Carruthers Creek Watershed Plan

Water Quantity Characterization

Prepared for the Region of Durham

September, 2018

Foreword

The Region of Durham recognizes watershed plans as an effective tool to inform the management of Durham's water resources, natural heritage, and natural hazards, such as flooding. In 2015, the Region retained the Toronto and Region Conservation Authority (TRCA) to update the watershed plan for Carruthers Creek.

This four-year study will build upon the goals, objectives, and management recommendations established in the 2003 *Watershed Plan for Duffins Creek and Carruthers Creek*, thereby ensuring a continuum of management efforts to achieve the desired ecological and sustainability objectives for the watershed.

The following report is one of a series of technical reports that were prepared at the end of the first phase of the watershed plan development process to characterize the existing conditions of the watershed. Information contained in these reports will provide the knowledge base necessary to develop management recommendations during Phase 2. The reports were subject to an independent peer review process. The final integrated watershed plan will be completed by the end of Phase 2.

This study was funded by the Region of Durham.

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1. Introduction

1.1. Carruthers Creek Watershed Plan Study Area

Carruthers Creek is a relatively small watershed with a drainage area of approximately 3,748 ha (9,261 acres), ranging from two to three km in width, and only 18 km in length (Figure 1). It is the easternmost watershed in Toronto and Region Conservation Authority's (TRCA's) jurisdiction and is located entirely in the Region of Durham. At the request of the Region of Durham, a small section of lands in East Duffins Creek subwatershed, which are immediately adjacent to Carruthers Creek watershed and outside of the provincial Greenbelt, were included in the study area.

The watershed occurs within the South Slope and Glacial Lake Iroquois physiographic regions, south of the Oak Ridges Moraine. Topographically, most of Carruthers Creek watershed is flat to slightly rolling. The exceptions are low hills associated with the Lake Iroquois Shoreline, notably the Kinsale Raised Shoreline immediately west of Audley Road and south of Highway 7, and the main valley feature of Carruthers Creek which forms a distinct but shallow ravine from Taunton Road south to Highway 401.

Carruthers Creek's headwaters form to the south of the Oak Ridges Moraine in the City of Pickering. Both the east and west branches of the creek originate north of Concession 8; the confluence is immediately north of Taunton Road and the creek enters Lake Ontario in the Town of Ajax. Carruthers Creek contains a total of 61 kilometres of stream channels. Historically, portions of the watershed would have supported cold water fish populations including Brook Trout, Atlantic Salmon, Slimy Sculpin, and Mottled Sculpin. Instream barriers to fish movement in the watershed adversely impact the aquatic system by limiting access to feeding and spawning areas, increasing water temperature, and affecting sediment transport. In addition, some instream structures increase water velocities to the point where fish passage is prevented. Instream structures that act as barriers to fish passage include dams, weirs, road and rail crossings, and some culverts.

Carruthers Creek watershed lies in the Great Lakes-St. Lawrence floristic region, which is comprised of mixed coniferous-deciduous forest. There are two provincial Areas of Natural and Scientific Interest (ANSI), as designated by the Ontario Ministry of Natural Resources and Forestry, in the watershed: the Kinsale Raised Shoreline Earth Science ANSI, designated for its distinct geological character as a well preserved part of the ancient Lake Iroquois Shoreline; and Shoal Point Marsh Life Science ANSI, which is included in the coastal Carruthers Creek Wetland Complex Provincially Significant Wetland. Two smaller wetlands are evaluated as Locally Significant: the Rossland Road Wetland Complex and the Salem Road Wetland Complex. The Carruthers Creek Wetland Complex is divided into two Environmentally Significant Areas: the coastal Carruthers Marsh and the Carruthers Creek Forest, a few hundred metres inland.

Long-term precipitation and air temperature patterns in the watershed are summarized from data collected by Environment and Climate Change Canada at the nearby Oshawa Water Pollution Control Plant station. In 2015, precipitation volumes of 985 mm exceeded the 30 year (1981-2010) normal of 892 mm, however the 2016 volumes were significantly lower at approximately 614 mm. For three of the last nine years, the total volume of precipitation exceeded the 30 year normal. Lower than normal precipitation volumes were reported in the years 2013, 2015, and 2016.

Stream flow records for the watershed are related to climate patterns. Preliminary water quantity data suggest that 2015 was a wet year in terms of stream flow and 2016 was significantly drier. Although stream flow has only been measured in the watershed for a relatively short period of record, a wide range of climatic conditions has been observed.

Carruthers Creek watershed is mainly rural north of Highway 7. From Highway 7 south to Taunton Road, the majority of lands are in the Protected Countryside of the provincial Greenbelt, however there is a noticeable loss of the integrity of the natural heritage system due to clearing of vegetation and filling. Low to medium density suburban development predominates from Taunton Road south to the lakeshore. Lands currently mapped as rural in the urban areas of Ajax are expected to be developed as employment lands to meet future demands. The older parts of the built urban area have little to no stormwater controls, while the newer parts include standard stormwater quality and quantity ponds accompanied by low impact development (LID) technologies. There is also a flood vulnerable area in the Pickering Beach neighbourhood of Ajax.

As expected, there are differences in agricultural land use in the upper reaches versus mid-reaches of the watershed which may be attributed to land tenure, drainage and soil properties, or a combination of factors. Horticulture dominates the east branch, whereas the west branch is predominantly cash crops and at least one livestock operation, although horticulture is also present. In the urban areas of Ajax, some lands slated for development are still cultivated with cash crops as an interim use.

Overall, the land use in this small watershed is in transition, therefore the characterization provided by the field work in Phase 1 of the watershed plan is an excellent benchmark for future study and decision-making. Regular monitoring during and following this watershed planning process continuously improves our understanding and will help to guide ongoing decision-making to protect, restore, and enhance Carruthers Creek watershed.

1.2.Surface Water Quantity

Surface water quantity is a term used to describe the volume, velocity, and timing of water moving through a stream network, also known as streamflow. Streamflow is influenced by several key factors, including climate (e.g. precipitation patterns, temperature), surficial geology, topography, and land cover (e.g. forest, bare soil, asphalt). These factors interact with one another to produce the streamflow patterns that are observed. Understanding streamflow patterns is important for the study of aquatic biota and water quality in the Creek, but also for human use and enjoyment of the Creek, and this understanding is therefore central to watershed planning.

This report describes the general trends in streamflow response to local climate and precipitation, and the spatial and temporal trends in streamflow within the Carruthers Creek Watershed, as observed over the first two years of enhanced streamflow monitoring (2015-2016) following installation of additional upstream gauges in the Creek in early 2015. The location and purpose of the additional stream gauges is described below in Section 2.

There have been both historical and recent flooding events in the Carruthers Creek watershed due to extreme precipitation events and other conditions generating excessive quantities of runoff. There is heightened public and political awareness of a potential for increased flooding risk in this small watershed resulting from urbanization and future climate change. A separate hydrology modelling study is underway to understand current flood risk situations and what needs to be done to protect property and lives from flooding hazards.

It is recommended that this water quantity technical report be read in concert with the Phase 1 Technical Report on Hydrogeology (Gerber & Doughty 2017), which describes the groundwater flow regime and provides insights into the baseflow components, as well as the Phase 1 Technical Report on Surface Water Quality (TRCA

2017). Together, these three reports provide the technical background and knowledge base for understanding the surface and groundwater flow regime within the Carruthers Creek watershed.

It should be noted that for the 2018 Binational Lake Ontario Cooperative Science and Monitoring Initiative tributary study, TRCA, with support from the Ministry of the Environment, Conservation and Parks (MECP), reinstalled a stream gauge at Bayly St., and are collecting event-based water quality samples at this location for the purposes of developing Lake Ontario loading estimates. Since these large watershed runoff events are minimally influenced by backwater effects, the Bayly St. location is suitable for this purpose. The Bayly St. station is a real-time station with access to flows and probe-based water quality parameters, which will be important assets in future hydrology modelling updates and flood forecasting. Through important investments made as part of this watershed plan development, there are now four operational stations, whereas there were none in 2000, enabling a much improved understanding of the watershed conditions and processes.

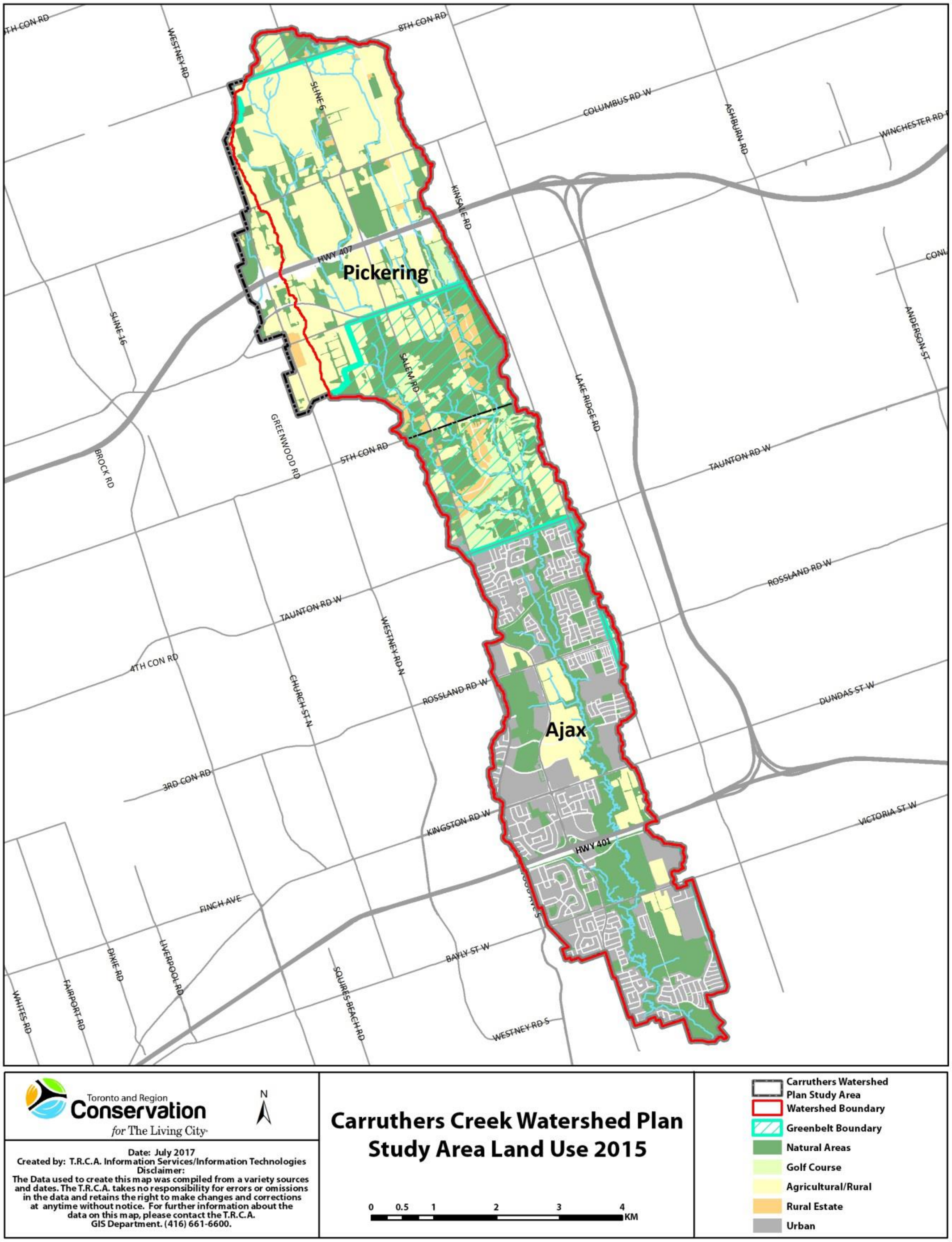

Figure 1: Land use within the Carruthers Creek Watershed Plan study area (2015).

2. Methods

2.1. Precipitation

Precipitation data from TRCA's Regional Watershed Monitoring Program (RWMP) rain gauge HY015 in Claremont were used to approximate precipitation in the Carruthers Creek watershed over the 2015-2016 study period. HY015 collects precipitation at 5 minute intervals but does not collect data during the winter months, so precipitation data for Environment and Climate Change Canada's (ECCC's) precipitation gauge at the Courtice Water Pollution Control Plant in Oshawa ("Oshawa WPCP", station 6155878) was used to augment the TRCA RWMP rain gauge. There were no closer rain gauges with continuous records for the period of interest.

2.2. Stream Gauges

No Water Survey of Canada stream gauges exist in the Carruthers Creek watershed. In the late 1960s and early 1970s, the Ontario Ministry of Environment installed a stream gauge near Shoal Point Road at the outlet to Lake Ontario as part of International Hydrologic Decade Study. After a few years of operation this gauge was abandoned and the flow records were subsequently lost. In early 2000 when the first watershed study commenced, TRCA re-installed the Shoal Point Road gauge. However, by that summer it was evident that this site was influenced by the backwater effect from Lake Ontario. In the autumn of 2001, the stream gauge was located north of Bayly Street. This site was also found to be inadequate due to backwater effects under high lake level conditions after several years of operation, and in 2008 this stream gauge was moved to the current location at Achilles Road (HY013). In 2015, two new stream gauges were added to TRCA's existing network as part of the Phase 1 field studies (HY089, HY090). The locations of all of the stream gauges are shown in Figure 2.

There are no water level recorders on the east branch of Carruthers Creek; however, as streamflow data are available for the west branch from HY089 and for the main channel just below the confluence of the east and west branches at HY090, the streamflow in the east branch can be estimated by subtracting the discharge measured at HY090 from that measured at HY089. All estimates of streamflow in the east branch of Carruthers Creek are derived using this approach.

To better understand the spatial and temporal patterns of streamflow in Carruthers Creek, lag time was calculated for each of the three operating stream gauges (HY013, HY089, HY090). Lag time is an important variable characterizing watershed hydrological response for many hydrological models, and represents the average velocity at which runoff produced by rainfall moves through a watershed to a defined point such as a stream gauge. The definition of lag time used by Eagleson (1962) was used to calculate this parameter for each of the three stream gauges in Carruthers Creek. For this analysis, lag time was calculated for six rainfall events exceeding 25 mm over the 2015-2016 period. For further detail on this method of calculating lag time, see Eagleson (1962).

