magnitude of flows during the July 26 2009 and July 22 2012 storm events. Some adjustments to channel form and in-stream structures were necessarily required following these storm events, with reconstruction works undertaken in 2010 and again in 2015. The 2015 reconstruction works through the King's Forest Golf Course have included widening bankfull creek geometry and golf cart bridge spans, as well as repairing in-stream structures; these modifications should further assist in increasing the stability of this section of Red Hill Creek in the future. However, it should be clearly understood that the channel is "natural infrastructure" and will always require some degree of maintenance, particularly after large magnitude flooding events, such as those previously noted.

Riparian vegetation (i.e. vegetation along Red Hill Creek) monitoring has demonstrated that planting and restoration works have achieved the original goals of the project. Vegetation indices have indicated that native (indigenous) species dominate the immediate riparian zone through to the end of 2012 (the last year of monitoring). It should be noted however that the majority of the areas surveyed in the riparian zone are considered to have moderate to high levels of invasive exotic species; this will continue to require maintenance and management. High disturbance areas of the riparian zone (i.e. upper reaches within the steepest section of Red Hill Creek) would also benefit from some enhanced riparian cover along the banks to further minimize erosion.

Groundwater and baseflow monitoring within Red Hill Creek has shown that there has been no observed decrease in creek baseflows as a result of the construction of the RHVP. Water temperature has also remained largely unchanged as compared to pre-construction levels. Water quality concentrations within Red Hill Creek, particularly during wet weather events, continues to be a concern. As evident from water quality sampling however, this issue is considered to be on a watershed scale, and unrelated to stormwater runoff from the RHVP itself (for which the constructed stormwater management quality control facilities are considered to be functioning largely as intended). Contaminant concentrations within Red Hill Creek runoff upstream of the RHVP were found to be well in excess of Provincial Water Quality Objectives (PWQOs); elevated concentrations were also noted further downstream within Red Hill Creek. These contaminants appear to be primarily sourced from municipal storm sewers, and from commercial and industrial land uses in particular (likely constructed in the era that pre-dates requirements for stormwater quality controls).

Combined Sewer Overflows (CSOs) have a negative impact on creek water quality, in addition to increasing creek flows and potentially erosion (through additional suspended sediment and solids). A number of overflows were recorded by the City of Hamilton to Red Hill Creek over the monitoring period, including the Greenhill CSO. The City of Hamilton has investigated these observations as part of a separate assessment, and found that these overflows were primarily attributable to the excessive wet weather conditions over several years. The City has since taken several further initiatives, including the implementation of real time control (RTC) over its sanitary and combined sewer system, and the operation of the Red Hill Valley Storage Pipe, which was constructed as part of the RHVP, but did not become operational until December 2011. This storage pipe eliminates three former CSO discharge points (at Lawrence Road, Queenston Road, and Melvin Avenue), and should assist in minimizing future discharges to Red Hill Creek.

The delay in the operability of the Red Hill Valley Storage Pipe may be a factor in the interpretation of the results of the benthic invertebrate sampling within Red Hill Creek. The results of this sampling work indicated no substantial change in the composition of the benthic invertebrate community as a consequence of the RHVP works. Likewise, no substantial change was noted in the composition of the fisheries community within Red Hill Creek over the monitoring period. Some differences were noted in year-to-year trends in fish density, which were considered to be somewhat surprising. However, it has been noted that this variation could be attributable to sampling numbers and other transient factors not assessed as part of the current study. In general, it is noted that Red Hill Creek is an urban watercourse, with a simple fisheries community dominated by tolerant species; this composition does not appear to have substantially changed as a result of the construction of the RHVP.

Stormwater Management Facilities and Wetland Areas

A number of stormwater management (SWM) facilities and wetland areas were designed and constructed as part of the Red Hill Valley Project (RHVP) in order to provide the required flood control, stormwater quality control, compensatory wetland habitat, and ecological function.

A total of three (3) major flood control facilities were designed and constructed as part of the RHVP: the Dartnall, Greenhill, and Davis Creek Flood Control Facilities (latter has been constructed, but as of the timing of this report, not yet commissioned). Monitoring results for the Dartnall Flood Control Facility (located at the confluence of Hannon Creek with Red Hill Creek) indicate that observed peak discharges from the facility were consistently below expected simulated values, confirming the original design. Likewise, monitoring results from the Greenhill Flood Control Facility (located within Greenhill Park) confirm that the flood control berm operates as per the intended design (i.e. creek flows in excess of the 2-year storm event). The Davis Creek Flood Control facility is not yet commissioned, and therefore cannot yet be assessed. A separate integrated monitoring program (5-year duration) has been commenced for this facility to satisfy regulatory requirements; this program is expected to extend from 2014 to 2018 inclusive.

A total of fourteen (14) stormwater quality control facilities were designed and constructed along the RHVP (11 of which are City-owned, and the remaining 3 of which are MTO-owned). Based on the results of a multi-year stormwater quality sampling program, these facilities are largely performing as per their approved design criteria (80% average annual removal of total suspended solids). For those facilities were performance was less than expected, the results may be due to operational conditions which makes field sampling difficult (such as a submerged outlet pipe), or due to maintenance/operational issues, which are currently, or have been, addressed by City staff. Contaminant levels from stormwater quality control facilities have been noted to be far lower than concentrations within Red Hill Creek itself (typically an order of magnitude lower or greater in many cases).

Similar to the observations along the riparian corridor, native (indigenous) species of vegetation were found to dominate within wetlands and SWM facilities; this observations was generally consistent year over year. Likewise, species richness was found to be stable year over year, although this richness was considered to be low within these areas. The initial design target of a 2:1 wetland gain has been exceeded, including RHVP works and the Windermere Basin wetland creation (constructed separately from the RHVP works by others). The overall increase in wetland area is some 15.9 ha, greater than the 10.45 ha targeted. These estimates also do not account for SWM facilities and enhancement work within the Red Hill Marsh.

The Red Hill Valley

The Integrated Monitoring Program (IMP) has considered numerous other environmental factors within the Red Hill Valley, which are not addressed by the preceding categories.

An assessment of groundwater levels, baseflows, and groundwater quality within the Red Hill Valley has shown that there has been no negative impact to these systems from the completion of the Red Hill Valley Project.

Over 100 hectares of restoration activities have been undertaken by Kayanase, an ecological restoration contractor that employed science-based techniques and adaptive management, along with Haudenosaunee cultural values and ecological knowledge, to carry out this design-build restoration and enhancement project (2007-2012). These works have been carried out along the entirety of the Red Hill Valley, from the upstream limits at the Lincoln Alexander Parkway, to the downstream limits at Lake Ontario. Many of the most problematic areas with respect to exotic invasive species were also treated as part of these restoration works.

Wildlife surveys were also undertaken as part of the overall RHVP IMP. A total of 42 species of birds were found as part of this survey work within the valley, 39 of which are possibly breeding or on territory. Four (4) species of amphibians were also found within the valley as part of monitoring survey work. Some work has been undertaken by researchers at McMaster University to assess the artificial tree structures created within the viaduct area to provide for the movement of the Southern Flying Squirrel. However, no conclusive research has yet emerged to confirm the effectiveness of the viaduct or these structures in this regard.

3.2 Recommendations and Future Monitoring/Maintenance Requirements

Based on the findings of the Integrated Monitoring Program, a number of recommendations and future monitoring/maintenance requirements have been identified:

Groundwater

1. Existing groundwater monitoring wells should be left in place for any future more regional monitoring program. The Hamilton Conservation Authority (HCA) or other governmental agencies should be contacted to confirm whether they would be interested in taking over the monitoring of these wells, potentially as part of the Ontario Groundwater Monitoring Network.

Surface Water

2. The Davis Creek Flood Control Facility monitoring program which was commenced in 2014 should continue, with the anticipation that the facility will become commissioned soon. The program is scheduled to last 5 years, consistent with the balance of the RHVP IMP monitoring activities.
3. The City of Hamilton may wish to further monitor and assess localized flooding locations identified within this summary (as well as the 2010 Annual Monitoring Report), as well as consider the preliminary list of proposed remedial measures.
4. The City of Hamilton and the Ministry of Transportation (MTO) may wish to undertake a climate change assessment, to better understand the potential vulnerabilities along the RHVP, and develop appropriate resiliency plans.

Water Quality

5. The City of Hamilton should continue to monitor combined sewer overflow (CSO) discharges to the Red Hill Valley over time to verify the effectiveness of the Red Hill Valley Storage Pipe, and whether any additional measures are warranted.
6. The City of Hamilton may wish to consider future continuous stormwater quality sampling of stormwater management facilities using an auto-sampler in order to better assess their performance. The City may also wish to consider further grab sampling or continuous sampling of Red Hill Creek during wet weather events given the high observed contaminant levels. This monitoring effort could be used to determine which areas of the watershed have relatively higher contaminant level contributions, and should be targeted for potential future remedial stormwater quality controls.
7. The City of Hamilton should consider undertaking repeat bathymetric surveys of stormwater quality management facilities in the next 5 to 10 years to better assess sediment accumulation rates and forecast future clean-out scheduling.
8. The City of Hamilton (and the MTO) should continue annual inspections of all stormwater management facilities in order to assess and proactively respond to any identified issues. The RHVP SWM Facility Operations and Maintenance Manual (to be completed later in 2015 by Amec Foster Wheeler) should assist in this regard.

Creek Morphology

9. The City of Hamilton may wish to continue monitoring erosion and along the Red Hill Creek corridor to continue to assess the bankfull meander migration of the channel over time. Recent channel works (2014/2015) within the King's Forest Golf Course in particular are recommended to be monitored for at least 5 years.
10. Maintenance of the Red Hill Creek corridor will continue to be required, particularly after large magnitude flood events. The corridor should be viewed as part of the City's "natural infrastructure", with associated ongoing maintenance requirements.
11. The City of Hamilton and its partners (such as the Hamilton Conservation Authority) should continue efforts to clean up anthropogenic material within Red Hill Creek (such as shopping carts) through annual creek clean-up days. The City (and potentially the HCA) should likewise continue to monitor and remove any potential debris jams at culverts and other hydraulics structures.
12. The ongoing erosion and sediment contribution upstream of the Buttermilk Falls tributary should be addressed in order to maintain downstream channel stability within Red Hill Creek. The rehabilitated channel reach was never designed to handle/receive the bed material load that is currently being generated by the upstream reach destabilized in the July 2009 flood. Measures should be taken to mitigate erosion in this reach and provide enhanced geotechnical slope stability.

Fisheries

13. The City of Hamilton, and affected regulatory agencies (Hamilton Conservation Authority, Ministry of Natural Resources and Forestry, Department of Fisheries and Oceans, Royal Botanical Gardens, Bay Area Restoration Council) may wish to consider transplanting suitable native stream fishes from other area watercourses, if a more diverse fish community in Red Hill Creek is desired. Further discussion would however be required on this subject.
14. The City of Hamilton and affected regulatory agencies should consider implementing carp control within the lower reaches of Red Hill Creek (as has been done in Windemere Basin). Key opportunities for carp exclusion exist in compensation wetlands Comp1 and Comp2, as well as new backwater channels created within ENH5 (Red Hill Marsh), and the north Van Wagner's Pond along with connecting waterways. Further discussion would again be required on this subject.
15. Benthic invertebrate sampling should be considered in the future, potentially within the next 5 years +\-, in order to assess potentially positive impacts of the Red Hill Valley Storage Pipe. This feature, which should reduce the number of combined sewer overflow discharges to Red Hill Creek, did not begin operating until December 2011; as such the monitoring data (ending in 2012) would not reflect the benefit of implementing this feature.

Terrestrial Ecology

16. Future terrestrial ecology monitoring of the riparian zone is recommended at 5 to 10 year intervals in order to evaluate long-term changes. Additional restoration efforts for high-disturbance areas of the riparian zone (i.e. upper reaches) would also be beneficial and should be considered.
17. It is recommended that the City of Hamilton consider future monitoring and management of invasive species within the Red Hill Valley in order to eradicate them or prevent any further spread.
18. It is recommended that the City of Hamilton undertake additional monitoring of the wetland enhancement areas (ENH5), given that only 2 years of data have been collected thus far.
19. It is recommended that turtle population status within the Red Hill Marsh and Van Wagner's Ponds, as well as habitat enhancement areas, be updated.
20. The City of Hamilton should consider undertaking repeat monitoring of permanent vegetation plots within the valley.
21. The City of Hamilton should consider periodically updating Environmental Land Classification (ELC) cover databases as part of any future watershed updates or new projects.
22. The City of Hamilton should consider completing a separate stand-alone report to summarize and address the full scope of the restoration works undertaken by Kayanase.

3.3 Lessons Learned – Application to Future City Projects

Given the scope and duration of the Red Hill Valley Project Integrated Monitoring Plan, a significant number of lessons have been learned. These lessons apply not only to specific disciplines and technical matters, but also to the overall process and study form. These lessons are presented herein so that the knowledge gained through this study can be applied to future City projects to their benefit.

Overall Project

1. The City of Hamilton's Environmental Coordinator enabled efficiencies, integration for synergies with other City projects, and follow-up between numerous construction and mitigation activities. For future large-scale projects which involve an environmental component, the involvement of an Environmental Coordinator would be invaluable.
2. The planning and design process for the RHVP was very successful from an ecological perspective. Documents such as the 1997 Watershed study and comprehensive action plan, the IADP, and the RHVP Landscape management plan resulted in significant design changes to the Parkway with a focus on ecological issues, and a range of restoration activities.

Surface Water

3. Flow monitoring within larger creek systems (such as Red Hill) is likely best done with a permanent installation to ensure gauge stability and avoid equipment loss. Gauge installation locations should also be chosen in areas with stable conditions where possible (i.e. shallower/less steep sections). In other areas temporary gauge installations are likely acceptable, but need to be securely anchored to the channel bed, likely to a minimum depth of 1 m.
4. In-stream velocity measurements cannot be safely obtained at higher flows (i.e. typically greater than 0.8 m depth), although this varies depending on the flow velocity. Other methods of obtaining velocity measurements at high flows are usually impractical or cost-prohibitive. As such, rating curves (the developed relationship between depth and flow for a given monitoring sections) should be developed using a hydraulic model rather than a simple trendline, which would not reasonably account for expect variations at higher depths. Reasonableness checks should also be incorporated into this process (i.e. verification of runoff volumes, comparison to other calibrated/verified models or local observed streamflows).
5. Fully calibrated hydrologic and hydraulic models are invaluable tools for any watershed. The calibrated HSP-F model of the Red Hill Creek watershed developed as part of previous studies was invaluable in conducting the forensic assessments of major storm events, such as the July 26 2009 and July 22 2012 storms. Developing such models, and continuing to maintain and update them as development proceeds within a watershed is invaluable in understanding watershed flows and rapidly assessing major storm events or development scenarios.
6. In addition to the benefit of calibrated hydrologic and hydraulic models, there is significant value in the City of Hamilton’s network of point rainfall gauges. This network has been relied upon in the forensic assessment of major storm events, including in the calibration of radar-generated rainfall data. Over time, this network will provide a long-term local rainfall dataset that could be used for multiple purposes, including continuous simulation, climate change assessments, intensity-duration-frequency rainfall statistics, and other projects.

Water Quality

7. Water Quality grab sampling provides a general indication of contaminant concentrations and potentially stormwater management facility performance. However, its limitations should be clearly understood. Grab samples characterize only a single point in time. Although best efforts are, and have been, made to collect samples at representative times, actual storms are unpredictable and impacted by a number of factors, including the accuracy of forecasts, weather patterns, and antecedent rainfall. Real world storm events rarely match the idealized “design” conditions, and a single sample is rarely sufficient to characterize conditions, particularly influent concentrations. Although continuous water quality sampling (using auto-samplers) is typically preferable, the high costs associated with obtaining this equipment and the associated laboratory costs to test the additional samples, typically makes this option cost-prohibitive for most projects.
8. The results of this monitoring effort indicated that municipal storm sewers tend to be much worse sources of stormwater pollutants than the Red Hill Valley Parkway. Commercial and

industrial land uses in particular appear to contribute the highest concentrations (as might be expected), particularly given that many of these areas pre-date requirements for stormwater quality controls. Ultimately, the long-term health of Red Hill Creek depends on further addressing these external contributors.

9. An as-constructed bathymetric survey of all stormwater management facilities should be mandatory before the City of Hamilton assumes control. The results of the analyses conducted for this study suggest that a large portion of the accumulated sediment likely resulted from construction activities, and was never restored to design levels.
10. Regular SWM inspections (annual at least) of stormwater management facilities are the best way to ensure efficient operation and to proactively address maintenance requirements as required.

Creek Morphology

11. A great deal of insight has been gained as a result of this project with respect to natural channel design techniques, particularly in steep slopes. These lessons should be applied to other channels within the City with similar conditions (i.e. channel sections immediately below the Niagara Escarpment in particular).
12. When constructing future in-creek structures, sills should be considered. These features are relatively low cost and have been shown to minimize disturbances and damage to in-stream structures.
13. All creek systems should be viewed as being part of the City's "natural infrastructure" and will always require some degree of maintenance, particularly after major storms.

Fisheries

14. Fisheries inventories need to ensure that an adequate number of reaches and habitats are sampled to confirm that year-to-year comparisons are reasonable.
15. The conversion of concrete habitat to natural substrate has been demonstrated to be very effective in increasing fish abundance, even when placed over concrete. This should be considered in the design of hydraulic structures where fish habitat and passage would be a factor. Likewise, although open-bottomed culverts are preferable, modified culvert designs can be considered using traditional closed culverts, whereby natural substrate is retained with baffles and a narrower low flow channel is included.

Terrestrial Ecology

16. Separating the major terrestrial mitigation efforts from the Red Hill Valley Parkway (RHVP) construction was a success in allowing enough time (5 years) to implement and follow up on a variety of measures which will continue to provide benefits as the restored communities undergo succession and proliferation;

17. Disturbances are important factors influencing establishment of vegetation and the stability of vegetation communities. Before the construction of the RHVP and the re-construction of Red Hill Creek, most of the valley had undergone significant disturbances since settlement. Flood events in 2009 and 2012 demonstrated the character of potential catastrophic flow events, and highlighted areas most sensitive to these events, primarily in the upper valley. Human impacts such as the creation of informal trails and disposal of garbage (e.g. shopping carts) may be compromising the function of the constructed channel and restoration works.
18. Recurring flooding and creek bank erosion also posed technical challenges to monitoring, as vegetation transect markers were washed out. Future studies in areas subject to similar conditions should consider more resistant markers.

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RED HILL CREEK VALLEY PROJECT
INTEGRATED MONITORING PLAN
CITY OF HAMILTON
LEGEND
STORMWATER FACILITY LOCATION
PREVIOUS RED HILL CREEK ALIGNMENT
CURRENT RED HILL CREEK ALIGNMENT
INSTREAM FLOW GAUGES (BY OTHERS)
SWM FACILITY PERFORMANCE MONITORING
• Water Quality
• Sediment
IN-STREAM WATER QUALITY MONITORING LOCATION
GROUNDWATER MONITORING SITE
PREVIOUSLY ESTABLISHED (2012) AMEC WATER LEVEL AND FLOW MONITORING LOCATIONS
PREVIOUS AMEC WATER LEVEL AND FLOW MONITORING LOCATIONS
CURRENT (2014) AMEC WATER LEVEL AND FLOW MONITORING LOCATIONS FOR DAVIS CREEK FLOOD CONTROL FACILITY
DRAWING 1 MONITORING LOCATIONS
SCALE 1 : 15000
0 100 200 400
amec
STONE CHURCH NORTH (2009-2012)
DARTNALL (2010-2012)
MT ALBION #2 (2008)
RED HILL CREEK AT MT. ALBION
MT ALBION #1 (2008)
REPLACEMENT FOR MT. BROW GAUGE
STONE CHURCH SOUTH (2010-2012)
STONE CHURCH SOUTH (2009)
DARTNALL ROAD
STONE CHURCH RD
DARTNALL QUANTITY CONTROL FACILITY
RYMAL ROAD
HIGHLAND RD W
MUD STREET FACILITY (CITY ID 116)
MUD STREET
BH96-3
ESCARPMENT FACILITY (CITY ID 117)
GREENHILL # 3 (2008)
GREENHILL #3 (2012)
BH96-1
GREENHILL #3 (2008-2011)
GREENHILL QUANTITY CONTROL FACILITY
GREENHILL #2 (2008-2012)
GREENHILL #1 (2009-2012)
GREENHILL #1 (2008-2009)
FACILITY B (CITY ID 108)
FACILITY C (CITY ID 109)
FACILITY D + ONLINE FACILITY (CITY ID 110)
GREENHILL AVENUE
DAVIS (2008-2009)
DAVIS CREEK FLOOD CONTROL FACILITY
KING STREET
FACILITY F-G (CITY ID 111)
QUEENSTON ROAD
FACILITY H (CITY ID 112)
FACILITY I (CITY ID 113)
MELVIN AVE. GAUGE
RED HILL CREEK AT BARTON ST.
FACILITY J DOWNSTREAM (2011-2012)
FACILITY J IN POND (2011-2012)
FACILITY J (CITY ID 114)
BARTON STREET
FACILITY K-L (CITY ID 115)
COMPENSATION WETLAND (2009-2012)
FACILITY M (MTO FACILITY 7)
FACILITY O (MTO FACILITY 4)
CENTENNIAL FACILITY (MTO FACILITY 8)
Plotted: 2014-10-30
Last Saved: 2014-10-30
Plotted By: josh.seraj
Last Saved By: josh.seraj

APPENDIX A

City of Hamilton

Red Hill Terrestrial Monitoring

Executive Summary

October 2014 (June 2018)

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APPENDIX 1 – Area Profiles

1. BACKGROUND

The Integrated Monitoring Plan (IMP) for the Red Hill Valley Project (RHVP) was developed to ensure environmental compliance required by the various agencies involved in the planning and approval process (City of Hamilton, 2006). The purpose of the IMP was to evaluate the performance of the Environmental Management System for the Red Hill Valley Project, and to provide adjustments to the plan recommendations through a process of adaptive management (City of Hamilton, 2006).

The Red Hill Valley Project encompassed construction and landscaping activities related to the new Parkway, the relocated Creek, and associated infrastructure (i.e. stormwater management facilities) but also incorporated major habitat protection, creation, restoration and enhancement initiatives that included:

- RHVP Impact Assessment and Design Process (IADP) (1999-2003)
- RHVP Landscape Management Plan (Envision et al 2003),
- Detailed design phases for the Parkway and the QEW interchange works (2005-2007),
- RHVP Landscape Design and Habitat Enhancement Plan (D&A 2005)
- RHVP Ecological Restoration and Landscaping Project (SNEOG 2006),
- Rennie/Brampton St. Landfill Remediation (1999-2005), and
- East Hamilton Trail and Waterfront Link (2008-2011).