2.3. Rating Curves

The new TRCA stream gauges required rating curves to be developed. A rating curve is an equation that relates each measurement of stream elevation, or stage, to a particular discharge, commonly expressed in units of m^3/s. The use of a rating curve permits continuous stream discharge to be estimated from continuous stage measurements, as discharge is much more difficult to measure continuously in the field than stage. After a sufficient number of manual measurements of stream discharge that span a range of streamflow conditions have been collected, a continuous curve can be estimated to interpolate discharge between the measured points.

For the rating curves in this study, a Flow Tracker® handheld acoustic Doppler velocimeter (SonTek, San Diego, California) was used to manually measure flow at the stream gauges in Carruthers Creek. A minimum of nine measurements were taken at each stream gauge over the 2015-2016 study period to develop the initial rating curves. Since capturing the full range of discharge conditions encountered at each stream gauge is inherently challenging, particularly for the highest discharge, the discharge data calculated as part of this report is considered provisional. Rating curves for each stream gauge will continue to be refined as time progresses.

2.4. Baseflow

Baseflow, defined as the estimated proportion of total streamflow volume derived from groundwater, was estimated for each of the major reaches of Carruthers Creek using field survey data collected in summer 2010. The method involved using a Flow Tracker® handheld acoustic Doppler velocimeter (SonTek, San Diego, California) to measure streamflow at each road crossing of a watercourse over the May to September period, and then comparing the upstream to the downstream discharge measurement to determine how much additional discharge was added or lost between the two points, and dividing this gain or loss by the length of stream between the measurement points (i.e. normalizing for stream length, with gain or loss values expressed in litres per second per kilometer of stream). Data was collected a minimum of 72 hours after a rain event so as to capture baseflow and not event flow.

2.5. Drainage Area, Soils, and Land Use

Elevation data from LiDAR imagery was analyzed using the ArcHydro tool in ArcGIS 10.4 (ESRI, Redlands, California) to determine the contributing drainage area for each of HY013, HY089 and HY090. The drainage area for the east branch was determined by subtracting the contributing drainage area estimated for HY089 from that estimated for HY090.

The surficial geology, soils, and patterns of land use within Carruthers Creek watershed are discussed in greater detail in the Carruthers Creek Hydreogeology report (Gerber & Doughty 2017) and in several other technical reports in this series, and so the reader is referred to these reports for further information on these subjects.

Figure 2: Study Area for Carruthers Creek Watershed Plan with local precipitation (HY015) and stream gauges (HY089, HY090, and HY013), and water quality sampling locations (CC011, CC005, 107002). Oshawa WPCP rain gauge (not pictured) is located approximately 13 kilometers east of the mouth of Carruthers Creek.

3. Results and Discussion

3.1. Local Climate and Precipitation

The Carruthers Creek watershed has a humid continental climate (Köppen climate region type *Dfb*) with warm humid summers and cold winters. Temperature and precipitation normals (1981-2010) for the Oshawa WPCP station show an average annual precipitation of 871.9 mm that is distributed relatively evenly throughout the year, with slightly less precipitation during the winter (Figure 3). Average daily temperatures range from -5°C in January to 21°C in July.

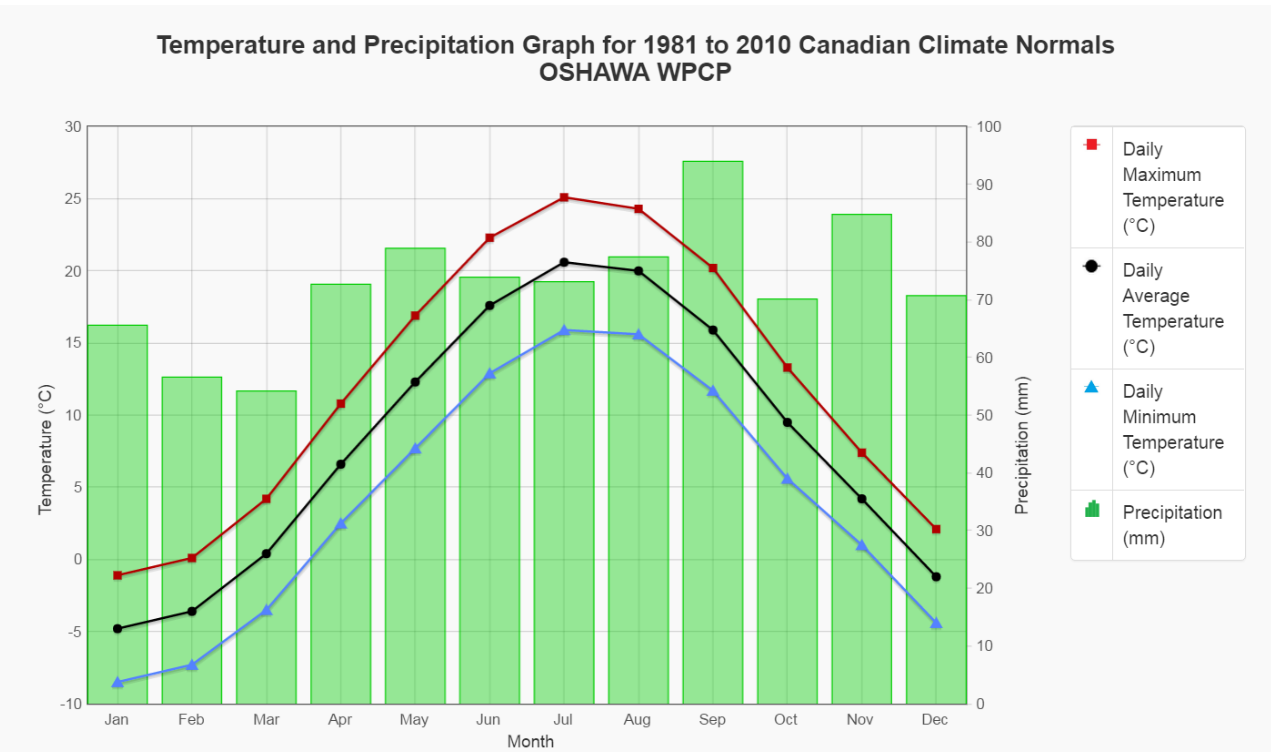

Figure 3: Temperature and precipitation climate normals 1981-2010 for the Oshawa WPCP.

Figure 4 shows the annual total precipitation for 2008 to 2016. The wettest year during this period was 2015 with 984.8 mm total precipitation, while 2016 (662.8 mm) was the second driest following 2008 (647.8 mm). The departure from the 1981-2010 climate normal in absolute and relative terms is shown in Figure 5. Over the period 2015-2016 for which streamflow data are available in the upper watershed, therefore, both a relatively wet and a relatively dry year are captured.

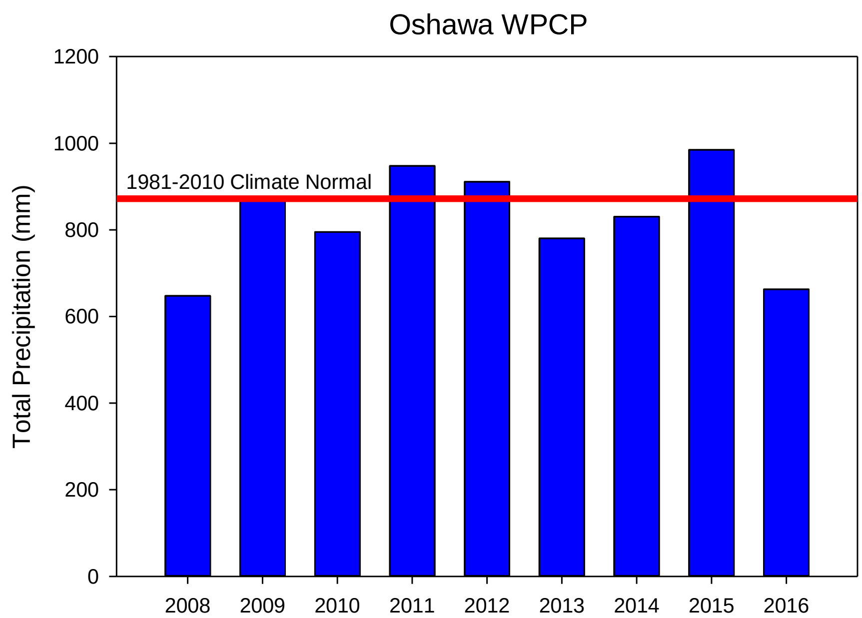

Figure 4: Total annual precipitation at the Oshawa WPCP station (Environment and Climate Change Canada) compared to the 1981-2010 climate normal of 871 mm (horizontal red line).

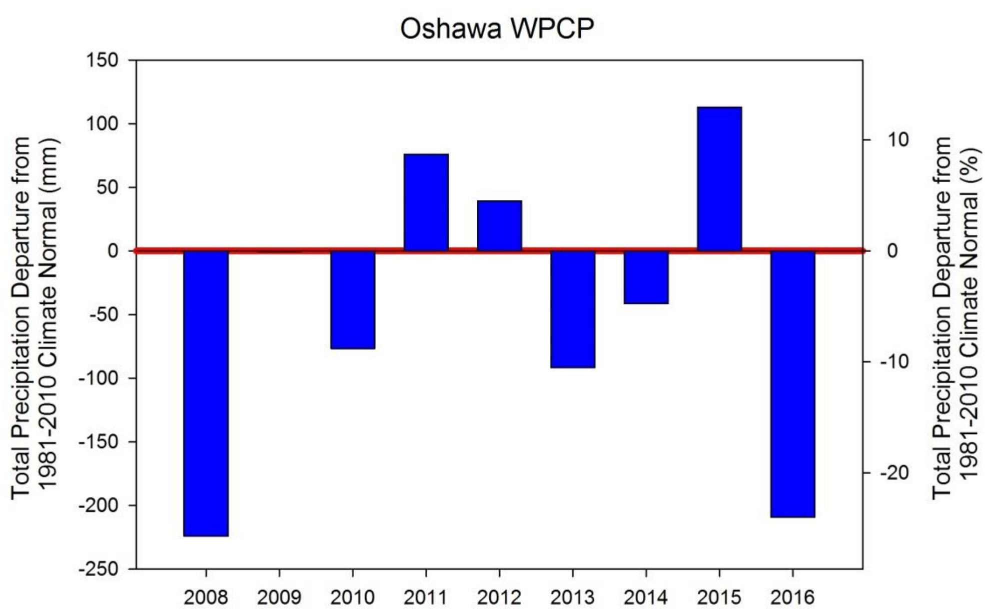

Figure 5: Comparison of total annual precipitation to the 1981-2010 climate normal; Left axis shows the departure in mm from the climate normal while the right axis shows the departure in percentage. The red line shows climate normal; 2009 is 3 mm below the normal but appears on the normal line.

Monthly precipitation data for 2015 and 2016 from the Oshawa WPCP station show large differences between the two years in the distribution of snow and rainfall (Figure 6). While total winter precipitation was comparable between the two years, spring and summer precipitation totals were much greater in 2015 relative to 2016. The month of June 2015 was particularly wet with 210.2 mm of precipitation, relative to the 1981-2010 monthly climate normal of 73.9 mm and the 31.2 mm received in 2016. Note that there are some missing data for a number of days in 2016 for the Oshawa WPCP station.

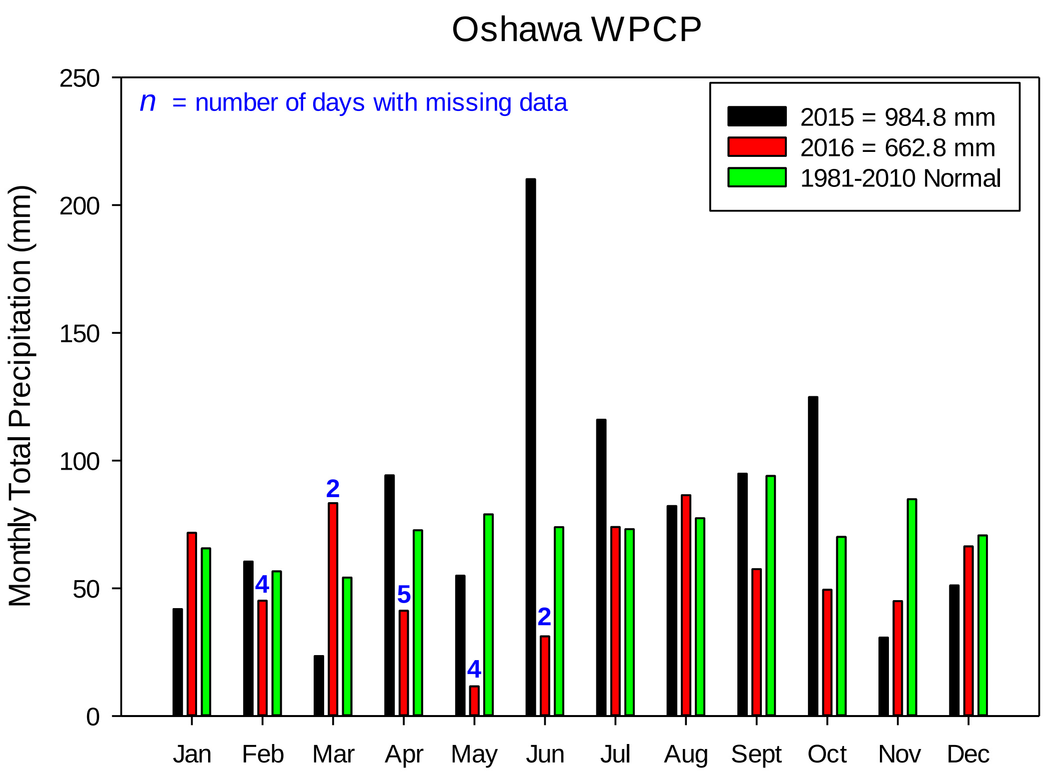

Figure 6: Total monthly precipitation in 2015 and 2016 based on Oshawa WPCP station (Environment and Climate Change Canada). Numbers above bars denote the number of days with missing precipitation data during the associated month in 2016.

While the Oshawa WPCP station has the benefit of being a 4-season station, as well as having a longer term record, the TRCA HY015 3-season rain gauge at Claremont is closer to all of the stream gauges in Carruthers Creek. Data from the Claremont rain gauge were therefore used to supplement data from the Oshawa WPCP station in analyses of rainfall event response for Carruthers Creek. Comparing rain event measurements at both rain gauges for the period of common record shows that a large majority of events register similarly at both locations, with a median difference of 2.6 mm for all days where both locations recorded rainfall (Figure 7; Figure 8). There was slightly more total precipitation recorded at Oshawa WPCP (1087.9 mm) than at Claremont (1002.0 mm) for the 2015-2016 period of common record, but overall the rain gauges appear to be good analogues for one another.[1]

[1] Civica Infrastrucure, who is currently completing a study of the hydrology of Carruthers Creek watershed as it pertains to flood risk has found that the existing precipitation gauges do not always measure accurately the rainfall that drives streamflow in the watershed. Civica is using radar precipitation maps to infill and estimate total rainfall for events measured in 2015 and 2016.

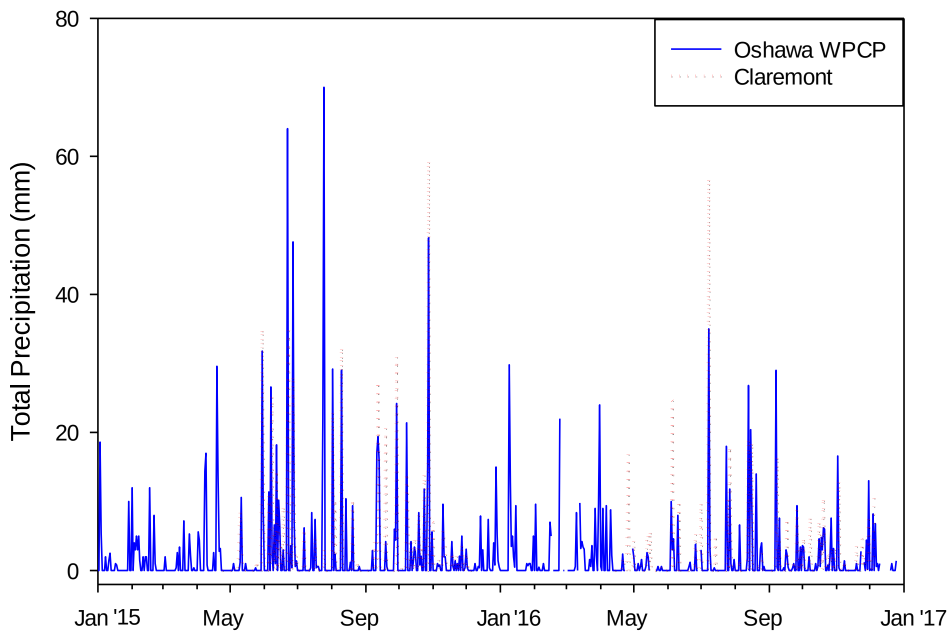

Figure 7: Recorded daily precipitation at both rain gauges; note that there are 4 dates in 2016 during which Oshawa WPCP has no data reported and Claremont has recorded precipitation.

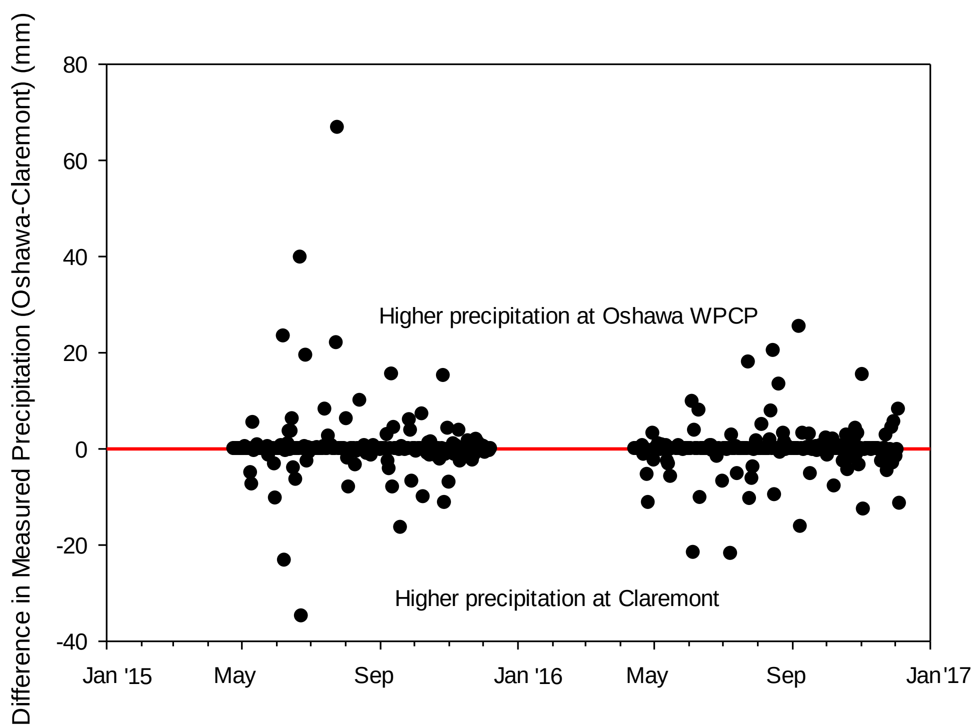

Figure 8: Comparison of daily totals between Claremont (HY015; TRCA) and Oshawa WPCP (Environment and Climate Change Canada) precipitation data, showing the magnitude and direction of difference in recorded precipitation between the rain gauges.

3.2. General Trends in Streamflow

The drainage area, elevation, and years of record for each of the three existing stream gauges in Carruthers Creek, as well as for the calculated East Branch discharge and the historical stream gauge at Shoal Point, are listed in Table 1. The provisional discharge (hereafter, referred to as simply "discharge") measurements at each stream gauge follow a consistent relationship in their response to precipitation events, whereby discharge at the lowest reaches (HY013 at Achilles Rd.) is greater than that at the confluence of the east and west branches (HY090, at Taunton Rd.), which in turn is greater than discharge at the base of the west branch (HY089 at Squires Dr.), as would be expected from the estimated contributing drainage areas for each stream gauge. Figure 9 shows the discharge at each of the three flow gauging stations (HY013, HY089, and HY090) against the measured precipitation at the HY015 rain gauge in Claremont (3-season station) and at Oshawa WPCP for the winter periods where no data was available at HY015.

Gauge Name	Description	UTM (easting, northing)	Drainage Area (ha)	Elevation (m)	Years of Record
HY089	Squires Dr. (Carruthers west branch)	658809, 4863087	975	127.4	2015-2016
HY090	Taunton Rd. (east-west confluence)	659147, 4862831	1976	107.3	2015-2016
HY013	Carruthers at Achilles Rd.	660490, 4857744	2906	86.9	2008-2016
–	Carruthers East Branch (calculated)	–	1001	–	–
–	Carruthers at Shoal Point (defunct)	661471, 4855146	3601	76.5	2002-2007

Table 1: Location, drainage area, elevation, and years of data for each stream gauge.

The discharge coming from the east branch of Carruthers Creek was calculated by subtracting the discharge measured at the base of the west branch (HY089 at Squires Dr.) from that measured just below the confluence of the east and west branches (HY090 at Taunton Rd.). The calculated discharge from the east branch is depicted in Figure 10 against the measured discharge in the west branch (HY089 at Squires Dr.). This simple calculation shows that daily discharge from the east branch generally exceeds that of the west branch by about 50 %, despite the two branches having similar drainage areas (1001 ha and 975 ha, respectively, as outlined in Table 1.

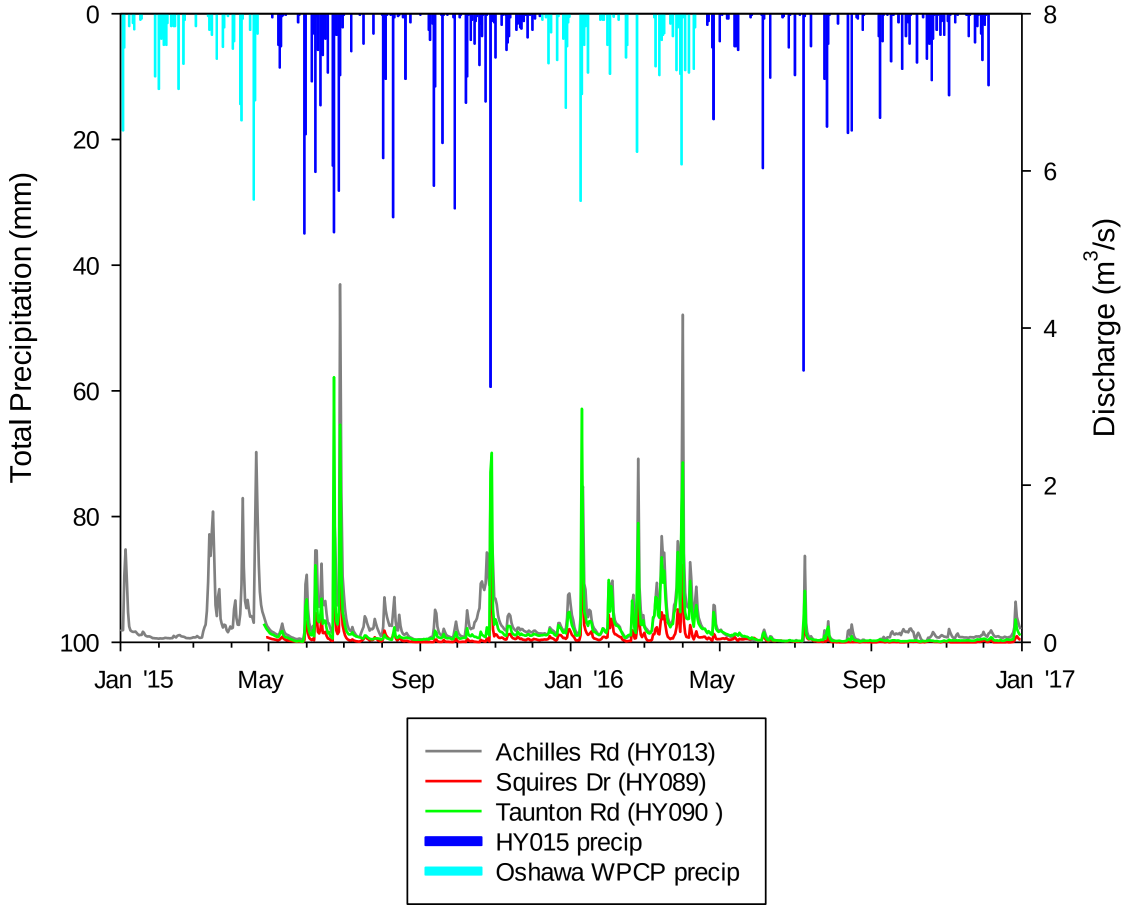

Figure 9: Discharge at stream gauges HY013 (at Achilles Rd.), HY089 (west branch, At Squires Rd), and HY090 (downstream of confluence of east and west branches, At Taunton Rd.) for 2015 and 2016 with precipitation measured at HY015 shown for period of data availability and precipitation at Oshawa WPCP shown for all other periods.

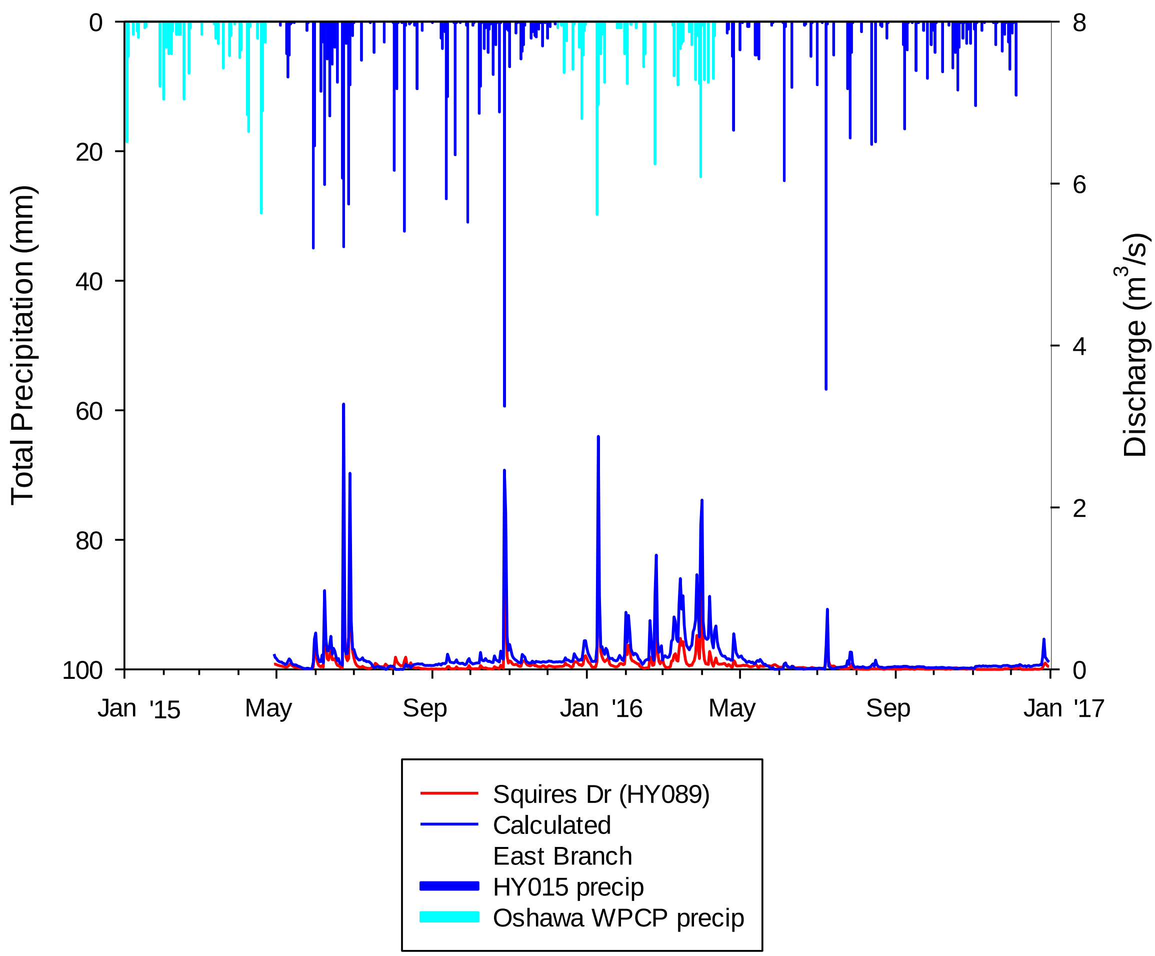

Figure 10: Discharge for stream gauge HY089 (at Squires Dr.) and the estimated discharge for the East Branch of Carruthers Creek; total precipitation measured at HY015 is shown for period of data availability and precipitation at Oshawa WPCP is shown for all other periods.