This report deals primarily with monitoring based on the Impact Assessment and Design Process (IADP) recommendations and agency approval conditions. However it also provides profiles of some key areas where a broader range of study, design and restoration initiatives were undertaken. It includes a summary of key lessons learned and challenges associated with the implementation and monitoring of terrestrial ecology-related aspects of the RHVP.

Monitoring of the natural heritage aspects within the Red Hill Valley Project study area focused on three levels to address agency requirements and planning objectives:

- *DFO Conditions of Approval (DFOCOA)* - identify plantings to be replaced; ensure that slope, channel and wetland plantings will be dominated by indigenous riparian species.
- *Landscape Management Plan (LMP)* - ensure that habitat restoration and enhancement works achieve objectives.
- *Impact Assessment and Design Plan Ecosystem Monitoring* (*IADPEM)* - assess ecosystem level diversity and functions in the longer term.

This summary report provides an overview of the work undertaken to evaluate the success of RHVP activities, and presents: methods used in monitoring; major results and findings of monitoring: and challenges and lessons learned during the process. For detailed methods and results for each year of the monitoring program, please refer to the 2008-2012 annual reports.

1.1. GOALS AND OBJECTIVES

The following objectives were developed for the terrestrial ecology component of the Integrated Monitoring Plan in order to meet agency requirements (see Table 6.1 in IMP):

- Regulatory monitoring of riparian vegetation along the Red Hill Creek (DFOCOA);
- Monitoring of vegetation planted within wetland compensation areas and within Stormwater Management (SWM) facilities (DFOCOA);
- Survey wildlife (i.e. breeding birds and amphibians) and vegetation long-term monitoring stations to collect baseline data (IADP);
- Watershed- and valley-level Ecological Land Classification (ELC) updates and characterization (IADP);
- Monitor vegetation planted within the wetland enhancement areas (LMP);
- Determine the Free-to-Grow status of habitat restoration areas (LMP)
- Survey invasive exotic species within the riparian area of the Red Hill Creek.

Specific questions for each component of the monitoring programs are outlined in the relevant methodology sections below.

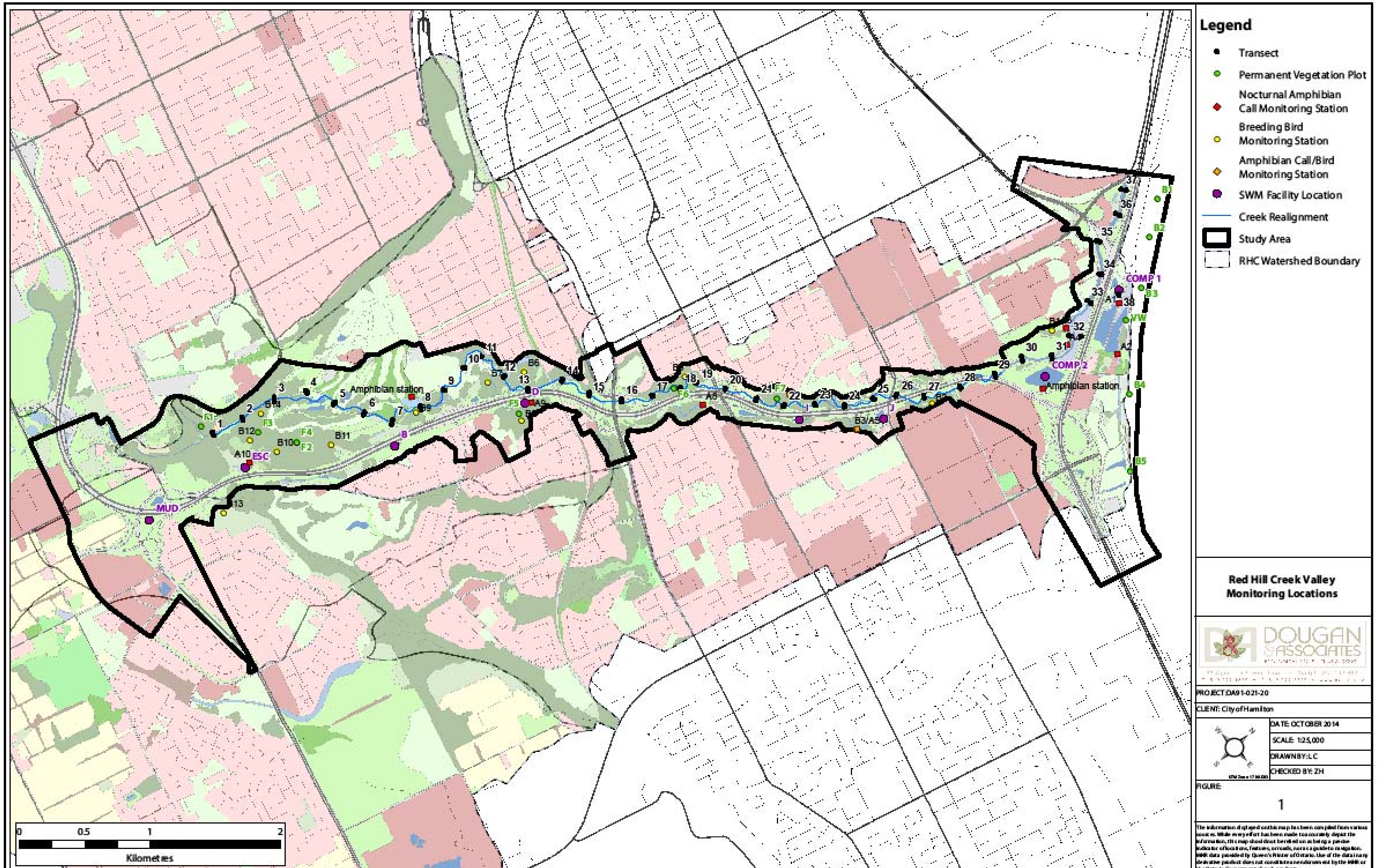
1.1.1. METHODOLOGY

The tasks completed from 2008-2012 as part of the Integrated Monitoring Plan are shown in Table 1. The methodology used for each component of the terrestrial monitoring program is summarized in the sections that follow. The primary study area and locations of the RHVP terrestrial monitoring are shown in Figure 1; the scope and scale of watershed level monitoring activities is addressed later in this report.

Table 1. Terrestrial Ecology Monitoring Timeline. Tasks were completed in shaded years.

Task	Year				
	2008	2009	2010	2011	2012
Riparian Vegetation Monitoring					
Wetland Compensation and SWM Monitoring					
Ecological Land Classification Updates					
EMAN Plot Monitoring					
Wildlife Plot Monitoring					
ENH5 Monitoring					
Invasive Exotic Species (IES) Surveys					
Free-to-Grow Evaluations					

Figure 1. Red Hill Valley Terrestrial Monitoring Locations



1.1.1.1. DFOCOA

__Riparian Vegetation__

The primary questions to be addressed for riparian vegetation monitoring were:

1) What is the structure and composition of riparian vegetation along the Red Hill Creek,
2) What spatial and temporal patterns occurred within the riparian vegetation community from 2008-2012, and
3) Which species define the riparian vegetation community along the Red Hill Creek in terms of relative importance?

These questions were addressed using 37 permanent transects spaced 250m apart along the length of the Red Hill Creek which were sampled repeatedly over the 5-year monitoring period. Six 1m x 1m quadrats (plots) were placed along each transect for a total of 222 sampling locations along the 9.5km length of creek. The length of transects ranged from 6m (average length 6.2 m), generally 3+ meters from edge of channel to each end in most locations, but one extended up to 52m for transect 32 through Red Hill Marsh Enhancement Area (Enh5). An additional transect with six plots was established on a section of the Red Hill Creek channel that connects to Van Wagner's Pond north of the QEW.

Each transect was photographed annually with a scale bar to document changes in vegetation, as shown in Figure 2. Quantitative sampling of vegetation at each transect took place at all transects in 2008, and alternating "even" (i.e. 2, 4, 6 etc.) and "odd" (i.e. 1, 3, 5 etc.) transects each year until 2012. Within each quadrat, the following data was collected: species presence/absence, estimated cover, and height values of individual species. Cover estimates were also recorded for mosses and liverworts, which were grouped as "non-vascular plants", and the area of bare soil and/or rock was also recorded. When observed, soils deposited during seasonal flooding were noted.

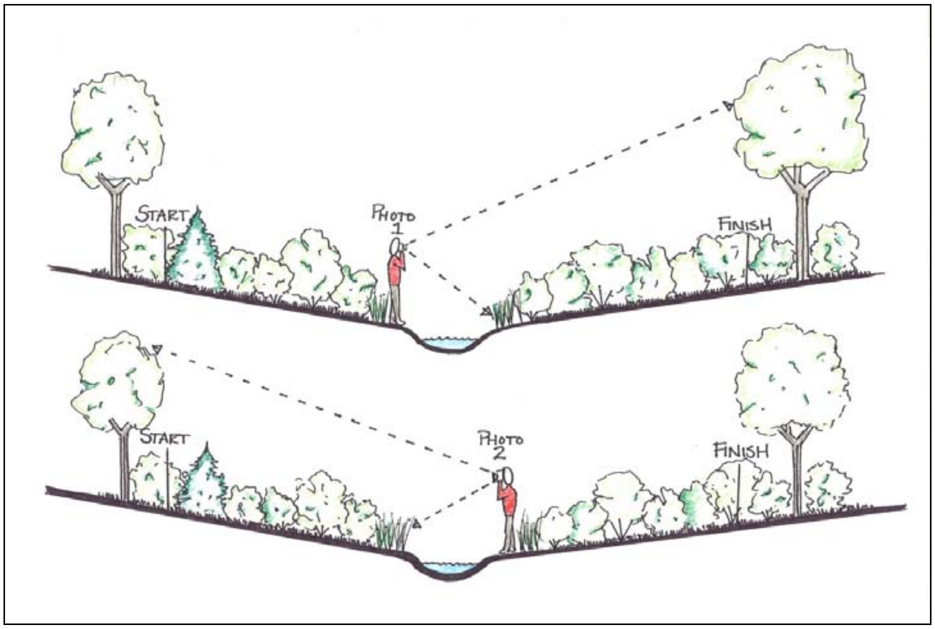


Figure 2. Approach for transect photomonitoring.

Several metrics associated with plant abundance and community diversity were calculated for each $1m^2$ quadrat, and averaged to produce transect and site-level estimates. These metrics included: species richness (exotic and native), Shannon Diversity Index (H) and Pielou's Evenness Index (J), and Floristic Quality Index (FQI).The Floristic Quality Index is a useful tool for monitoring habitat restoration (Oldham et al. 1995). For each species, Frequency, Average Cover, Relative Cover, Relative Frequency, Importance, and Relative Importance values were calculated. These metrics were used to evaluate changes in community structure and composition over the 5-year monitoring period, as well as to compare to historical conditions.

In order to compare the riparian vegetation community along the reconstructed Red Hill Creek Channel to pre-construction conditions, data from "The Vegetation and Flora of the Red Hill Valley and Environs" (Goodban 1996) was used which provided a comprehensive list of plant species reported up to 1996 within the Red Hill Valley, and therefore serves as a valuable reference for baseline plant diversity. As discussed later in this report, the sampling methods used in the monitoring study were quite different than the historical flora approach of Goodban (1996); our sampling approach was intensive and focused within the newly constructed and modified riparian environments of the Red Hill Cree.