Average daily discharge values for the lower reaches of Carruthers Creek (HY013, at Achilles Rd.) over the 2015-2016 period of record range from a high of 4.60 m^3/s to a low of 0.02 m^3/s (Figure 11). Monthly average discharge at HY013 is 0.25 m^3/s averaged over the 2015-2016 period of record, ranging from a high of 0.72 m^3/s in June 2015 to a low of 0.04 m^3/s in June 2016 (Figure 12). The monthly average discharges recorded at HY090 (Taunton Rd.), HY089 (Squires Dr.), and the calculated East Branch, were 66%, 27%, and 39%, respectively of the monthly average discharge at HY013 over the period of common record for all stream gauges.

Whereas the lower reaches of the watercourse never dry out over this period, there are periods when streamflow in the west branch of Carruthers Creek (HY089, at Squires Rd.) is below what can be reliably measured in the field (Figure 11). These values are recorded as zero flow but the streambed remains wet during these periods according to TRCA hydrometric staff. There are no periods of near-zero flow measured at the upper main channel of Carruthers Creek (HY090, at Taunton Rd.), suggesting that the east branch of the creek also flows year round under most conditions. The periods of near-zero flow in the west branch observed during late 2016 can likely be attributed to the water lost to recharge as the stream passes over the unsaturated highly porous deposits of the Lake Iroquois shoreline, in addition to the relatively small contributing drainage area for this stream reach. While estimated streamflow in the East Branch appears to decline significantly during certain periods, such as May-June 2016, this is more likely an artifact introduced by small differences in the lower range of the ratings curves for the stream gauges at Taunton Rd. (HY090) and Squires Dr. (HY089), as both of those gauges exhibit sustained streamflows during the same period.

It should be noted that streamflow is a strong influence on surface water quality, and that the connections between surface water quantity and quality are further discussed in the Surface Water Quality Characterization report (TRCA 2017).

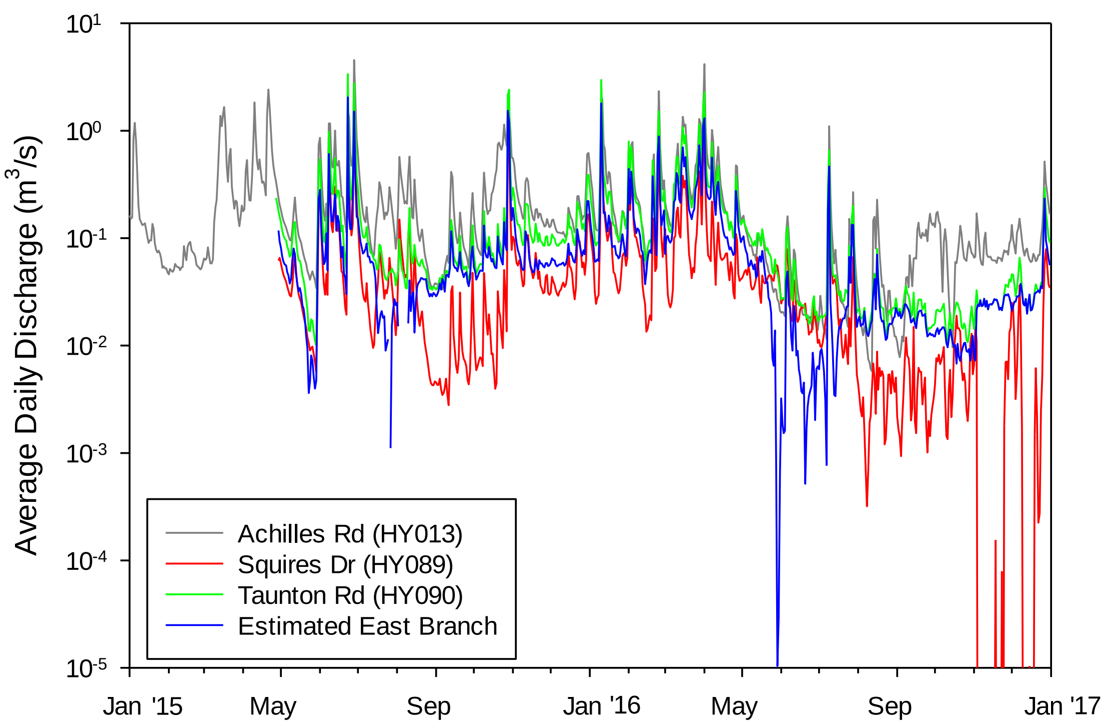

Figure 11: Average daily hydrographs for 2015 and 2016, shown on log scale to emphasize low flows

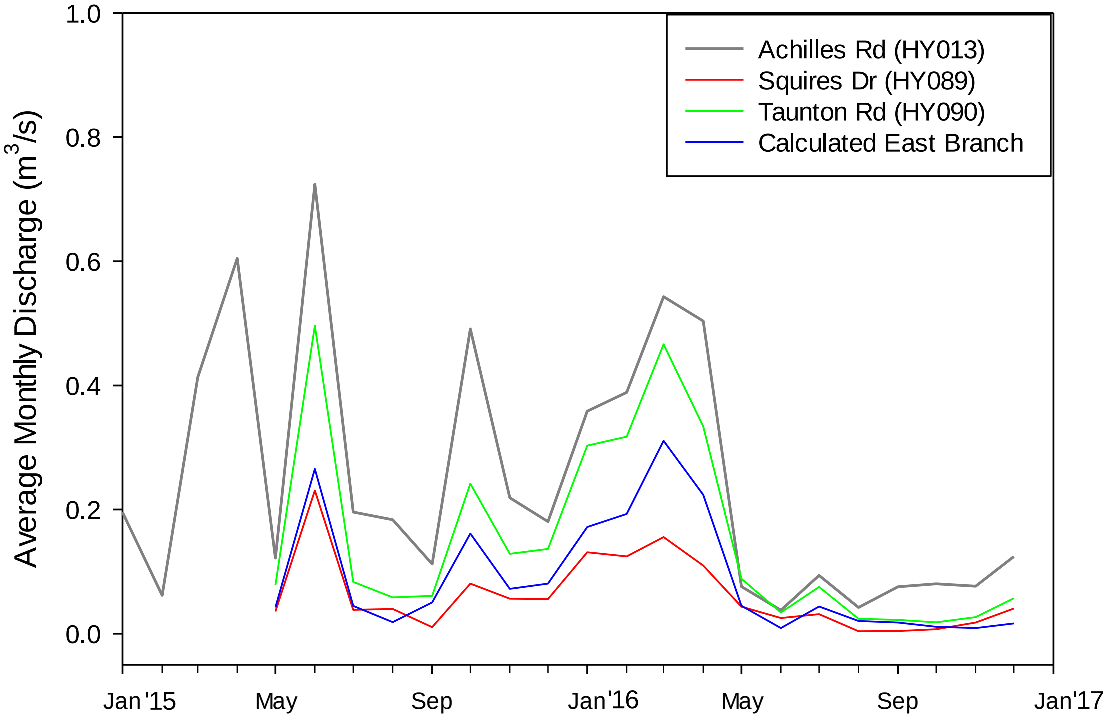

Figure 12: Average monthly hydrograph for 2015 and 2016

3.3. Monthly, Seasonal, and Annual Streamflow Totals

Streamflow in the main channel and tributaries of Carruthers Creek responded strongly to individual precipitation and snowmelt events, as shown by large differences in monthly total volume at all of the stream gauges for 2015 and 2016 (Figure 13). Carruthers Creek had the highest total monthly volume in June 2015, with 2.05×10^6 m^3 measured in the lower reaches at HY013 (at Achilles Rd.). This was nearly ten times more than the discharge of 2.07×10^5 m^3 measured at HY013 in June 2016, and is attributable to the very high amount of precipitation that fell in June 2015 of 210.2 mm, three times the 1981-2010 climate normal of 73.9 mm for June (Environment and Climate Change Canada, 2017). The overall pattern of the 2016 streamflow data is closer to what might be expected for a typical southern Ontario watershed, with the maximum monthly total volume in March and April during the spring freshet when melting snowpack combines with rainfall to produce higher runoff volumes. However, the exceptionally dry late spring of 2016 contributed to summer and fall total volume that was much lower at all stream gauges in 2016 as compared to 2015. Low flow volumes during 2016 were likely substantially lower than the long term average. The west branch of Carruthers Creek (HY089) recorded near-zero flow for 35 days in 2016, whereas the flow measured below the east-west confluence at Taunton Rd. (HY090) did not record such low flow volumes and therefore it is likely that the majority of water below the confluence was derived from the East Branch over this period.

The total monthly volumes measured at the three stream gauges, and the calculated east branch monthly discharge, are shown in Figure 14. This figure illustrates that the east branch of Carruthers Creek generally contributes more water to the Creek than the west branch, and also that there is substantially more water flowing through the lower reaches (HY013 at Achilles Rd.) than there is flowing through the reach below the east-west confluence at Taunton Rd. (HY090) even after accounting for the larger contributing drainage area. This is discussed further in section 3.4

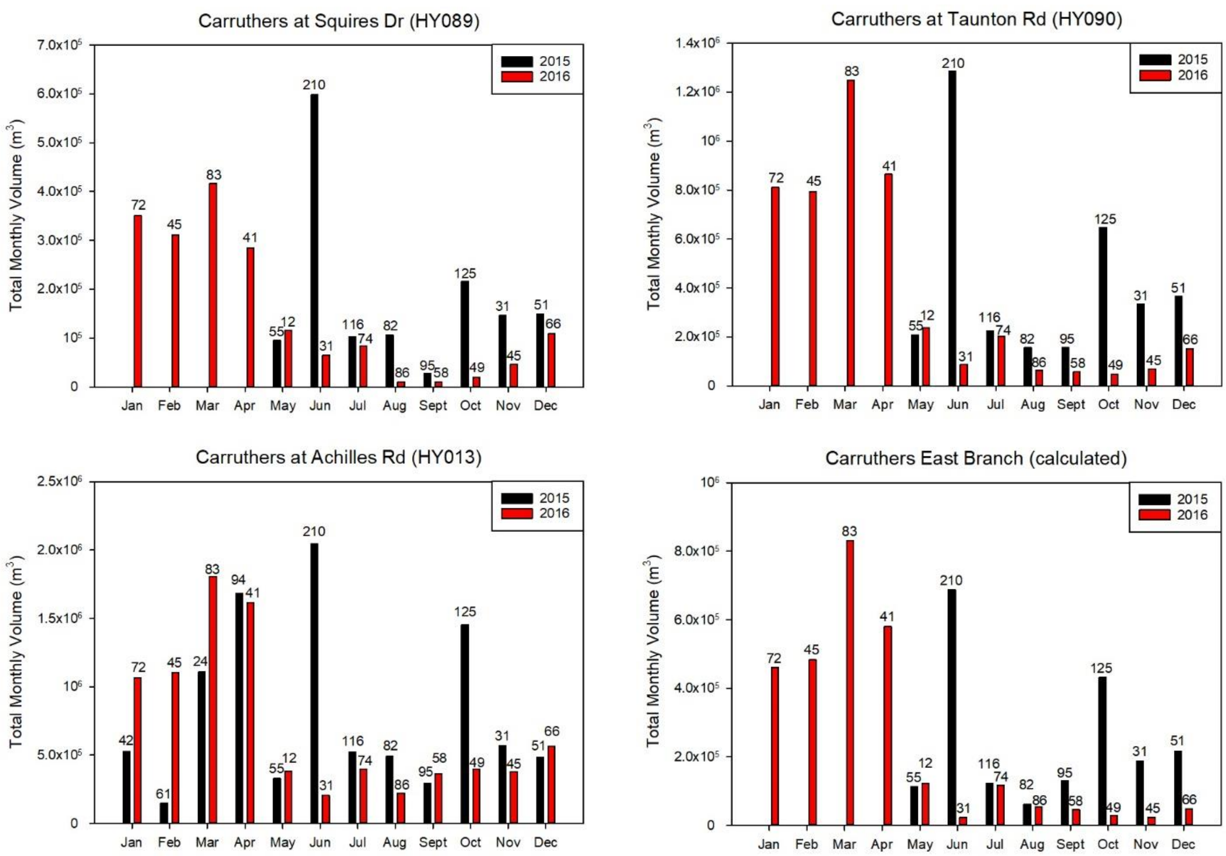

Figure 13: Total monthly volume for 2015 and 2016 data. Numbers above the bar plots are total monthly precipitation measured at Oshawa WPCP in mm. Note that streamflow measurements begin in May 2015 for all stream gauges except HY013.