We summarized the species listed by Goodban (1996) attributed to riverine, marsh/meadow marsh, and deciduous floodplain woodland valley habitats. These habitat types are most similar to those monitored within the riparian zone in this study. For each species, we applied the same set of species attributes used in this study (i.e. native/exotic, conservation status, Coefficient of Conservatism, Floristic Quality, growth form, etc),to the Goodban data to compare the characteristics of the current vegetation communities to those reported from the Red Hill Creek circa 1995.Throughout the results summarized in this report, our findings are compared to those provided in Goodban (1996).

To evaluate differences in vegetation community performance between transects and reaches, standardized measures were applied: species richness, proportion of native species, floristic quality index, Shannon diversity index, and ground cover in each quadrat. The results were further standardized using “z-scores” (variable-mean/standard deviation), and averaged across all years at the transect level. Standardized values are between -1 and 1, with 0 being the mean of all plots. This approach allows for the comparison of transects to each other, given the average conditions for the site. Z-scores for each metric were then averaged for each transect to obtain an overall score. These values were then plotted and mapped to show variation in vegetation community performance along the Red Hill Creek.

Shannon Diversity and Pielou’s Evenness Index values were calculated using the Vegan Package in the “R” statistical software (Oksanen 2012) and statistical analysis was performed in JMP 11.0.0 (2013 SAS Institute Inc). “Even” and “odd” transects were analyzed separately within each year for variation in measures of species richness, floristic quality, and diversity using an ANOVA, with plot nested within transects, and both treated as random factors. Transect distance along the creek (reach distance) and plot positions were each treated as fixed factors. Full results of the statistical analysis are not provided in this report, but are summarized to highlight the patterns observed.

Wetland Compensation and Stormwater Pond Vegetation

The primary questions to be addressed through monitoring the stormwater management facilities and wetland compensations areas (referred collectively to as 'ponds') were:

1) What is the structure and composition of vegetation within and surrounding the ponds, and
2) What spatial and temporal patterns in vegetation occurred within and among ponds from 2009-2012.

Fourteen (14) ponds are located adjacent to the Red Hill Parkway along the length of the Red Hill Creek and near the QEW interchange (Table 2; Figure 1). In 2009, seven were chosen for quantitative sampling based on key attributes (e.g. extent of surrounding roads and natural vegetation cover) in order to represent the variety of conditions present among ponds. We categorized ponds based on similarity of attributes, including; the surroundings (road vs natural/naturalized), size, and re-vegetation efforts. Those in Category 1 (MUD, J, COMP1), being the least natural, were typically surrounded by roads on all sides and with minimal natural features in the vicinity, whether natural or part of a restoration initiative. In contrast, SWMs and wetlands in Category 3 (ESC and COMP2) were the most natural, being in proximity to only one or no roads, and having the most extensive natural features in the vicinity. Those in Category 2 (B and I) were intermediate. This categorization ensured that SWM facilities and wetlands of varying quality and setting were represented, and allowed for randomized selection within each category. Wetland Compensation Area 2 (COMP2) was also surveyed from 2010 – 2012 for a total of 8 within the study area.

Vegetation sampling of the pond was also conducted using transects, four per pond, and three quadrats per transect, except for the Escarpment viaduct pond, which had fewer transects installed due to ongoing construction, and more quadrats per transect to account for larger area. In total, 99 pond quadrats were sampled each August from 2009-2012.

A nested ANOVA was used to determine if vegetation community quality varied among years, ponds, and transects nested within ponds, with category included as a fixed factor.

1.1.1.2. IADP

Ecological Land Classification

In 2010 GIS data was compiled from existing sub-watershed studies to aid in producing an updated (current to 2009 orthophotography) base map of Ecological Land Classification (ELC) communities for the Red Hill Creek Watershed, which could then be compared to 1997 estimates of vegetation cover to detect changes in cover between 1997 and 2009. Key areas were visited in 2010, 2011, and 2012 to remap, if necessary, to at the ELC Community Series level. We used this updated mapping to answer the following questions:

1) How did the landcover within the Red Hill Creek Watershed and Red Hill Valley change from 1997 to 2012, and;
2) Were wetland compensation targets achieved?

We provide a summary of the changes in land cover across the Red Hill Creek watershed, as well as the Red Hill Valley, and address the achievement of wetland compensation targets outlined in the DFO approval conditions in Section 4.3.

Permanent Vegetation Monitoring Plots

A network of permanent vegetation and wildlife monitoring stations was established in the Valley in the spring of 2010 according to the terrestrial vegetation biomonitoring protocols developed by Environment Canada's Ecological Monitoring and Assessment Network (EMAN 1996). The intent of these vegetation plots is to track representative vegetation types and habitats, and changes within these areas over the long term. For the surveys conducted in 2010, our goal was to determine baseline conditions in terms of species richness and community composition. Seven permanent (10m x 10m) vegetation monitoring plots were installed and sampled at forest sites using the methods outlined in Chambers and Lee (1992) with some modifications. In addition to the forest plots, Van Wagner's Ponds and Beach was added as an additional site to improve representation of the different habitats present in the area. We also used a transect-based monitoring approach at these locations. The IADP recommended the re-sampling of these EMAN plots on a five year cycle, for a minimum of 20 years. For more details specific to the EMAN protocols, refer to EMAN (1996), and for our adaptation of the methodology see the Integrated Monitoring Plan Red Hill Valley Project 2010 Annual Report (AMEC 2010).

Permanent Wildlife Monitoring Plots

A total of 12 nocturnal amphibian call (*i.e.* frog and toad) and 14 breeding bird monitoring stations were established in the Red Hill Creek study area in December 2008 with the purpose of estimating species diversity and abundance in key areas (Figure 1). The selection of nocturnal amphibian call monitoring stations was carried out with the objective of covering the majority of potentially suitable amphibian breeding habitats in the valley. Nocturnal amphibian call surveys were monitored according to the Marsh Monitoring Program (MMP) protocols (BSC 2003), except that monitoring sites were not restricted to marsh habitats. Three surveys were conducted for amphibians on April 30, May 20 and June 27, 2010.

Two breeding bird surveys were also conducted in 2010 for each sample point shown on Figure 1, with the first round taking place on May 25 and 26, and the second taking place on June 15 and 17, 2010. The surveys followed the protocols outlined by the Ontario Breeding Bird Atlas (OBBA 2001).

The Urban-Rural Biomonitoring & Assessment Network (URBAN), a citizen-science program based at McMaster University in Hamilton, Ontario, also completed breeding bird and amphibian surveys according to the MMP at three locations within the Red Hill Valley in 2011 and 2012. The sites surveyed were Van Wagner Marsh (amphibians in 2011), Rosedale Marsh (amphibians in 2011 and 2012, birds in 2011), and Compensation Area 2 (both 2011 and 2012). Where possible, we will compare our findings to URBAN`s.

ENH5 Monitoring

The wetland enhancement area within Red Hill Marsh (ENH5, Figure 1) was monitored during the 2011 and 2012 mid-summer season. The approach to monitoring this feature was similar to that used in the stormwater ponds. We installed 13 transects that extended from the edge of the vegetation within the channels to the top of the adjacent mounds, with 3 1m x 1m quadrats along each, as in the pond monitoring. This allowed for a more detailed and comprehensive survey of the vegetation within this important wetland feature. Data was collected and summarize in the same fashion as for the ponds.

1.1.1.3. LANDSCAPE MANAGEMENT PLAN

Ecological restoration works within the Red Hill Valley were undertaken by Kayanase, an ecological restoration contractor and native plant nursery based at Six Nations in Oshweken, ON. This new company employed science-based techniques and adaptive management, along with Haudenosaunee cultural values and ecological knowledge, to carry out this design-build restoration and enhancement project over a 6-year period (2007-2012). The preliminary design concepts, contained within the RHVP Landscape Design and Habitat Enhancement Plan (D&A 2005), were adopted and expanded by Kayanase to develop detailed design plans in order to guide the ecological restoration and landscaping works. These initial plans were augmented to account for invasive species, to test new approaches such as direct seeding of woody species, and to better utilize and improve the function of existing natural features. In doing so, a relatively large area (just over 100 ha) of the Red Hill Valley Study Area received restoration and enhancement treatments (Kayanase 2006). The following is a brief overview of the restoration plan and works undertaken. The Kayanase work was directed by City staff; D&A provided technical guidance on matters such as invasive species and 'free to grow' interpretation, but were not provided with any reports by the City after 2009. For a detailed account of the Kayanase work plan, refer to the Red Hill Valley Project Ecological Restoration and Landscaping Proposal (SNEOG 2006) and Red Hill Valley Ecological Restoration Detailed Design Plan Report (Kayanase 2006).

The overriding goals of the ecological restoration plan were to:

- Protect and conserve existing native plants and plant communities to the maximum extent possible;
- restore degraded habitat areas through sustainable ecological restoration efforts; and,
- increase the connectivity and size of natural habitat areas.

The detailed restoration plans were developed by initially conducting existing habitat assessments of all areas to be restored to identify and delineate existing environmental and habitat conditions which were used to define working Restoration Units (Polygons). Using this information, an appropriate Reference Model (i.e. Ecological Land Classification ecosite model) was chosen. Reference Models were based on 1) intact and/or remnant elements of healthy ecosites and vegetation communities with similar abiotic conditions within the RHV, 2) documented historical vegetation communities with comparable environmental conditions, and 3) adaptations of these existing or historical features based on sound ecological reasoning. Using these Reference Models, plant diversity and density metrics were applied to each Restoration Unit, and serve as restoration targets and objectives for each area.

In order to achieve the diversity and density targets applied to each restoration unit, a number of Restoration Templates were developed which included the plant species and quantities required to meet the targets. Restoration Templates include a range and diversity of species that may occur along a continuum of overlapping Reference Model community types. Therefore, each Restoration Unit was assured a minimum diversity and density of plant material, while allowing for a number of possible ecological communities (i.e. Reference Models) to develop over a long-term successional trajectory. Specific Reference Models and Restoration Templates are described in the RHVP Ecological Restoration Plan (Kayanase 2006).

Summaries of profiled areas are provided in Appendix 1, including an overview of site history, restoration works undertaken and key findings from monitoring work.

1.1.1.4. ADDITIONAL TERRESTRIAL MONITORING

Invasive Exotic Species (IES) Surveys (2009)

Following submission of the 2008 annual monitoring report, the City of Hamilton requested that D&A develop more detailed mapping of the extent of invasive exotic species (IES) along the riparian zone, to assist in the direction to be given to their restoration contractor. Field assessments and discussion with City and D&A staff familiar with the new creek channel and its landscaping were undertaken in the spring of 2009. A field protocol supported by GIS mapping was developed and applied.

The study area for the assessment of Invasive Exotic Species (IES) included the riparian zone of the lower Red Hill Creek, with some additional adjacent areas of concern. Using the framework provided by the existing creek transects, the riparian zone was split into 36 transect units (labelled according to the corresponding transect) approximately 250m in length, with five 50 m long IES sub-units within each on either side of the creek. Each IES sub-unit was field assessed by botanists to determine the presence and extent of IES, along with additional data used to estimate the successional stage of each IES sub-unit.

The IES data was compiled and analyzed to provide an overall value and condition for each IES sub-unit, then prioritized sub-units for intervention to manage invasive exotic species. Furthermore, the data identified which type(s) of IES are prevalent (grasses, clovers/vetches, trees/shrubs/ other herbs), and summarized additional abiotic factors affecting the establishment of native species (e.g. prevalence of bare soil, shade). The information was summarized, and mapped using GIS onto aerial photos.

Free-to-grow Monitoring (2012)

In 2009 and 2011 Kayanase conducted plot-based free-to-grow surveys in-pre-selected restoration polygons. The objective of these surveys was to identify restoration areas that were ‘free-to-grow’, i.e. areas that had a viable woody stem density/ha that met target densities outlined by Kayanase and the City of Hamilton. Once designated as ‘free-to-grow’, an area is considered capable of self-regeneration and thus does not require further restoration effort.

In 2012, Dougan & Associates was retained by the City of Hamilton to resample ten percent of the ‘free-to-grow’ plots sampled in 2011 (12 plots). The purpose of this resample was to produce a third-party verification of the free-to-grow results obtained in 2011, based on the exact methodology employed by Kayanase in their surveys. A separate report on findings was submitted to the City in 2012.

2. MAJOR FINDINGS

2.1.1. DFOCOA

__Riparian Vegetation__

Photos of each vegetation sampling transect were taken annually from approximately the same distance and aspect as those taken in 2008. This proved difficult due to bank erosion, and in some cases the line of sight was obscured by vegetation growth during the latter years of monitoring. However, the photos demonstrate substantial growth and transitioning of vegetation, in particular woody vegetation, along reaches of the creek, as well as changes in the composition of herbaceous vegetation. These photos also provide a visual record to track areas where the creek bank eroded or the channel migrated over the monitoring period. This provides useful information when evaluating quantitative monitoring parameters. Photographs documenting each year for two transects are shown in Figure 3 below.

The total number of vascular plant species observed in the immediate riparian zone between 2008 and 2012 totaled 311, of which 176 (56.6%) were native species, and 135 (43.4%) were considered exotic (Table 2). This percentage of native species was comparable to the average of ~56% observed across all years. The addition of new species observed between 2008 and 2012 was steady, increasing by approximately 25 species per year between 2009 and 2012, with the overall increase in the final year (2012) being primarily due to new records of native species. This finding suggests that species richness within the riparian zone was adequately captured given the timeframe for monitoring and the extent to which we sampled. The continued observation in increased native species richness successional changes in the riparian community.

Goodban (1996) listed 287 species occurring within riverine (2 species), marsh or meadow marsh (78 species), and deciduous floodplain woodland habitats (249 species) within the Red Hill Valley from surveys conducted in 1995 and earlier (Table 2). Some species occurred within multiple habitat types. This list was comprised of 221 (77%) native species, which is higher than the 56% we observed in the immediate area of the new creek. Both marsh and floodplain woodland habitats were dominated by native species, at 82% and 76%, respectively. The Goodban (1996) list included 129 native species and 26 exotic species not observed during our monitoring, whereas we observed 84 native species and 95 exotic species that were not listed in Goodban (1996). The two lists have 130 species in common, including 90 native and 40 exotic species.

Figure 3. Photo monitoring images for transects 15 (left) and transect 19 (right) from 2008 – 2012.

In terms of site-level floristic quality, the vascular plant list reported by Goodban (1996) had an FQI of 53.96, whereas our list value was 47.71.This 6 point difference was due to a higher richness of native species recorded in the Goodban study (221 vs. 176). We observed a slightly higher average coefficient of conservatism (3.63 vs. 3.58), suggesting a slightly higher affinity of species for specific natural habitats (Oldham et al. 1995); however, this difference nominal. Furthermore, the FQI does not take into account exotic species, which have apparently increased over historical conditions.

Table 2. Comparison of species richness by growth form and native status, and Floristic Quality, between surveys conducted by Goodban (1996) and D&A (2008-2012) for Riverine, Meadow Marsh, and Deciduous Floodplain Forest Habitats within the Red Hill Valley.

Origin	Dougan	Goodban	Species in Common to Both Studies
Native Species	176	221	90
Exotic Species	135	66	40
Total Species	311	287	130
Floristic Quality Assessment			
Sum Coefficient of Conservatism (CC)	633	791	-
Average (CC)	3.60	3.58	-
Floristic Quality Index (FQI)	47.71	53.96	-
Growth Form			
Ferns	1	7	1
Forbs	182	154	69
Grasses	34	24	13
Rushes	4	5	3
Sedges	19	24	9
Shrubs	34	38	19
Trees	24	26	11
Herbaceous Vines	9	4	2
Woody Vines	4	5	4

In terms of growth forms, both lists are dominated by forbs (i.e. broad-leaved herbaceous flowering plants). We documented more forbs, grasses, and herbaceous vines than Goodban (1996); however, his study documented a higher richness of ferns, rushes, sedges, shrubs, trees, and woody vines which is not surprising given the focus of our monitoring (immediate creekside environment) vs Goodban's broader habitat coverage.

The overall richness of native species was higher within the riparian habitats of the Red Hill Creek historically (pre 1996) than detected in the post-construction monitoring of the Red Hill Expressway (2008-2012).These findings do not imply a loss of some native species (i.e.129 native species reported by Goodban were not encountered during our monitoring), or the introduction of new exotic species not previously recorded (95 species). Rather, the habitat in the immediate vicinity of the reconstructed channel is in a younger successional state than the historic Red Hill Creek, and it is expected that more disturbance-tolerant and early-successional species, which are typically exotic, would be more frequently encountered during our monitoring. D&A monitoring was focused on the immediate riparian zone of the reconstructed channel (Figure 1), whereas Goodban (1996) encompassed more extensive habitat areas within the valley. The Goodban (1996) data also included previous observations from historic data sources, reported between 1976 and 1995. As a result, the coverage in Goodban (1996) was more comprehensive in terms of habitat coverage, which would increase the number of species observed.

Variation in mean overall species richness at the plot level was not significantly different between years for 'even' or 'odd' numbered transects. Species richness was highest in 2009 (even) and 2010 (odd), and lowest in the final sampling year (2012) for both sets of transects. The results for native species richness were consistent with these findings, with a decline in richness over the 5-year monitoring period, but these changes were relatively minor and more likely reflect temporal variation in patterns of succession rather than long-term trends. These trends reflect literature findings for old field succession over time (Prach et al, 2007). It should be noted that most areas of the Red Hill Creek Valley, including the Escarpment / King's Forest area as well as the downstream floodplain and many valley slope areas, were affected at various times since settlement by clearing, intensive agriculture, monoculture plantations, land filling, utility corridors, and infrastructure works. In essence the valley ecosystem has been in a perpetual recovery mode. The restoration of flooding and natural channel functions due to the creek reconstruction, and restoration works (including plantings by Kayanese of more than 240 native species) have long term implications for species richness that extend well beyond the 5-year timeframe of this monitoring program.

In terms of spatial patterns, variation in species richness was higher among plots nested within transects than among transects, regardless of the year or subset of transects analyzed (i.e. odd or even numbered transects). This implies that processes occurring at the local scale (e.g. environmental variation within individual transects) were more influential on species richness than differences among transects (e.g environmental variation among creek reaches). We found that in some years, species richness was slightly higher for plots farthest from the creek (i.e. top of bank) than those closest, though this relationship was not statistically significant. Disturbance processes, such as erosion and deposition, play a strong role in limiting species richness along the creek banks by constraining vegetation establishment, or removing fragile-rooted cover (e.g. Figures 4 and 5). The Red Hill Creek experiences strong storm event flows due to the urbanized watershed and presence of steep gradients just below the Escarpment, resulting in localized reaches where active erosion and deposition are accentuated. Significant flow events occurred in 2009 and 2012 that exceeded the 100 year event in magnitude, resulting in overbank flooding and bank scouring in the upper reaches.

Figure 4. Extensive erosion of the creek channel and embankment following the flood on July 29th, 2009. King's Forest between transects 2 and 3.

Figure 6 shows standardized values for the 3-year average of species richness, proportion of native species, FQI, Shannon Diversity Index, and ground cover at each transect along the creek. Values above 0 are above the average observed for the whole site, and values below 0 are below average. The 'cubic splines' (smoothed lines) show longitudinal patterns for each metric based on predicted values. The proportion of native species, ground cover, and the proportion of native species each increased along the length of the creek, whereas FQI, Species Richness, and the Shannon Diversity Index were each lowest across specific reaches of the creek. Below-average FQI values coincide with transects that either had few native species, or had native species with low Coefficients of Conservatism (i.e. "weedier" species). For instance, the lowest FQI observed was between transects 5 -7, located within the King's Forest Golf Course. Riparian plantings were limited in this area, particularly of woody species (Figure 5). As a result, non-native species have persisted, with lower opportunity for recruitment or establishment of native species, thus depressing the FQI below average. This area is also more affected by major flow events than down-stream reaches, as indicated by below-average ground-cover, inhibiting the establishment of a native-dominant riparian vegetation community (Figure 5).

Transects 32-35 were also lower in terms of species richness and Shannon diversity, though they maintained a high proportion of native species, ground cover, and FQI. This pattern is expected through this section of the creek as these transects are located largely within riparian wetlands, including the Red Hill Marsh (transect 32) and riparian fringe wetlands downstream (transects 33-37), and are dominated by relative monocultures of native species such as Cattails (*Typha latifolia* and *T. angustifolia*), water smartweed (*Polygonum amphibium*), Bugleweeds (*Lycopus sp*), Reed Canary Grass (*Phalaris arundinacea*), and Softstem Bulrush (*Schoenoplectus tabernaemontani*).

Figure 5. Red Hill Creek post-flood event on August 9th, 2012 showing extensive scouring of the channel bank and loss of vegetation in King's Forest Golf Course.

The average of all scores combined increased with transect number, indicating that overall riparian community quality increased from the high-energy, more frequently disturbed reaches of the upper Red Hill Creek, to the lower-energy, more stable reaches of the lower Creek. Though individual transects results are highly variable, transects 1-13 are generally below-average in terms of species richness, native dominance, FQI, Shannon diversity, and ground cover, whereas transects 14-37 are at or slightly above-average. These patterns are likely due to the increased vulnerability of the upper channel reaches to channel disturbances, in particular through and above the golf course (Annable et al. 2012, Figure 5), as well as limitations on restoration efforts and less opportunity for natural recruitment of higher-quality native species.

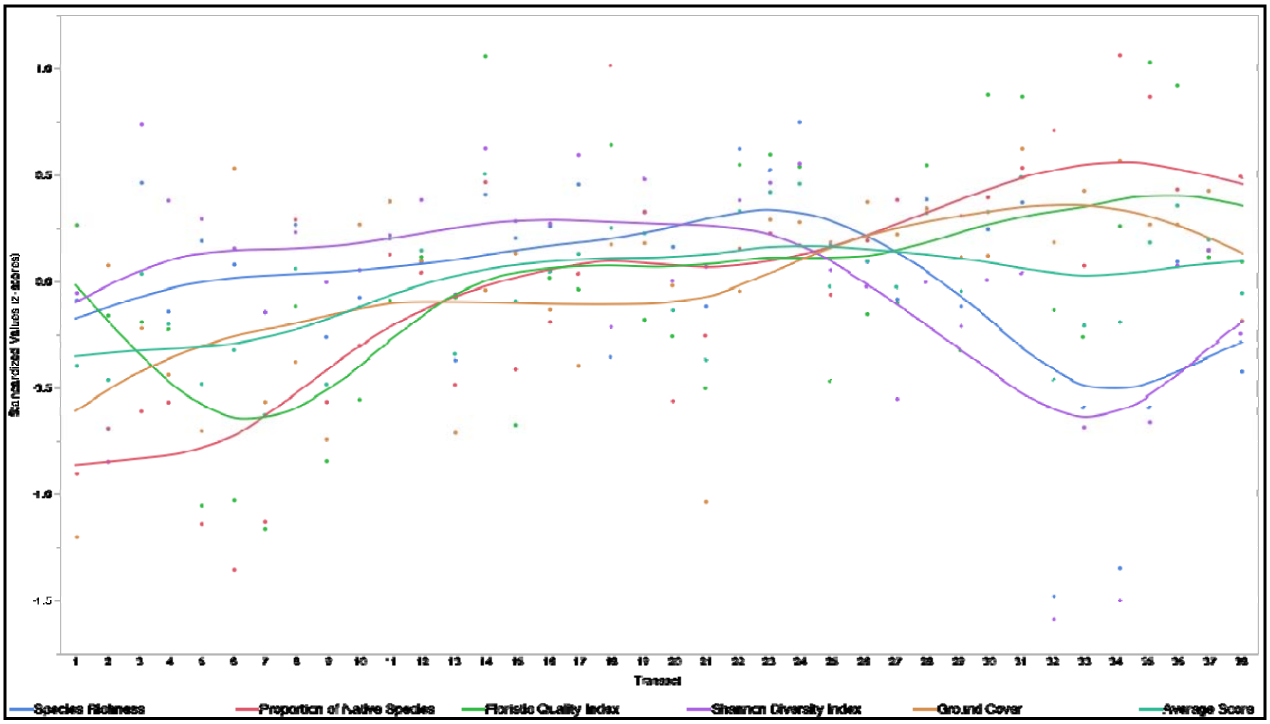


Figure 6. Standardized scores (z-score) for mean species richness, proportion of native species, FQI, Shannon Diversity Index, and Ground Cover by transect. Individual points are averages for each transect across 5 monitoring years.