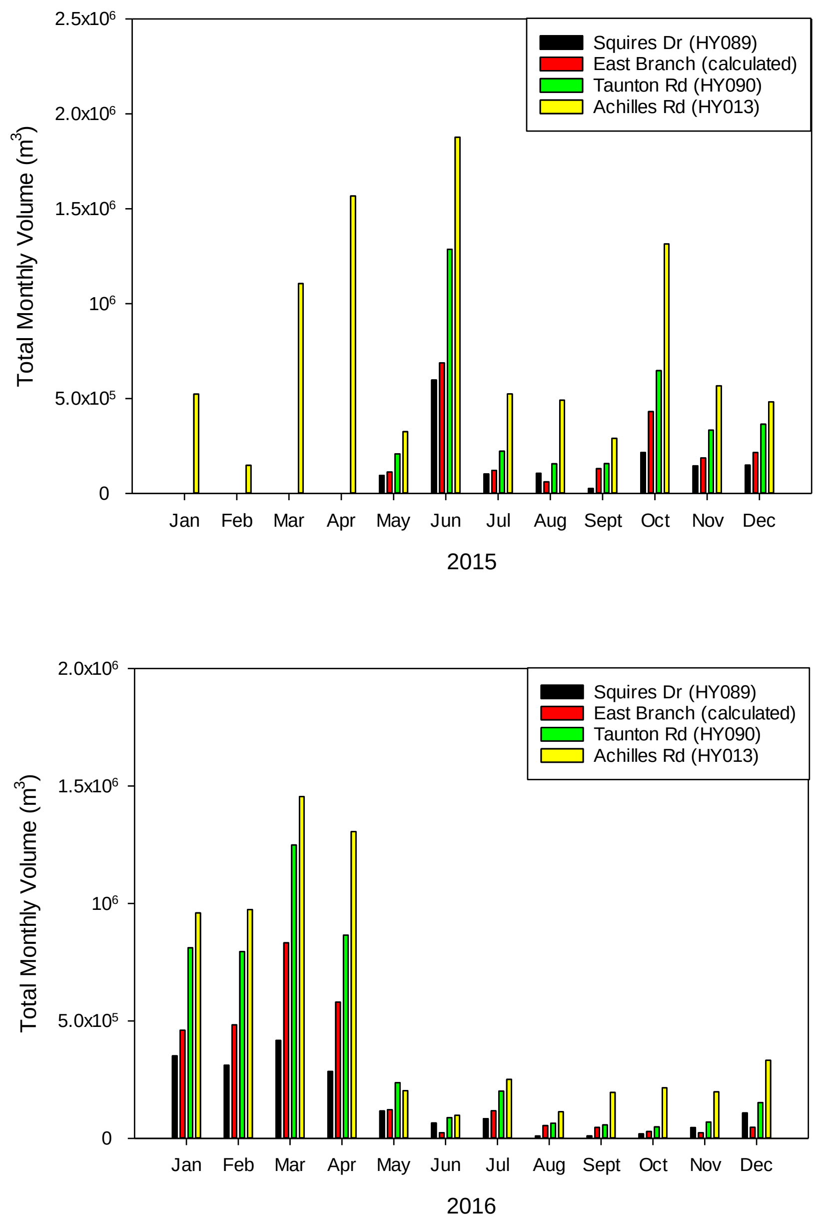

Figure 14: Total monthly volume recorded at all stream gauges and the calculated east branch in 2015 and 2016. Note that measurements did not begin until May 2015 for all gauges except HY013.

On an annual basis, the lower reaches of Carruthers Creek at Achilles Rd. (HY013) had an average total volume of 1.14×10^7 m^3 over the 2008-2016 period (Figure 15). This corresponds to a discharge rate of 0.360 m^3/s when averaged on an annual basis. Compared to the 2008-2016 average total annual volume (1.14×10^7 m^3), 2015 was 19 % lower at 9.23×10^6 m^3, while 2016 was 44 % lower at 6.30×10^6 m^3.

Of this total volume for 2016, the first full year for which gauging data was available for the upper stream gauges (HY089 and HY90), an estimated 21.4 % was derived from the west branch of Carruthers Creek, whereas the east branch supplied an estimated 33.1 %. An estimated 45.5 % of the total annual volume measured in the lower reaches (HY013 at Achilles Road) was supplied from south of Taunton Road (downstream of HY090), demonstrating that there are significant inputs to Carruthers Creek over this relatively short length of watercourse. For example, flows through the lower reaches of the creek in August through December of 2016 were 1.92×10^6 m^3, which exceeded the flows measured at HY090 at Taunton Road (3.92×10^5 m^3) by an estimated 4.9 times. These inputs may be derived from stormwater, groundwater, irrigation water, or other sources; these spatial trends in streamflow are explored in section 3.4.

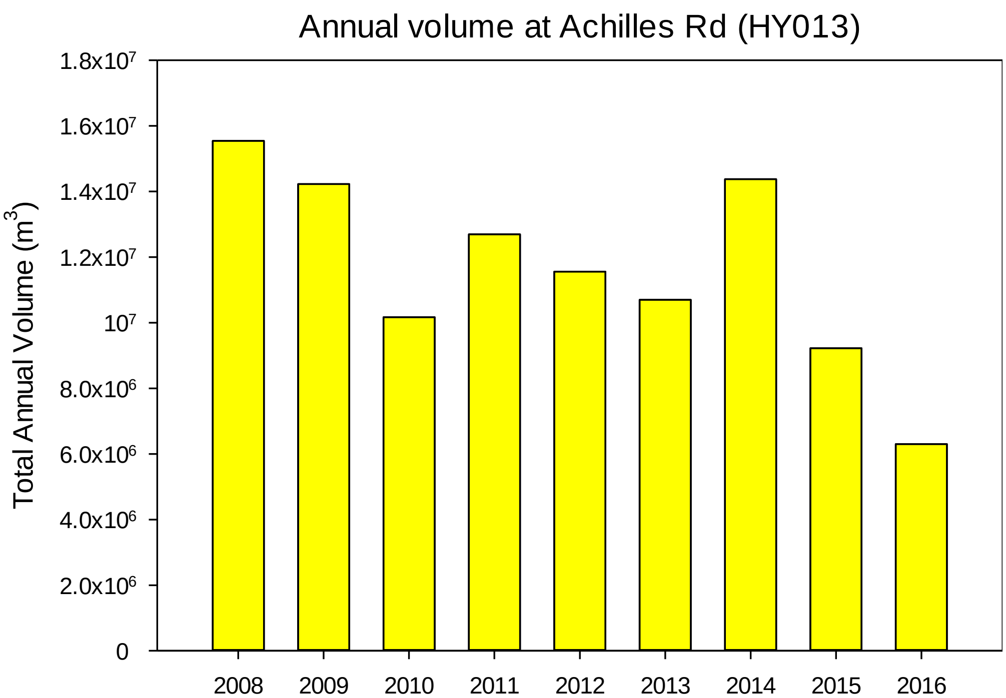

Figure 15: Total annual volume for Carruthers Creek at HY013 at Achilles Rd., 2008–2016.

3.4. Spatial Patterns in Streamflow and Baseflow

The streamflow in the various reaches of Carruthers Creek can be compared on an areal basis by dividing the measured discharge by the area contributing drainage to the measurement point, as determined through LiDAR analysis of topography (Table 1). When compared on the basis of discharge per hectare of drainage area (see Table 1), discharge in the lower reaches (HY013 at Achilles Rd.) appears broadly similar to that near the east-west confluence at Taunton Road (HY090) (Figure 16). Responses to precipitation and snowmelt events are quite similar in the winter months and during larger events (> 20 mm). The differences in hydrological response can be seen mainly in the summer and fall, when the response to smaller precipitation events is much more muted in the upper watershed relative to the lower watershed. This can likely be attributed to the higher proportion of impervious cover in the lower watershed, which leads to faster runoff peaks and greater total runoff. Whereas the upper and watershed responses are more similar in the winter when the ground is frozen, the additional storage volume created by pervious soils and by the summer soil moisture deficit leads to lower summer-fall runoff per unit area in the upper watershed relative to the more developed lower reaches. The difference between the upper and lower watershed runoff responses is most pronounced in the fall when streamflow is at its annual minimum. The higher total volume values measured in the lower reaches of Carruthers Creek likely reflect additional groundwater inputs south of Taunton Road, as well as stormwater inputs and the possible addition of municipal water from irrigation and/or distribution system leakage. It is not possible to determine the relative contributions of each of these potential sources of additional streamflow in the absence of additional information.

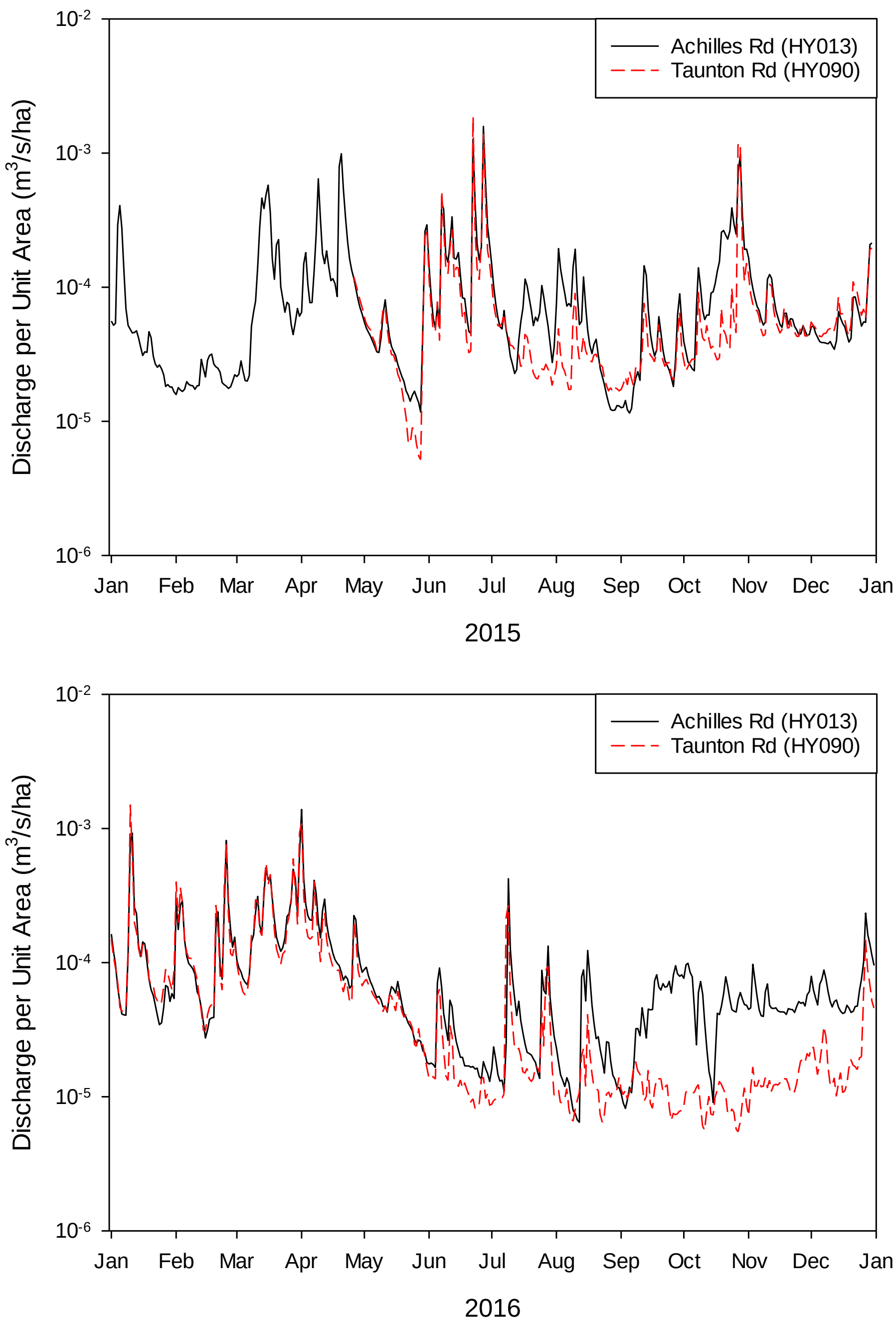

Figure 16: Discharge per unit area at Taunton Rd. (HY090) and Achilles Rd. (HY013) (log scale)

Discharge per unit area is relatively similar between all the different reaches, as illustrated in Figure 17. Again, the lower reaches (HY013) of the Creek tend to show greater precipitation response in the summer and fall, although peak flows per unit area actually tend to be highest in the east branch, and the hydrograph for the lower reaches at HY013 tends to have more prolonged rising and recession limbs relative to all the other reaches. Discharge per unit area was lowest under almost all conditions for the west branch (HY089 at Squires Road), possibly suggesting that there is more water lost to groundwater recharge or other possible sinks for this reach. The difference in discharge between the east and west branches on an areal basis is striking, and is most likely attributable to differences in soil and hydrogeological setting between these two areas of the upper watershed, as explored in greater detail in the Phase 1 hydrogeology report in support of this watershed plan (Gerber & Doughty 2017).

Event lag time estimates, as per the method of Eagleson (1962), show a median value of 10.6 hours for the lower reaches (HY013), 6.1 hours for the confluence (HY090), and 9.0 hours for the west branch (HY089). The faster response time below the confluence at HY090 than above the confluence at HY089 on the west branch suggests that the east branch responds more quickly to rainfall events than the west branch, likely attributable to tighter soils with less capacity to infiltrate rainwater in the northeast portion of the watershed. However, as noted previously, spatial variability in rainfall and in soil moisture storage across the watershed introduces uncertainty in the calculation of event lag time.