In addition to the metrics discussed above (i.e. species richness, floristic quality, etc), the change in relative importance of the species observed is a good gauge of changes in community composition. Because relative importance incorporates species abundance in addition to presence/ absence, it can be more sensitive to community changes on shorter time-scales. Furthermore, it identifies which specific species are important, or are changing in importance through time. As shown in Table 3, we observed an increase in the cumulative importance of the top-20 ranked species between 2008 and 2012, with a slight decline in the years 2010 and 2011. The spike in relative importance in 2012 is due to an increase in the frequency and importance of exotic species, which was the highest for all of the monitoring years. The years 2009 and 2010, both the second round of monitoring for even and odd transects, showed the highest incidence of top-ranked native species and the highest cumulative importance for native species.

Table 3. Cumulative Relative Importance Values (RIV) for the top 20-ranked species in each monitoring year.

Year (group)	RIV of the top 10 species			Number of species	
	Total	Exotic	Native	Exotic	Native
2008 (all)	56.00	22.34	33.65	10	10
2009 (even)	56.14	13.60	42.54	6	14
2010 (odd)	55.64	12.10	43.53	6	14
2011 (even)	55.84	14.87	40.97	8	12
2012 (odd)	59.28	22.51	36.77	9	11

Wetland Compensation and Stormwater Pond Vegetation

The total number of vascular plant species observed in stormwater management ponds and wetland compensation areas from 2009 to 2012 was 247; not including those specimens identified only to genus (45). The percentage of native species observed over the monitoring period was 57%, and was consistent with each year of monitoring (min= 56.0% in 2011, max = 58.3% in 2010). This suggests that species richness within these features was stable across the 4 years of monitoring, with native species being slightly dominant over exotic species. For details regarding the conservation status and rarity of species recorded, please see Appendix F7 in the 2012 annual monitoring report.

The number of new species observed in ponds each year declined from 67 in 2010, to 44 in 2011, and 28 in 2012. Cumulative species richness across all features continued to increase with each year of sampling through to 2012. Therefore, our estimates of species richness at the site-level for stormwater management facilities and wetland compensation areas are likely conservative. Average species richness within ponds increased annually to 2011, then dropped significantly in 2012. This drop in average species richness was due to fewer native species primarily, though the number of exotic species also declined over the four monitoring years as well. Average FQI also decreased from 2009 (4.07) to 2012 (3.40), though annual changes were insignificant.

2.1.2. IADP

Ecological Land Classification (2010-2012)

Vegetation community mapping was updated over the five year monitoring period for the Red Hill Creek Valley Study Area and for selected areas in the Red Hill Creek watershed in 2012, to determine the extent to which land cover had changed between the 1997 Watershed Study and 2012 conditions. This work was primarily scoped to focus on wetlands and areas transitioning to wetland ecotypes in the Valley, either due to natural succession or restoration work. The original cover mapping was prepared prior to the adoption of the MNR's Ecological Land Classification system (introduced in 1998) and was reliant in part on vegetation cover mapping contained in the 1995 Red Hill Biological Inventory (HFN 1995) which was adopted for the Parkway planning and design studies (including the 2003 Final Impact Assessment Report – Terrestrial Resources) since it was the most current available information.

The most significant changes in the Red Hill Creek Watershed between 1997 and 2012 were in aquatic ELC cover types (OAO, SAF, and SAS), which increased from approximately 4.62ha to 34.08ha (638% increase) and shoreline (BBO) communities. The increase in open aquatic communities was due to specific wetland creation projects (Comp1 and Comp2, and new wetland in the vicinity of the Escarpment Viaduct), the construction of numerous stormwater management facilities within the Valley and in the upper watershed, and conversion of several sections of the former creek to stormwater management functions.

Agricultural (AGR) and successional (BLO, CUM, CUT, and HR) communities decreased in area between 1997 and 2012. Agricultural lands have undergone urban development above the Escarpment, which has contributed to this change. Successional communities also decreased over this time period by 50ha (-7% of 1997 area), which is explained in part by increases in anthropogenic woodlands (32.92ha to 119.78ha) and anthropogenic open space (481.37ha to 572.36ha). There was a slight net increase of natural woodlands and forest (0.34ha; 0.09%) between 1997 and 2012, despite continuing development within the watershed. The distinction of successional communities under the ELC is also more refined than was the case using the pre-ELC 1995 mapping.

Prior to construction of the Parkway in 2003, wetland vegetation communities were estimated at 13.28 ha of the Parkway Study Area shown on Figure 1, while aquatic communities occupied 19.02 ha. Wetland communities were more extensive prior to the urbanization of the Red Hill Creek Watershed; Snell (1987) estimated that there was 76.4% wetland loss in Hamilton-Wentworth since settlement; as of 1997 wetland cover constituted only 0.3% of the Red Hill Creek Watershed. The total estimated area of wetland cover within the Red Hill Creek watershed as of 2012 was 61.05 hectares.

The Terrestrial Resources IADP Report (Dougan & Associates, 2003) was based on preliminary design of the Parkway, Creek and QEW works, and predicted a 5.04ha loss of wetlands (3.3ha in Study Area 1, Mud Street Interchange to the CNR; and 1.74ha in Study Area 2, CNR to the QEW). At the time of the detailed design in 2005, the estimated loss of wetlands within the project study area (including fish habitat) had increased to 5.22 ha (estimate on file with Dougan & Associates, 2005). Based on the recommended minimum 2:1 replaced ratio identified in the

IADP, this would require the creation of 10.45 ha of new wetland through the construction of stormwater management facilities (wet ponds, wetlands, and grass swales), regular floodplain inundation through the restoration of natural channel processes, and conversion of the abandoned channel sections into wetlands.

Based on cover mapping that was re-classified under ELC and progressively updated during the monitoring project, overall wetland cover in the Parkway Study Area increased from 20.32 ha pre construction, to 27.54 ha as of 2012. This gain in 7.22 ha includes 2.76 ha of open and shallow aquatic communities constituted by SWM facilities. The gain of new, non-SWM wetland within the Parkway Study Area was 4.47ha; functional enhancement works within the Red Hill Marsh treated a further 3.23 ha, considered equivalent to a 50% gain (1.62 ha – not included in total area gain) based on the 2005 estimates. Table 4 summarizes the relative gains and losses by ELC types.

In a separate project, approximately 11 ha of wetland was created within Windermere Basin between 2010 and 2012, providing a restored estuarine ecosystem with wildlife habitat and recreational trails within this highly industrialized area of the lower watershed. The restored basin includes three wetland zones across an aquatic-upland gradient with both terrestrial and aquatic habitat features for species such as Common Tern, Northern Pike, Large Mouth Bass, and White Sucker. The Windermere Basin project included a barrier to Common Carp, an introduced fish species that has constrained the spread of emergent marsh cover in Comp1 and Comp2, as well as in Enh5. This feature complements the restoration and enhancement works completed upstream in the Red Hill Marsh (Enh5), plus the Comp1/Comp2 wetland creation, thereby providing more overall habitat for wildlife, and improving connectivity of the riparian and wetland habitats along the lower Red Hill Creek, and to the Lake Ontario shoreline.

Factoring in the Windemere Basin works, the overall increase in wetland area (not including SWM facilities and Enh5 enhancement) has achieved 15.47 ha, compared to the 10.45 ha targeted in 2005. This represents a 76.17% increase in wetland cover within the Red hill Valley.

Table 4.Summary of change in vegetation cover types between 1997 and 2012 within the Parkway Study Area.

Wetland Type	ELC Code	2003		2012		Change in Area from 2003 to 2012	
		Area(ha)	%Cover*	Area(ha)	%Cover*	Area(ha)	% Change
Swamp Thicket	SWT	0.00	0.00	1.27	0.17	1.27	-
Deciduous Swamp	SWD	0.68	0.09	1.69	0.23	1.01	149
Meadow Marsh	MAM	2.65	0.36	2.7	0.36	0.05	2
Shallow Marsh	MAS	9.95	1.34	7.23	0.97	-2.72	-27
Open Aquatic	OAO	2.19	0.29	11.36	1.53	9.17	419
Shallow Aquatic	SAS	4.84	0.65	0.53	0.07	-4.31	-89
Total		**20.31**	**2.73%**	**24.78**	**3.33%**	**4.47**	**22%**
Other Features**							
Open Aquatic (SWM Ponds)	OAO	-	-	2.32	0.31	-	-
Shallow Aquatic (SWM Ponds)	SAS	-	-	0.44	0.06	-	-
Red Hill Marsh Enhancement (Enh5)	MAS	-	-	1.62	0.22	-	-
Total				**4.38**	**0.59**		

* Percentage of total estimated Parkway Study Area, calculated as 744.71 ha in the 2003 IADP, based on the 1997 Watershed Study mapping.
** Not included in wetland change total.

Figure 7. Shallow marsh developing within former floodplain forest near Rosedale Park following restoration. Photo taken July 4th 2014.

Figure 8. Ecological Land Classification for Red Hill Creek Project Study Area

Ecological Monitoring and Assessment Network Plots (2010)

A total of 92 vascular plant species were detected within the permanent vegetation plots (Figure 1) sampled in 2010, including specimens identified to genus only (8 in total). Of the total identified to species, 57 (67.9%) are native species, and 27 (32.1%) are considered exotic. No species of conservation concern were recorded.

In terms of total species richness, the plot containing the highest species diversity was Forest Plot 1, which is located on the Niagara Escarpment near Buttermilk Falls, while the lowest diversity plot was in Forest Plot 3. The total Floristic Quality Index (FQI) for these plots also ranged considerably, from 6.42 for Forest Plot #6 to 18.14 for Forest Plot #1. The transects established at Van Wagner's Beach showed a low FQI for the site, due primarily to a high proportion of exotic species (60%), which reflects the level of human disturbance in this area. The northern half of Van Wagner's Pond showed a high proportion of native species (88%) and a moderate FQI value (9.22), however, overall species richness was not high (17 species in total).