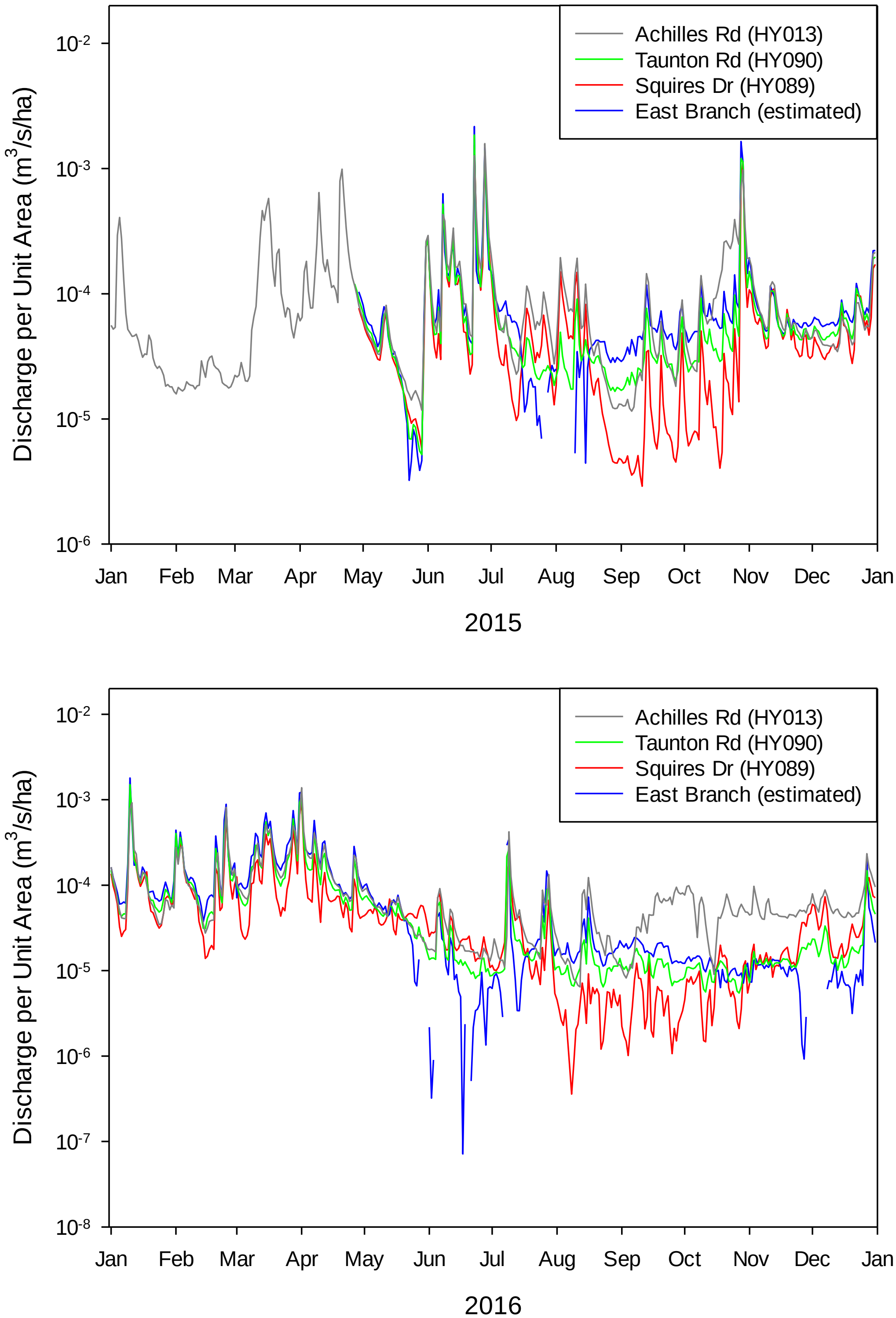

Figure 17: Discharge per unit area at all stream gauges plus the calculated east branch discharge (log scale).

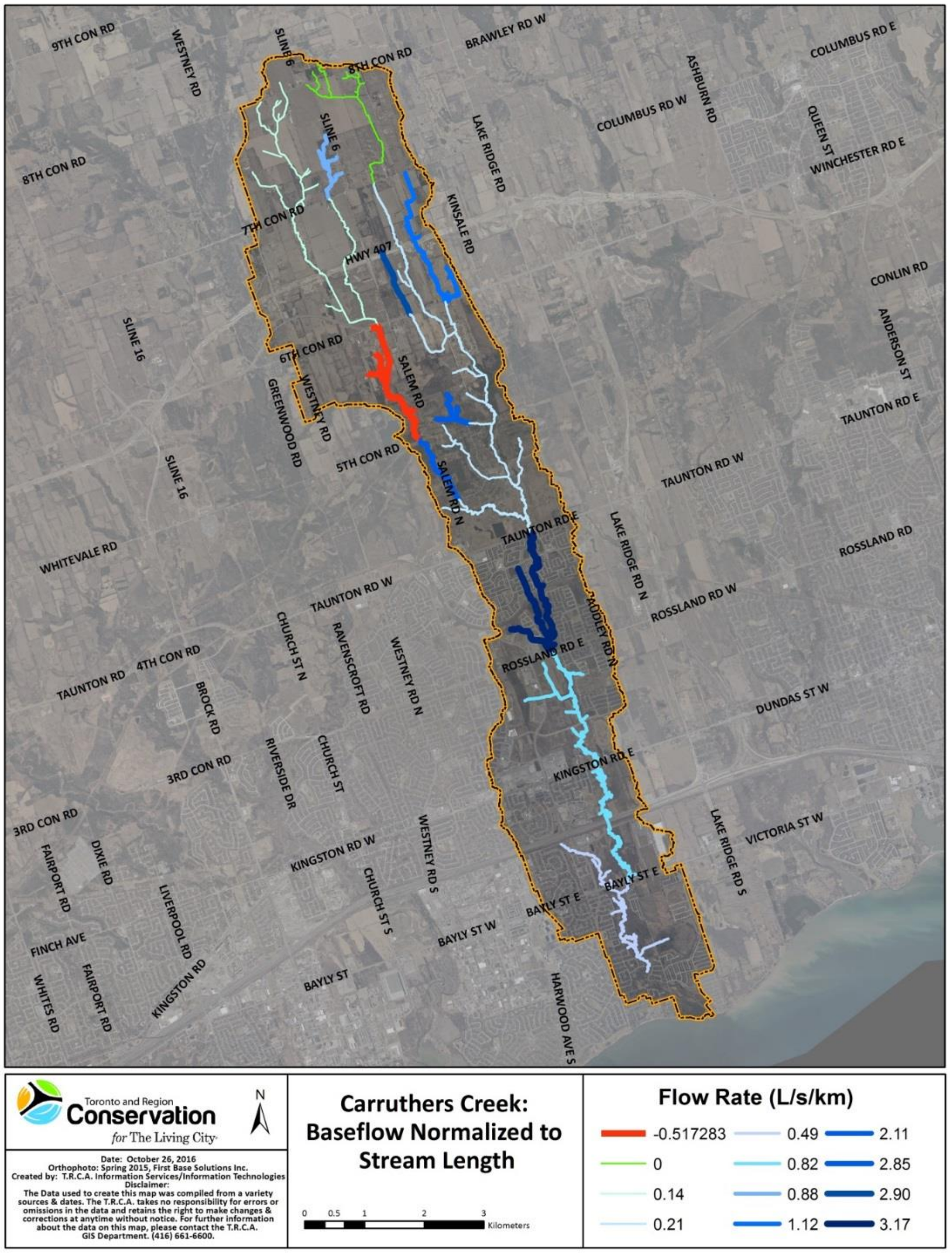

Figure 18: Baseflow normalized to stream length.

The estimated distribution of baseflow throughout the Carruthers Creek watershed is shown in Figure 18. The field measurements of baseflow help to validate many of the trends noted in the area-normalized discharge analysis. For instance, the lower reaches of the west branch of Carruthers Creek are shown to be losing reaches (i.e. there is a net outflow of water from the streambed to groundwater), whereas the east branch is a slightly gaining reach (i.e. there is net inflow of groundwater into the stream). This can be tied to the hydrogeological setting of the creek (see Gerber & Doughty 2017). At the outcropping of the Thorncliffe formation near and to the south of Taunton Rd., groundwater contributions to baseflow are higher than anywhere else in the watershed. This helps to account for the additional water observed in the lower reaches of the Creek relative to discharge below the confluence at Taunton, although other contributing sources, such as irrigation or stormwater cannot be ruled out. With maximum estimated baseflow rates of 3.17 L/s/km, baseflow contributions in Carruthers Creek could be described as low to moderate relative to other watercourses in TRCA's jurisdiction.

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Appendix: Daily average discharge measurements for 2015-2016

Appendix 1A: 2015 Discharge Summary for station HY013 at Achilles Road. Discharge is in m^3/s.

Carruthers at Achilles 2015 Summary:												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1	0.16	0.05	0.06	0.18	0.18	0.85	0.60	0.11	0.04	0.16	0.56	0.13
2	0.15	0.05	0.06	0.19	0.16	0.42	0.42	0.22	0.04	0.11	0.48	0.15
3	0.16	0.05	0.07	0.44	0.14	0.25	0.30	0.56	0.04	0.10	0.35	0.15
4	0.85	0.05	0.08	0.53	0.13	0.17	0.22	0.40	0.04	0.08	0.28	0.13
5	1.18	0.05	0.07	0.30	0.13	0.14	0.17	0.32	0.04	0.08	0.24	0.12
6	0.80	0.06	0.06	0.22	0.11	0.21	0.15	0.26	0.03	0.07	0.21	0.11
7	0.38	0.05	0.06	0.22	0.11	0.15	0.14	0.21	0.04	0.07	0.19	0.11
8	0.20	0.05	0.06	0.39	0.10	1.25	0.19	0.22	0.05	0.21	0.17	0.11
9	0.15	0.05	0.15	0.73	0.09	1.11	0.14	0.21	0.06	0.41	0.15	0.11
10	0.14	0.05	0.19	1.87	0.12	0.51	0.11	0.41	0.07	0.29	0.16	0.11
11	0.13	0.05	0.23	0.92	0.18	0.45	0.09	0.56	0.06	0.19	0.33	0.11
12	0.13	0.05	0.42	0.52	0.23	0.61	0.08	0.26	0.20	0.17	0.36	0.11
13	0.14	0.08	0.82	0.44	0.17	0.97	0.07	0.15	0.42	0.18	0.34	0.10
14	0.12	0.07	1.34	0.54	0.13	0.48	0.07	0.16	0.36	0.18	0.25	0.12
15	0.10	0.06	1.12	0.41	0.11	0.47	0.12	0.35	0.20	0.26	0.20	0.19
16	0.09	0.08	1.42	0.33	0.10	0.53	0.16	0.21	0.13	0.27	0.17	0.17
17	0.10	0.09	1.68	0.34	0.09	0.36	0.20	0.14	0.10	0.31	0.15	0.16
18	0.09	0.09	1.04	0.31	0.08	0.24	0.33	0.11	0.09	0.38	0.15	0.15
19	0.14	0.08	0.47	0.25	0.07	0.24	0.30	0.09	0.10	0.45	0.19	0.13
20	0.12	0.07	0.33	2.32	0.06	0.18	0.24	0.11	0.18	0.75	0.19	0.11
21	0.09	0.07	0.60	2.88	0.06	0.14	0.19	0.12	0.13	0.77	0.15	0.12
22	0.08	0.07	0.66	1.60	0.05	0.13	0.15	0.09	0.10	0.71	0.17	0.25
23	0.07	0.06	0.29	0.97	0.05	3.69	0.17	0.07	0.08	0.67	0.17	0.25
24	0.08	0.05	0.24	0.64	0.04	1.24	0.16	0.06	0.08	0.77	0.15	0.21
25	0.07	0.05	0.19	0.47	0.05	0.61	0.19	0.05	0.07	1.14	0.14	0.18
26	0.06	0.05	0.22	0.39	0.05	0.46	0.30	0.05	0.06	0.86	0.13	0.15
27	0.05	0.05	0.22	0.34	0.04	0.58	0.24	0.04	0.05	0.72	0.13	0.16
28	0.05	0.06	0.15	0.28	0.04	4.60	0.19	0.04	0.09	2.09	0.15	0.16
29	0.05		0.13	0.24	0.03	1.81	0.15	0.04	0.18	2.83	0.14	0.31
30	0.05		0.16	0.20	0.14	0.83	0.11	0.04	0.26	0.99	0.13	0.61
31	0.05		0.20		0.76		0.08	0.04		0.56		0.62
Mean Average Daily Discharge (m^3/s)	0.20	0.06	0.41	0.65	0.12	0.79	0.20	0.18	0.11	0.54	0.22	0.18
Max Average Daily Discharge (m^3/s)	1.18	0.09	1.68	2.88	0.76	4.60	0.60	0.56	0.42	2.83	0.56	0.62
Min Average Daily Discharge (m^3/s)	0.05	0.05	0.06	0.18	0.03	0.13	0.07	0.04	0.03	0.07	0.13	0.10
Total Discharge (m^3/s)	6.07	1.73	12.81	19.44	3.80	23.68	6.05	5.69	3.38	16.81	6.57	5.60
Total Volume (Dam^3)	524	149	1107	1680	329	2046	523	491	292	1452	568	484
		Total Annual Discharge (m^3/s)			112							
		Total Annual Volume (Dam^3)			9644							

Appendix 1B: 2016 Discharge Summary for station HY013 at Achilles road. Discharge is in m^3/s.

Carruthers at Achilles 2016 Summary:												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1	0.47	0.81	0.30	4.02	0.26	0.05	0.05	0.07	0.03	0.22	0.13	0.23
2	0.35	0.51	0.27	1.24	0.27	0.05	0.07	0.05	0.03	0.28	0.13	0.18
3	0.28	0.78	0.25	0.79	0.23	0.05	0.05	0.04	0.02	0.29	0.28	0.16
4	0.19	0.83	0.22	0.65	0.21	0.05	0.04	0.04	0.03	0.25	0.22	0.14
5	0.15	0.43	0.21	0.60	0.19	0.20	0.04	0.03	0.03	0.23	0.16	0.20
6	0.12	0.32	0.20	0.60	0.17	0.26	0.04	0.04	0.03	0.13	0.13	0.22
7	0.12	0.29	0.23	1.19	0.16	0.19	0.03	0.04	0.05	0.07	0.12	0.26
8	0.12	0.27	0.41	0.95	0.16	0.12	0.07	0.03	0.09	0.17	0.12	0.22
9	0.33	0.26	0.47	0.58	0.15	0.10	1.22	0.02	0.09	0.21	0.18	0.18
10	2.26	0.24	0.69	0.44	0.14	0.08	0.37	0.02	0.08	0.17	0.20	0.15
11	2.68	0.18	0.90	0.70	0.14	0.15	0.22	0.02	0.13	0.10	0.14	0.14
12	0.75	0.16	0.55	0.86	0.12	0.14	0.16	0.02	0.11	0.07	0.13	0.15
13	0.67	0.13	0.48	0.57	0.16	0.09	0.12	0.23	0.08	0.04	0.13	0.15
14	0.39	0.10	0.95	0.46	0.19	0.08	0.15	0.26	0.13	0.04	0.13	0.14
15	0.32	0.08	1.47	0.39	0.18	0.06	0.11	0.15	0.13	0.03	0.13	0.13
16	0.41	0.09	1.21	0.34	0.17	0.06	0.09	0.36	0.13	0.06	0.12	0.12
17	0.40	0.11	1.28	0.31	0.21	0.06	0.07	0.23	0.21	0.12	0.12	0.12
18	0.29	0.11	0.87	0.29	0.17	0.05	0.06	0.14	0.24	0.12	0.12	0.14
19	0.22	0.11	0.60	0.28	0.14	0.05	0.06	0.10	0.19	0.14	0.12	0.13
20	0.18	0.53	0.45	0.25	0.12	0.05	0.06	0.08	0.18	0.17	0.13	0.12
21	0.17	0.69	0.39	0.21	0.11	0.05	0.06	0.08	0.20	0.23	0.13	0.13
22	0.14	0.28	0.35	0.23	0.10	0.05	0.05	0.06	0.19	0.19	0.13	0.14
23	0.12	0.22	0.37	0.22	0.10	0.05	0.04	0.05	0.19	0.15	0.12	0.14
24	0.10	0.73	0.44	0.19	0.09	0.05	0.04	0.04	0.21	0.13	0.14	0.18
25	0.10	2.36	0.64	0.20	0.08	0.04	0.25	0.07	0.17	0.13	0.15	0.22
26	0.13	0.81	0.67	0.65	0.07	0.04	0.18	0.07	0.24	0.12	0.14	0.30
27	0.20	0.51	0.85	0.60	0.08	0.05	0.17	0.05	0.28	0.15	0.15	0.68
28	0.19	0.38	1.44	0.36	0.08	0.05	0.39	0.04	0.24	0.17	0.14	0.47
29	0.15	0.45	1.23	0.29	0.06	0.04	0.16	0.04	0.23	0.15	0.17	0.40
30	0.17		0.67	0.25	0.06	0.04	0.11	0.03	0.24	0.14	0.18	0.33
31	0.16		1.83		0.05		0.08	0.03		0.14		0.28
Mean Average Daily Discharge (m^3/s)	0.40	0.44	0.67	0.62	0.14	0.08	0.15	0.08	0.14	0.15	0.15	0.21
Max Average Daily Discharge (m^3/s)	2.68	2.36	1.83	4.02	0.27	0.26	1.22	0.36	0.28	0.29	0.28	0.68
Min Average Daily Discharge (m^3/s)	0.10	0.08	0.20	0.19	0.05	0.04	0.03	0.02	0.02	0.03	0.12	0.12
Total Discharge (m^3/s)	12.34	12.79	20.92	18.70	4.45	2.39	4.61	2.56	4.20	4.62	4.39	6.51
Total Volume (Dam^3)	1066	1105	1807	1616	384	207	398	221	363	399	379	562
		Total Annual Discharge (m^3/s)			98							
		Total Annual Volume (Dam^3)			8508							

Appendix 1C: 2015 Discharge Summary for station HY089 at Squires Rd. Discharge is in m^3/s.

Carruthers at Squires 2015 Summary:												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1					0.06	0.26	0.14	0.02	0.00	0.01	0.10	0.03
2					0.05	0.11	0.09	0.05	0.00	0.01	0.10	0.04
3					0.05	0.06	0.06	0.15	0.00	0.01	0.07	0.04
4					0.04	0.04	0.04	0.09	0.00	0.01	0.06	0.04
5					0.04	0.03	0.03	0.07	0.00	0.01	0.06	0.03
6					0.04	0.05	0.03	0.06	0.00	0.01	0.06	0.03
7					0.03	0.03	0.03	0.04	0.00	0.01	0.06	0.03
8					0.03	0.40	0.04	0.05	0.00	0.01	0.04	0.03
9					0.03	0.34	0.02	0.04	0.00	0.05	0.04	0.03
10					0.04	0.13	0.02	0.11	0.00	0.03	0.04	0.04
11					0.06	0.11	0.01	0.14	0.00	0.02	0.09	0.04
12					0.07	0.18	0.01	0.06	0.01	0.01	0.10	0.04
13					0.05	0.29	0.01	0.03	0.03	0.02	0.11	0.04
14					0.04	0.12	0.01	0.03	0.03	0.01	0.07	0.04
15					0.03	0.12	0.02	0.08	0.01	0.01	0.05	0.08
16					0.03	0.13	0.03	0.04	0.01	0.01	0.05	0.05
17					0.02	0.08	0.04	0.03	0.01	0.01	0.04	0.05
18					0.02	0.05	0.07	0.02	0.01	0.00	0.05	0.05
19					0.02	0.05	0.06	0.02	0.01	0.01	0.07	0.03
20					0.02	0.03	0.05	0.02	0.03	0.03	0.06	0.03
21					0.01	0.02	0.04	0.02	0.01	0.02	0.04	0.03
22					0.01	0.03	0.03	0.01	0.01	0.02	0.05	0.10
23					0.01	1.49	0.03	0.01	0.01	0.01	0.04	0.09
24					0.01	0.36	0.03	0.01	0.01	0.01	0.03	0.09
25					0.01	0.15	0.04	0.01	0.01	0.05	0.03	0.07
26					0.01	0.10	0.07	0.01	0.00	0.03	0.03	0.05
27					0.01	0.16	0.05	0.01	0.00	0.01	0.04	0.06
28					0.01	1.26	0.04	0.00	0.01	0.73	0.05	0.05
29				0.07	0.01	0.53	0.03	0.00	0.02	1.11	0.03	0.06
30				0.07	0.04	0.22	0.02	0.00	0.05	0.16	0.03	0.16
31					0.23		0.01	0.00		0.08		0.17
Mean Average Daily Discharge (m^3/s)	#DIV/0!	#DIV/0!	#DIV/0!	0.07	0.04	0.23	0.04	0.04	0.01	0.08	0.06	0.06
Max Average Daily Discharge (m^3/s)	0.00	0.00	0.00	0.07	0.23	1.49	0.14	0.15	0.05	1.11	0.11	0.17
Min Average Daily Discharge (m^3/s)	0.00	0.00	0.00	0.07	0.01	0.02	0.01	0.00	0.00	0.00	0.03	0.03
Total Discharge (m^3/s)	0.00	0.00	0.00	0.14	1.10	6.92	1.19	1.23	0.31	2.50	1.69	1.73
Total Volume (Dam^3)	0	0	0	12	95	598	103	107	27	216	146	149
		Total Annual Discharge (m^3/s)			17 from April 29 to December 31, 2015							
		Total Annual Volume (Dam^3)			1454 from April 29 to December 31, 2015							

Appendix 1D: 2016 Discharge Summary for station HY089 at Squires Rd. Discharge is in m^3/s.

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Carruthers at Squires 2016 Summary:												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1	0.13	0.35	0.12	0.93	0.04	0.02	0.01	0.00	0.00	0.00	0.01	0.06
2	0.10	0.18	0.06	0.26	0.05	0.03	0.01	0.00	0.00	0.01	0.02	0.06
3	0.08	0.30	0.03	0.11	0.05	0.03	0.01	0.00	0.00	0.01	0.02	0.04
4	0.06	0.26	0.02	0.07	0.05	0.03	0.01	0.00	0.00	0.01	0.01	0.03
5	0.03	0.14	0.02	0.07	0.05	0.07	0.01	0.00	0.00	0.01	0.01	0.03
6	0.02	0.10	0.03	0.06	0.05	0.08	0.02	0.00	0.00	0.01	0.01	0.05
7	0.03	0.10	0.03	0.23	0.05	0.04	0.02	0.00	0.01	0.01	0.01	0.07
8	0.03	0.09	0.10	0.16	0.04	0.02	0.13	0.00	0.01	0.01	0.01	0.05
9	0.09	0.08	0.10	0.07	0.03	0.02	0.18	0.00	0.01	0.00	0.02	0.03
10	1.17	0.07	0.18	0.04	0.03	0.02	0.09	0.00	0.01	0.00	0.01	0.02
11	0.68	0.07	0.19	0.09	0.04	0.04	0.05	0.00	0.01	0.00	0.01	0.01
12	0.22	0.04	0.11	0.14	0.04	0.04	0.04	0.00	0.00	0.00	0.01	0.01
13	0.16	0.03	0.10	0.08	0.07	0.02	0.04	0.01	0.00	0.01	0.01	0.01
14	0.12	0.02	0.25	0.07	0.05	0.02	0.04	0.00	0.01	0.00	0.01	0.02
15	0.09	0.01	0.39	0.06	0.03	0.02	0.03	0.00	0.00	0.00	0.01	0.02
16	0.11	0.01	0.29	0.06	0.03	0.02	0.02	0.01	0.00	0.01	0.01	0.01
17	0.13	0.02	0.34	0.07	0.05	0.02	0.01	0.00	0.00	0.01	0.02	0.02
18	0.14	0.02	0.21	0.07	0.04	0.02	0.02	0.01	0.01	0.02	0.02	0.02
19	0.07	0.02	0.11	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.03
20	0.05	0.15	0.07	0.05	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.03
21	0.05	0.13	0.06	0.04	0.04	0.02	0.01	0.01	0.00	0.01	0.01	0.03
22	0.04	0.05	0.04	0.06	0.04	0.02	0.01	0.00	0.00	0.01	0.01	0.02
23	0.03	0.05	0.05	0.05	0.05	0.01	0.01	0.00	0.00	0.00	0.01	0.02
24	0.03	0.17	0.05	0.03	0.04	0.01	0.01	0.00	0.00	0.01	0.02	0.03
25	0.03	0.64	0.09	0.03	0.04	0.01	0.02	0.01	0.00	0.00	0.03	0.03
26	0.05	0.24	0.11	0.11	0.04	0.02	0.01	0.01	0.00	0.00	0.04	0.05
27	0.07	0.10	0.19	0.09	0.05	0.02	0.03	0.00	0.00	0.00	0.04	0.10
28	0.07	0.07	0.43	0.05	0.06	0.02	0.07	0.01	0.00	0.00	0.03	0.12
29	0.07	0.10	0.28	0.04	0.06	0.01	0.03	0.00	0.00	0.01	0.04	0.09
30	0.06		0.13	0.04	0.04	0.01	0.01	0.00	0.00	0.01	0.05	0.07
31	0.07		0.63		0.03		0.01	0.01		0.01		0.07
Mean Average Daily Discharge (m^3/s)	0.13	0.12	0.16	0.11	0.04	0.03	0.03	0.00	0.00	0.01	0.02	0.04
Max Average Daily Discharge (m^3/s)	1.17	0.64	0.63	0.93	0.07	0.08	0.18	0.01	0.01	0.02	0.05	0.12
Min Average Daily Discharge (m^3/s)	0.02	0.01	0.02	0.03	0.03	0.01	0.01	0.00	0.00	0.00	0.01	0.01
Total Discharge (m^3/s)	4.06	3.61	4.82	3.30	1.35	0.76	0.97	0.12	0.12	0.22	0.54	1.26
Total Volume (Dam^3)	351	312	417	285	117	65	84	10	11	19	46	108
		Total Annual Discharge (m^3/s)			21							
		Total Annual Volume (Dam^3)			1825							

Appendix 1E: 2015 Discharge Summary for station HY090 at Taunton Rd. Discharge is in m^3/s.

Carruthers at Taunton 2015 Summary:												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1					0.14	0.53	0.29	0.04	0.03	0.07	0.30	0.09
2					0.12	0.23	0.21	0.05	0.03	0.06	0.25	0.11
3					0.11	0.13	0.15	0.10	0.04	0.05	0.18	0.10
4					0.10	0.09	0.12	0.06	0.04	0.05	0.15	0.10
5					0.10	0.09	0.10	0.05	0.04	0.05	0.13	0.09
6					0.08	0.15	0.10	0.05	0.05	0.06	0.13	0.09
7					0.08	0.08	0.11	0.04	0.04	0.06	0.12	0.08
8					0.07	1.03	0.13	0.03	0.04	0.06	0.10	0.09
9					0.07	0.55	0.09	0.03	0.05	0.18	0.09	0.09
10					0.10	0.28	0.09	0.12	0.05	0.10	0.09	0.10
11					0.14	0.25	0.07	0.18	0.05	0.08	0.21	0.10
12					0.14	0.39	0.07	0.08	0.06	0.08	0.21	0.09
13					0.10	0.53	0.07	0.06	0.15	0.10	0.20	0.09
14					0.07	0.24	0.06	0.06	0.12	0.08	0.14	0.11
15					0.06	0.28	0.06	0.08	0.07	0.07	0.11	0.17
16					0.06	0.27	0.05	0.07	0.06	0.07	0.10	0.12
17					0.05	0.18	0.05	0.06	0.06	0.06	0.09	0.13
18					0.04	0.12	0.09	0.06	0.05	0.06	0.10	0.11
19					0.04	0.13	0.08	0.05	0.07	0.06	0.14	0.09
20					0.03	0.08	0.07	0.06	0.10	0.14	0.11	0.09
21					0.03	0.06	0.06	0.06	0.07	0.10	0.09	0.10
22					0.02	0.07	0.05	0.06	0.06	0.09	0.11	0.22
23					0.01	3.66	0.04	0.05	0.05	0.07	0.09	0.19
24					0.01	0.51	0.04	0.05	0.05	0.07	0.09	0.18
25					0.02	0.27	0.04	0.04	0.05	0.19	0.09	0.15
26					0.02	0.22	0.05	0.04	0.04	0.11	0.08	0.12
27				0.24	0.01	0.46	0.05	0.03	0.04	0.09	0.10	0.14
28				0.21	0.01	2.75	0.05	0.04	0.05	2.37	0.10	0.12
29				0.18	0.01	0.87	0.05	0.03	0.09	2.23	0.09	0.20
30				0.16	0.10	0.37	0.05	0.04	0.13	0.41	0.09	0.38
31					0.47		0.04	0.03		0.22		0.39
Mean Average Daily Discharge (m^3/s)	#DIV/0!	#DIV/0!	#DIV/0!	0.20	0.08	0.50	0.08	0.06	0.06	0.24	0.13	0.14
Max Average Daily Discharge (m^3/s)	0.00	0.00	0.00	0.24	0.47	3.66	0.29	0.18	0.15	2.37	0.30	0.39
Min Average Daily Discharge (m^3/s)	0.00	0.00	0.00	0.16	0.01	0.06	0.04	0.03	0.03	0.05	0.08	0.08
Total Discharge (m^3/s)	0.00	0.00	0.00	0.78	2.42	14.89	2.58	1.81	1.83	7.50	3.86	4.23
Total Volume (Dam^3)	0	0	0	67	209	1286	223	157	158	648	334	365
		Total Annual Discharge (m^3/s)			40 from April 27 to December 31, 2015							
		Total Annual Volume (Dam^3)			3447 from April 27 to December 31, 2015							

Appendix 1F: 2016 Discharge Summary for station HY090 at Taunton Rd. Discharge is in m^3/s.