Wildlife

During the surveys conducted by Dougan & Associates in 2010, forty-two (42) species of birds were detected. Of these, 39 were considered as possibly breeding or on territory. Great Blue Heron, Black-crowned Night-Heron and Turkey Vulture were detected flying over the study area, but would not be considered breeding in the vicinity. Of the 39 breeding species, two are introduced (non-native): European Starling and House Sparrow. Eastern Wood-pewee is listed as Special Concern by COSSARO (COSSARO 2013) and COSEWIC (COSEWIC 2012), and Wood Thrush is listed by COSSARO as Special Concern (COSSARO 2013) and Threatened by COSEWIC (COSEWIC 2012). Of the remaining 35 species, none are designated as species at risk by COSEWIC or OMNR (COSEWIC 2014; OMNR 2009), and most are considered either common or abundant, and widespread, within the City of Hamilton (Curry 2003). The only exceptions are Wood Duck, Green Heron and Belted Kingfisher, which are considered uncommon and widespread within the City (Curry 2003).

At a regional level, six species – Belted Kingfisher, Northern Flicker, Eastern Wood-Pewee, Wood Thrush, Rose-breasted Grosbeak and Baltimore Oriole – have been designated by Partners in Flight as priority landbird species in BCR 13 (Lower Great Lakes/St. Lawrence Plain) (OPIF 2006); BCR 13, the Lower Great Lakes – St. Lawrence Plain, corresponds roughly with the area south of the Canadian Shield. Partners in Flight, from which the list of priority landbird species was obtained, is a coalition of government agencies and organizations led by Environment Canada Ontario Region (EC) and the Ontario Ministry of Natural Resources (OMNR), in partnership with Bird Studies Canada (BSC).

Figure 9. Red-tailed Hawk on a raptor perching pole on north side of the Red Hill Creek near transect 13. Photo taken June 3, 2011.

The highest level of breeding evidence obtained was fledged young seen of the following five species: American Robin, European Starling, Northern Cardinal, Song Sparrow and Common Grackle. The second highest level of breeding evidence was probable breeding, represented by territorial males, based on being present singing at the same location on both surveys, and pairs. This evidence was obtained for 15 species: Great Crested Flycatcher, Warbling Vireo, Red-eyed Vireo, Blue Jay, Northern Rough-winged Swallow, House Wren, American Robin, Gray Catbird, Cedar Waxwing, Yellow Warbler, Song Sparrow, Northern Cardinal, Red-winged Blackbird, Baltimore Oriole and American Goldfinch. The next highest level of breeding evidence was possible breeding, represented by singing males; this evidence was obtained for 25 species. For details on the breeding bird surveys, please see Appendix F16 in the 2010 annual report.

Figure 10. Juvenile Black-crowned Night Heron utilizing riparian habitats along the lower Red Hill Creek. Photo taken April 4 2010.

Additional breeding bird monitoring was completed by URBAN in 2011 within close proximity to our B9 site (Figure 1), which is located near Rosedale Marsh. At this location, we detected the same number of individuals in 2010 as they did in 2011, however the average number per point count was lower for their surveys (Table 5).

Table 5. Comparison of breeding bird data collected by Dougan & Associates and URBAN at Station B9.

Indicator	D&A (2010) ($1^{st}/2^{nd}$ survey)	URBAN (2011)
Total Number of Birds	16 / 14	16
Average Number of Birds per Point Count	15	8
Total Species Richness	8 / 10	5
% Wetland-Dependent	0	0

Four species of amphibians were detected during the three nocturnal amphibian surveys conducted in 2010: American Toad, Gray Treefrog, Green Frog and Northern Leopard Frog. All four species are considered abundant within the City of Hamilton (Lamond and Duncan 2003). Green Frog was the most widespread, detected at eight of the 12 point counts, while Northern Leopard Frog was the least widespread, detected at only three of the 12 point counts. Gray Treefrog and American Toad were detected at eight and seven of the 12 point counts, respectively. The only point counts to have all four species present were A9 and A12.

Amphibian surveys by URBAN were competed at 3 of the same locations sampled in 2010 RHVP monitoring, but in 2011 and 2013. These locations included A1 (Van Wagner's), A11 (Rosedale Marsh), and A5 (COMP 2; see Figure 1). At A1, URBAN detected only Gray Treefrog in 2011 and 2013 at moderate abundance, whereas we detected only Greenfrog at moderate abundance in 2010. At A11, URBAN detected two additional species (Wood Frog and Spring Peeper) in 2011 and 2013 than we did in 2010 (Gray Treefrog, Green Frog, and American Toad), increasing the species richness from 3 to 5 species at this site. However, abundance for all species was low across all years at this location. At station A5, URBAN observed

It should be noted that some of the point counts, especially those adjacent to the Queen Elizabeth Way (Q.E.W.) (A1, A2, A3, A4 and A5), were particularly noisy, even late at night. This may have affected both the species and number of individuals detected.

Additional wildlife species were noted incidentally during creek monitoring, including Milksnake (observed near transect 18 during the creek monitoring), Green Heron (foraging along marsh edges in Red Hill Marsh), Peregrine Falcon (nesting on a hydro wire structure near Van Wagner's Ponds), Red-tailed Hawk (Figure 9), and Black-crowned Night Heron (Figure 10).

Two McMaster University undergraduate students have done follow-up studies related to wildlife utilization of the Escarpment viaduct. Christina Huminski (2007) devoted her honours thesis project to a Fall 2006 wildlife assessment, focused on the 17 artificial trees constructed beneath the viaduct. While she was unable to demonstrate that Southern Flying Squirrels (SFS) were utilizing the structures, she found evidence of activity of dogs, deer and raccoons at 9 of the 17 structures, and postulated that SFS might be avoiding the structures due to lack of vegetation cover. Subsequently City of Hamilton staff consulted with other SFS researchers and added cross-beams with protective plastic tubes to provide more cover for SFS that could be using the structures, as they are cavity-users and actively avoid exposure to nocturnal predators such as owls and raccoons. On March 12, 2012, the Hamilton Spectator published an interview with another McMaster biology student, Ashley Cantwell, who had documented suspected SFS using the structures, using an infrared automatic camera. In preparation for this Executive Summary report, we contacted Dr. Pat Chow-Fraser at McMaster, who indicated that other than the work by URBAN (see above), no further monitoring studies have been completed on the SFS or other wildlife.

2.1.3. LANDSCAPE MANAGEMENT PLAN

Restoration Activities

No annual report of Kayanase restoration activities was provided to Dougan & Associates by the City beyond the 2009 monitoring season. We reviewed the Kayanase stock and planting records provided to date by the City of Hamilton to provide this brief summary.

Based on GIS data provided by the City of Hamilton, the total treatment area within the Red Hill Valley Project was 100 hectares, and involved 305 distinct restoration units with an average size of 0.33ha (Figure 11; Table 6). The areas restored extend from the Lincoln Alexander Parkway to the Lake Ontario Shoreline, and included early successional, thicket, and forested communities within escarpment, riparian, wetland, and shoreline environments. Nearly half of the areas restored were based on template 1; however, there is considerable overlap in target community types between each template. Table 6 provides a summary of each restoration template in terms of coverage and species richness.

Figure 11. Ecological Restoration Sites based on mapping by Kayanase from 2008 - 2012.

Table 6. Summary of Restored Areas within the Red Hill Valley, 2008 - 2012

Template	Target ELC Ecosite*	Total Area (ha)	Restoration Units (# of polygons)	Species Richness by Canopy (Trees, Shrubs, Herbaceous)
1	FOD2, FOD3, FOM2, FOM4, FOM5	46.57	104	Open: 22, 33, 42 Partial: 25, 43, 61 Closed: 10, 14, 18
2	FOD7, FOD8, FOD9, FOM5, SWM3	19.28	73	Open: 27, 28, 48 Partial: 31, 33, 75 Closed: 12, 13, 24
3	FOD1, FOD2, FOD3, FOM5	0.80	4	All: 5, 31, 7
4	CL, AL, TAS/TAT1	9.67	32	Open: 23, 34, 43 Partial: 23, 43, 69 Closed: 10, 13, 31
5	FOD2, FOD3, FOD9, FOM2, FOM4, FOM5	2.47	17	All: 16, 23, 62
6	NA	0.55	1	NA
NPS	NA	6.31	26	NA
Special Case	e.g. Baltimore Fen	13.52	44	9, 11, 31
TB	NA	0.87	4	NA
Total		100.03	305	See text for full summary

* FOD1 - Dry-fresh Red Oak Deciduous Forest, FOD2 - Dry-Fresh Oak Maple Hickory Deciduous Forest, FOD3 - Dry-Fresh Poplar-White Birch Deciduous Forest, FOD7 - Fresh-Moist Lowland Deciduous Forest, FOD8 - Fresh-Moist Poplar Deciduous Forest, FOD9 - Fresh-Moist Oak-Maple-Hickory Deciduous Forest, FOM2 - Dry-Fresh White Pine-Maple-Oak Mixed forest, FOM3 - Dry-Fresh Hardwood-Hemlock Mixed Forest, FOM4 - Dry-Fresh White Cedar Mixed Forest, FOM5 - Dry - Fresh White Birch-Poplar-Conifer Mixed Forest, FOM7 - Fresh-Moist White Cedar-Hardwood Mixed Forest, SWM3 - Birch-Poplar Mineral Mixed Swamp, SWD1 - Oak Mineral Deciduous Swamp, CL/AL - Carbonate Cliff Rim and/or Alvar, TAS/TAT1 - Shrub Talus and/or Treed Talus

From 2007 to 2012, 242 locally sourced native species were seeded or planted by Kayanase in restoration areas within the Red Hill Valley (Figure 5). Among these species, 60 families were represented, with the most species-rich groups being the asters (Asteraceae; 33 species), the rose family (Rosaceae; 23 species), and the sedge family (Cyperaceae; 20 species). Within these families, 129 genera of plants were represented with the most species-rich being the sedges (Carex; 17 species). Forbs were the most common growth form represented, with 112 (46%) species, followed by 41 shrubs species and 40 tree species. Grasses, sedges, rushes, ferns, and woody and herbaceous vines were also widely planted. During riparian vegetation monitoring, we encountered 75 of the 242 (31%) species planted.

Invasive Exotic Species (IES) Surveys (2009)

The conditions determined for each IES sub-unit were mapped by D&A, along with species of particular concern, and accompanied the 2010 annual report. As of the 2009, most (88.7%) of the areas surveyed in the riparian zone of the Red Hill Creek had moderate to high levels of invasive exotic species according to our rating system. A small number of areas had healthy, native dominated cover, or required further monitoring due to their early successional stage. The most problematic species included Common Reed (*Phragmites australis*), Reed Canary Grass (*Phalaris arundinacea*), Crown Vetch (*Coronilla varia*), Sweet Clovers (Melilotus spp.), Manitoba Maple (*Acer negundo*), Tatarian Honeysuckle (*Lonicera tatarica*), Common Buckthorn (*Rhamnus cathartica*), Black Locust (*Robinia pseudo-acacia*), exotic Willows (Salix spp.), Garlic Mustard (*Alliaria petiolata*), and Dames Rocket (*Hesperis matronalis*). A complete list of problematic species was provided to the City of Hamilton, along with mapping of the riparian zone along the Red Hill Creek with ratings based on the severity of infestation. As a result of this work, many of the most problematic species and areas were subsequently treated during restoration works by Kayanase. Despite this, many invasive species persist, in particular exotic grasses and shrubs.