Carruthers at Taunton 2016 Summary:

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1	0.29	0.79	0.19	2.16	0.14	0.03	0.02	0.02	0.02	0.02	0.01	0.05
2	0.22	0.39	0.16	0.62	0.15	0.03	0.02	0.02	0.02	0.02	0.02	0.05
3	0.18	0.71	0.14	0.38	0.14	0.03	0.02	0.02	0.02	0.02	0.03	0.04
4	0.14	0.55	0.12	0.31	0.13	0.03	0.02	0.02	0.02	0.02	0.02	0.03
5	0.09	0.29	0.11	0.30	0.12	0.11	0.02	0.02	0.02	0.02	0.02	0.03
6	0.09	0.24	0.12	0.30	0.11	0.13	0.02	0.02	0.02	0.02	0.03	0.05
7	0.09	0.21	0.16	0.80	0.10	0.06	0.02	0.02	0.03	0.02	0.02	0.07
8	0.09	0.21	0.32	0.48	0.10	0.04	0.43	0.01	0.04	0.02	0.02	0.06
9	0.27	0.20	0.33	0.28	0.09	0.03	0.53	0.01	0.03	0.02	0.03	0.03
10	2.97	0.17	0.58	0.20	0.09	0.03	0.12	0.02	0.03	0.01	0.02	0.02
11	1.25	0.15	0.56	0.40	0.09	0.07	0.07	0.02	0.03	0.01	0.03	0.02
12	0.39	0.11	0.34	0.46	0.09	0.06	0.05	0.02	0.02	0.02	0.02	0.03
13	0.33	0.09	0.31	0.29	0.11	0.03	0.04	0.04	0.02	0.02	0.02	0.02
14	0.25	0.06	0.77	0.24	0.11	0.03	0.05	0.05	0.03	0.01	0.02	0.02
15	0.21	0.06	1.09	0.21	0.10	0.02	0.04	0.02	0.02	0.01	0.02	0.03
16	0.27	0.08	0.75	0.18	0.09	0.03	0.03	0.08	0.02	0.02	0.03	0.02
17	0.27	0.09	0.90	0.17	0.12	0.02	0.03	0.04	0.02	0.02	0.03	0.02
18	0.24	0.10	0.54	0.17	0.10	0.03	0.03	0.03	0.03	0.03	0.03	0.02
19	0.15	0.09	0.34	0.17	0.09	0.02	0.03	0.02	0.03	0.02	0.03	0.03
20	0.13	0.53	0.25	0.14	0.08	0.02	0.03	0.02	0.03	0.02	0.02	0.04
21	0.13	0.35	0.22	0.12	0.08	0.02	0.03	0.02	0.02	0.02	0.02	0.03
22	0.11	0.15	0.19	0.14	0.07	0.02	0.03	0.01	0.02	0.01	0.02	0.03
23	0.10	0.12	0.23	0.13	0.07	0.02	0.03	0.01	0.02	0.01	0.02	0.03
24	0.10	0.74	0.24	0.10	0.06	0.02	0.03	0.01	0.02	0.02	0.02	0.04
25	0.10	1.52	0.38	0.10	0.05	0.02	0.09	0.02	0.01	0.02	0.03	0.04
26	0.13	0.45	0.43	0.40	0.05	0.03	0.05	0.02	0.01	0.01	0.04	0.11
27	0.18	0.23	0.56	0.30	0.06	0.03	0.17	0.02	0.01	0.01	0.04	0.29
28	0.16	0.22	1.18	0.17	0.05	0.02	0.19	0.02	0.01	0.01	0.04	0.17
29	0.14	0.28	0.71	0.15	0.05	0.02	0.07	0.02	0.02	0.02	0.04	0.14
30	0.12		0.38	0.13	0.04	0.02	0.03	0.02	0.02	0.02	0.04	0.10
31	0.18		1.84		0.03		0.02	0.03		0.02		0.09
Mean Average Daily Discharge (m^3/s)	0.30	0.32	0.47	0.33	0.09	0.03	0.08	0.02	0.02	0.02	0.03	0.06
Max Average Daily Discharge (m^3/s)	2.97	1.52	1.84	2.16	0.15	0.13	0.53	0.08	0.04	0.03	0.04	0.29
Min Average Daily Discharge (m^3/s)	0.09	0.06	0.11	0.10	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.02
Total Discharge (m^3/s)	9.39	9.20	14.45	10.01	2.74	1.02	2.33	0.75	0.66	0.56	0.80	1.77
Total Volume (Dam^3)	811	795	1249	865	237	88	201	64	57	49	69	153
		Total Annual Discharge (m^3/s)			54							
		Total Annual Volume (Dam^3)			4639							

Appendix 1G: 2015 Estimated Discharge Summary for the East Branch. Discharge is in m^3/s.

Carruthers Estimated East Branch 2015 Summary:												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1					0.08	0.27	0.15	0.03	0.03	0.05	0.19	0.06
2					0.07	0.12	0.12	0.00	0.03	0.05	0.15	0.07
3					0.06	0.08	0.09	0.00	0.03	0.04	0.11	0.06
4					0.06	0.06	0.08	0.00	0.04	0.04	0.09	0.06
5					0.06	0.06	0.07	0.00	0.03	0.05	0.08	0.06
6					0.05	0.11	0.07	0.00	0.04	0.05	0.07	0.05
7					0.04	0.05	0.08	0.00	0.04	0.05	0.06	0.06
8					0.04	0.63	0.09	0.00	0.03	0.05	0.05	0.06
9					0.04	0.22	0.07	0.00	0.05	0.13	0.05	0.06
10					0.06	0.15	0.07	0.01	0.05	0.07	0.05	0.06
11					0.08	0.14	0.06	0.03	0.04	0.07	0.12	0.06
12					0.07	0.21	0.06	0.02	0.05	0.07	0.10	0.06
13					0.05	0.24	0.06	0.03	0.12	0.08	0.09	0.06
14					0.04	0.12	0.05	0.03	0.08	0.07	0.06	0.07
15					0.03	0.16	0.04	0.00	0.06	0.06	0.06	0.09
16					0.03	0.14	0.02	0.03	0.05	0.06	0.05	0.07
17					0.03	0.10	0.01	0.04	0.05	0.06	0.05	0.07
18					0.02	0.07	0.01	0.04	0.05	0.05	0.05	0.07
19					0.02	0.08	0.02	0.04	0.06	0.05	0.06	0.06
20					0.02	0.05	0.02	0.04	0.07	0.10	0.05	0.06
21					0.01	0.04	0.02	0.04	0.05	0.07	0.05	0.07
22					0.01	0.04	0.02	0.04	0.05	0.07	0.06	0.12
23					0.00	2.17	0.01	0.04	0.04	0.06	0.06	0.10
24					0.00	0.15	0.01	0.04	0.05	0.06	0.06	0.09
25					0.01	0.12	0.01	0.03	0.05	0.14	0.05	0.08
26					0.01	0.12	0.00	0.03	0.04	0.09	0.05	0.07
27					0.01	0.30	0.00	0.03	0.04	0.08	0.06	0.08
28					0.00	1.49	0.02	0.03	0.04	1.65	0.06	0.07
29				0.10	0.00	0.35	0.02	0.03	0.07	1.12	0.05	0.14
30				0.09	0.06	0.16	0.03	0.03	0.08	0.25	0.06	0.22
31					0.24		0.02	0.03		0.15		0.22
Mean Average Daily Discharge (m^3/s)	#DIV/0!	#DIV/0!	#DIV/0!	0.10	0.04	0.27	0.05	0.02	0.05	0.16	0.07	0.08
Max Average Daily Discharge (m^3/s)	0.00	0.00	0.00	0.10	0.24	2.17	0.15	0.04	0.12	1.65	0.19	0.22
Min Average Daily Discharge (m^3/s)	0.00	0.00	0.00	0.09	0.00	0.04	0.00	0.00	0.03	0.04	0.05	0.05
Total Discharge (m^3/s)	0.00	0.00	0.00	0.20	1.31	7.97	1.41	0.71	1.51	5.00	2.17	2.50
Total Volume (Dam^3)	0	0	0	17	113	688	122	62	131	432	188	216
Total Annual Discharge (m^3/s)	23 from April 29 to December 31, 2015											
Total Annual Volume (Dam^3)	1968 from April 29 to December 31, 2015											

Appendix 1H: 2015 Estimated Discharge Summary for the East Branch. Discharge is in m^3/s.

Carruthers Estimated East Branch 2016 Summary:												
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1	0.16	0.44	0.07	1.23	0.10	0.00	0.01	0.02	0.02	0.01	0.01	0.00
2	0.12	0.21	0.10	0.36	0.10	0.00	0.01	0.02	0.02	0.01	0.01	0.00
3	0.10	0.42	0.11	0.26	0.09	0.00	0.01	0.02	0.02	0.01	0.01	0.00
4	0.08	0.29	0.09	0.24	0.08	0.00	0.01	0.02	0.02	0.01	0.01	0.00
5	0.06	0.16	0.09	0.23	0.07	0.04	0.01	0.02	0.02	0.01	0.01	0.00
6	0.06	0.13	0.10	0.24	0.05	0.05	0.00	0.02	0.02	0.01	0.01	0.00
7	0.06	0.11	0.13	0.57	0.06	0.02	0.00	0.02	0.02	0.01	0.01	0.00
8	0.06	0.12	0.22	0.33	0.06	0.02	0.29	0.01	0.02	0.01	0.01	0.01
9	0.18	0.12	0.23	0.21	0.06	0.01	0.35	0.01	0.02	0.01	0.01	0.01
10	1.80	0.10	0.40	0.16	0.05	0.01	0.02	0.01	0.02	0.01	0.01	0.01
11	0.57	0.08	0.37	0.31	0.06	0.02	0.02	0.02	0.02	0.01	0.01	0.01
12	0.17	0.07	0.23	0.33	0.04	0.02	0.01	0.02	0.02	0.01	0.01	0.01
13	0.18	0.06	0.21	0.22	0.05	0.01	0.00	0.03	0.02	0.01	0.01	0.01
14	0.14	0.04	0.52	0.17	0.06	0.01	0.00	0.04	0.02	0.01	0.01	0.01
15	0.12	0.05	0.70	0.14	0.07	0.01	0.01	0.02	0.02	0.01	0.01	0.01
16	0.16	0.07	0.46	0.12	0.06	0.00	0.01	0.07	0.01	0.01	0.01	0.01
17	0.15	0.07	0.56	0.11	0.08	0.00	0.01	0.04	0.02	0.01	0.01	0.01
18	0.10	0.08	0.33	0.10	0.06	0.00	0.01	0.02	0.02	0.01	0.01	0.01
19	0.08	0.07	0.23	0.10	0.05	0.00	0.02	0.02	0.02	0.01	0.01	0.01
20	0.08	0.38	0.18	0.09	0.04	0.00	0.02	0.02	0.02	0.01	0.01	0.00
21	0.08	0.22	0.17	0.08	0.04	0.00	0.02	0.02	0.02	0.01	0.01	0.01
22	0.07	0.10	0.15	0.08	0.03	0.00	0.02	0.01	0.02	0.01	0.01	0.01
23	0.07	0.07	0.18	0.08	0.03	0.00	0.02	0.01	0.02	0.01	0.01	0.01
24	0.06	0.57	0.19	0.07	0.02	0.00	0.02	0.01	0.01	0.01	0.01	0.01
25	0.07	0.88	0.29	0.07	0.01	0.00	0.07	0.02	0.01	0.01	0.01	0.01
26	0.09	0.22	0.32	0.28	0.01	0.01	0.04	0.02	0.01	0.01	0.00	0.06
27	0.11	0.13	0.37	0.21	0.01	0.00	0.15	0.02	0.01	0.01	0.00	0.20
28	0.09	0.15	0.75	0.13	0.00	0.00	0.12	0.02	0.01	0.01	0.00	0.05
29	0.07	0.18	0.43	0.11	0.00	0.01	0.05	0.02	0.01	0.01	0.00	0.04
30	0.07		0.25	0.09	0.00	0.01	0.02	0.02	0.01	0.01	0.00	0.03
31	0.11		1.20		0.00		0.01	0.02		0.01		0.02
Mean Average Daily Discharge (m^3/s)	0.17	0.19	0.31	0.22	0.05	0.01	0.04	0.02	0.02	0.01	0.01	0.02
Max Average Daily Discharge (m^3/s)	1.80	0.88	1.20	1.23	0.10	0.05	0.35	0.07	0.02	0.01	0.01	0.20
Min Average Daily Discharge (m^3/s)	0.06	0.04	0.07	0.07	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00
Total Discharge (m^3/s)	5.33	5.60	9.63	6.72	1.41	0.27	1.36	0.63	0.54	0.34	0.28	0.55
Total Volume (Dam^3)	460	483	832	580	122	24	117	54	47	29	24	47
		Total Annual Discharge (m^3/s)			33							
		Total Annual Volume (Dam^3)			2821							

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