Free-to-grow Monitoring (2012)

Our resampling of the 'free-to-grow' plots was completed on May 17th, 24th and 30th, 2012. We found that, of the 12 plots resurveyed 2012, 11 exceeded the Kayanase estimates for stem density (stems/m^2) taken in 2011, confirming their status as 'free-to-grow' according to the density criteria. Though our estimate was lower than Kayanase's for the remaining plot, all were above the threshold for 'free-to-grow' status.

3. LESSONS LEARNED

This executive summary outlines the methods and key findings from 5 years of monitoring terrestrial ecology. Here, we discuss the primary outcomes and lessons learned as a result of this monitoring work as well as the overall RHVP implementation.

Project Level Learning

The Red Hill Valley Project brought many innovations to the planning and implementation for a major regional highway project. These included:

- Completion of the 1997 Watershed study to guide preliminary design; this produced a comprehensive Action Plan from public and interdisciplinary consultations and resulted in significant design changes for the Parkway and associated infrastructure works;
- The IADP provided a detailed focus on ecological issues such as significant habitats and species, wildlife corridors, regional bird migration, road noise, road salt, and identification of ecological restoration opportunities; it also identified precedent-setting targets for wetland and general habitat compensation on a watershed basis, and prescribed monitoring at both project and watershed scales;
- The RHVP Landscape Management Plan paralleled the IADP process and effectively combined Parkway and creek construction with a range of landscape restoration initiatives that addressed Watershed Action Plan and mitigation principles and objectives, encompassing many areas such as landfill re-use, trails, and wetland impact mitigation.
- The Detailed Design of the Parkway and QEW works, CSO, stormwater management systems, landfill re-use and trail system works, all built upon previous experience (i.e. Lincoln Alexander Parkway landscape performance, Dartnall Road Interchange) and integrated IADP and LMP principles and objectives, allowing testing and improving a variety of innovative approaches for

environmental protection and management, construction, and impact mitigation.

- The negotiation and assignment of Kayanase's ecological restoration role in the project was pivotal to the initiation of numerous site-specific and science-based approaches, with more than 300 polygons treated, representing the targeted 100 ha of works to compensate for Parkway and Creek relocation works. Kayanese has continued to be a leading practitioner in habitat restoration in southern Ontario;
- The strategy of separating the major terrestrial mitigation efforts from the Parkway construction was a success in allowing enough time (5 years) to implement and follow up on a variety of measures (such as invasive species management and custom native species propagation and planting) which will continue to provide benefits as the restored communities undergo succession and proliferation;
- The City's engagement of an Environmental Coordinator enabled efficiencies, integration for synergies with other City projects, and follow-up between numerous construction and mitigation activities.

Terrestrial Monitoring Program Learning

The terrestrial monitoring work completed within the Red Hill Valley, in particular along the riparian zone of the reconstructed creek, provided an opportunity to observe ecological changes within a naturalized urban system. The primary findings from this work include:

- The riparian monitoring and underlying planting and restoration works achieved the terrestrial goals of the DFO Authorization. The Cumulative Relative Importance Values (Table 3) indicate that native (indigenous) species dominated the immediate riparian zone when monitoring was initiated in 2008, and this dominance was maintained up to the end of monitoring in 2012.
- In terms of spatial patterns, we observed increased native species presence, floristic quality, and ground cover from transect 1 (upper Red Hill Creek) to transect 37 (lower Red Hill Creek). However, there was significant variation within and between transects in each of these metrics. This indicates spatial patterns in community composition at multiple scales (i.e. the watershed, reach, and creek

bank). Species richness and Shannon Diversity Index were relatively stable along the length of the creek, but decreased through specific reaches along the lower creek due to relatively stable conditions and resultant lower environmental heterogeneity.

- Minor temporal changes in the structure and composition of the riparian vegetation community were observed between 2008 and 2012. We saw variation between years that likely reflects year-to-year environmental variation as much as successional changes in the riparian vegetation community. The monitoring time frame was relatively short, however, and represents primarily the early-successional stages of the various plant communities present. Declines in species richness in early successional communities may be expected ~5 years after disturbance due to the establishment of long-lived perennials and competitive exclusion of early-colonizing species (Prach et al. 2007). However the flow dynamics of the creek are a factor which triggers more volatility of diversity in areas where more extreme flow effects are experienced. The continued availability of native plant propagules to re-populate disturbed bank areas is a key requirement to ensure a resilient native flora throughout the creek system; however, adequate riparian habitat that is unconstrained by conflicting landscape maintenance objectives (such as golf course and recreational playing field maintenance) is also essential to maintain sites that perpetuate the species that are more adapted to volatile conditions. Our findings suggest that the upper reaches would benefit from more extensive riparian habitat.
- Disturbances due to ongoing natural and anthropogenic factors are important factors influencing establishment of vegetation and the stability of vegetation communities within the riparian zone of the Red Hill Creek. Before the Parkway and creek construction, most of the valley had undergone significant disturbances since settlement. The flood events that occurred in 2009 and 2012 demonstrated the character of potential catastrophic flow events, and also highlighted areas most sensitive to these events, which are primarily in the upper valley. At smaller scales, human impacts such as the creation of informal trails and disposal of garbage (e.g. shopping carts) may be compromising the function of the constructed channel and extensive restoration works that have

been completed. Anecdotal evidence suggests that these trails have an impact on species richness and abundance through trampling and soil compaction, which may subject the creek bank to further erosion and degradation.

- Recurring flooding and creek bank erosion also posed technical challenges to monitoring, as many of the t-bars used to mark permanent vegetation transects were washed out. This made relocation of these plots difficult and time consuming. The changes to the creek bank morphology as a result of these events also resulted in the loss of several plots along the edge of the creek, which could not be resampled. Future monitoring of this kind should incorporate such unpredictability into the sampling design in such a way that these forms of disturbances are accounted for as both technical factors and causal processes.
- Stormwater management facilities were consistently native-dominant (57%) across the 4 years of monitoring, but varied from year-to-year in composition. Based on species accumulation, our estimate of site-level species richness is likely low. Because these facilities function to store water and regulate hydrology within the RHV, the environment within these ponds (e.g. water level, nutrients) likely changes annually based on factors such as precipitation. As a result, species composition will shift annually as opportunities for colonization are presented during dry years where water levels are low, or limited during wet years by high-water levels.
- Restoration work completed by Kayanase has resulted in the creation and enhancement of approximately 100ha of upland, riparian, and wetland habitats within the Red Hill Valley. This work involved site preparation (i.e. soil amendments, invasive species removal, and enhancement of topography), planting and seeding, and free-to-grow monitoring. The 242 native species used were taxonomically and functionally diverse, and were sourced from within xxkms of the Red Hill Valley to ensure that locally-adapted genotypes were represented. We detected 31% of these species while monitoring riparian areas of the Red Hill Creek.
- The targeted 2:1 wetland gain within the RHVhas been exceeded, including RHVP works and the Windemere Basin wetland creation,

with a total gain of 15.47 ha. Watershed wetland cover now is 39.59ha, compared to 22.83ha in 1997.
- Wetland succession has been impeded by impacts from Common Carp. The potential to restrict access for this introduced species was first attempted in Cootes Paradise and its exclusion was determined to be very beneficial to wetland diversity. The wetland creation completed in Windemere Basin in 2011 has also applied a carp barrier. In the lower Red Hill Valley there are several key opportunities for carp exclusion; in particular Comp1 and Comp2, new back channels created within Enh5 (Red Hill Marsh), and the north Van Wagner's Pond along with connecting waterways would all benefit from carp elimination.

3.1. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings from this study, we offer the following conclusions and recommendations relating to ongoing biological monitoring at the site:

1. High-disturbance areas of the RHC (i.e. upper reaches) would benefit from further restoration work focused on providing greater bank stability and enhanced vegetation cover along the creek bank, which would aid in mitigating the effects of flooding and erosion. This would also promote the diversity and resilience of native species within these areas, increase connectivity between escarpment habitats and the lower reaches, and increase the overall quality of the riparian vegetation community.
2. Future monitoring at 5-10 year intervals is recommended to evaluate long-term changes within the riparian zone of the Red Hill Creek, and to better understand the success of the restoration efforts on a more ecologically meaningful time scale.
3. Invasive plant species are prevalent within the Red Hill Valley and were documented during this monitoring project; these include Common Buckthorn (*Rhamnus cathartica*), Garlic Mustard (*Alliaria petiolata*), Black Locust (*Robinia pseudoacacia*) and Common Reed (*Phragmites australis*) which were targeted by specific management

during the implementation of the Landscape Management Plan. In order to ensure the long-term ecological integrity of the Red Hill Valley, surveys for invasive or otherwise problematic species should be conducted as part of future monitoring to ensure that established populations and new introductions of these species are managed appropriately, and that action can be taken to eradicate or prevent their spread.

4. The wetland enhancement area within Red Hill Marsh (ENH5) should be further monitored to ensure that native plant species persist and continue to establish, as only two years of monitoring have been completed to date. Particular focus should be paid to invasive species such as Reed Meadowgrass (*Glyceria maxima*), which currently occupies a substantial area within the marsh, and Common Reed (*Phragmites australis ssp. australis*). Documenting and preventing the spread of these and other exotic invasive species will help ensure that the flora of Red Hill Marsh is predominantly of native species.
5. Monitoring of wildlife habitats would be valuable to assess the various created habitats and built initiatives (such as QEW culvert) to be evaluated to determine their effectiveness in supporting local wildlife populations and habitat functions. City staff had originally contemplated that university and college partners could become engaged in more extended wildlife monitoring. Currently, the Urban-Rural Biomonitoring & Assessment Network (URBAN) has engaged community volunteers to continue monitoring amphibians and birds in wetlands within the RHV; however, these are limited in extent (i.e. number of monitoring locations) and have not obtained yearly data at each station. Our own findings suggest that not all species have been detected, and that road noise at some locations may inhibit detection. Additional locations in less noisy environments would be beneficial.
6. No conclusive research has been conducted indicating the effectiveness of the escarpment viaduct as a wildlife movement corridor for the population of Southern Flying Squirrels (*Glaucomys volans*) that was documented between 1999 and 2001; this remains a key knowledge gap. Turtle population status within the Red Hill Marsh and Van Wagner's Ponds, as well as habitat enhancement areas, should also be updated.

7. Common Carp is prevalent within the lower Red Hill Creek and connected habitats. This species poses a direct threat to native fish and wildlife species, water quality in wetlands, and ecosystem functions, by disturbing sediments and uprooting aquatic vegetation (Hill, 1999). As a result, attempts to control Common Carp populations should be undertaken, as has been done in Windermere Basin and Cootes Paradise.
8. The permanent vegetation plots established in 2010 were intended to document the native vegetation communities found within the Red Hill Creek Valley. The results indicate moderate to high levels of diversity and floristic quality in plots located in low disturbance areas, such as the Niagara Escarpment, in contrast to areas such as Van Wagner's Beach that showed relatively low native species diversity and floristic quality, and which are subject to higher levels of human disturbance. These plots do not provide a comprehensive documentation of the plant diversity found within these vegetation communities, as they covered only a relatively small area. However; they will serve as an effective means of tracking changes in these vegetation communities over time if monitoring is repeated at regular intervals, such as on a 5-10 year cycle.
9. Our findings indicate that wetland cover has increased by 15.47 ha within the Red Hill Valley since 2003, most of which is the result of habitat enhancement and wetland restoration work. In order to track the progress of wetland and aquatic habitats within the watershed,
   ELC cover should be periodically updated, preferably as part of watershed updates or new project undertakings.
10. This report provides only a brief summary of ecological restoration work completed by Kayanase under the direction of City staff. A separate report would be valuable to address the full scope of this work.

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