Streamflow Variability in Agricultural Watersheds that Provide Habitat for Redside Dace

Prepared for: Fisheries and Oceans Canada

Redside Dace captured during Lake Huron Tributary inventory, June 2011

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Executive Summary

The Redside Dace (*Clinostomus elongatus*) is a small, colourful cyprinid species found in the pools and slow-flowing sections of small streams. Due to recent declines and threats to remaining populations, the species has been designated as Endangered in the province of Ontario and in Canada. Habitat degradation caused by agricultural activities has been identified as a threat facing Canadian Redside Dace populations; however, impacts affecting Redside Dace in agricultural landscapes has not been evaluated through rigorous investigation. The Redside Dace Recovery Strategy has identified agricultural development that causes declines in Redside Dace populations as a gap in the research. Populations of Redside Dace have been monitored in two small, agricultural Lake Huron tributaries, Gully Creek and Stanley Tributary J.

According to population studies, the Gully Creek and Stanley Tributary J populations of Redside Dace are considered stable. Long-term goals for the recovery of Ontario Redside Dace populations include protection and restoration of their habitat. Since 2007, 115 best management practices (BMPs) have been implemented in Gully Creek, while several projects have been completed in the Stanley Tributary J watershed.

Changes in some streamflow indices were observed in Gully Creek (*e.g.,* increasing baseflows, decreasing stream flashiness), which may benefit the species. For instance, increasing baseflows in Gully Creek may help to improve Redside Dace habitat, particularly during the summer low-flow period. Further, a decrease in stream flashiness may improve aquatic habitat by reducing erosion of the stream bed and bank. Although there was limited data available, the low level of baseflows in Stanley Tributary J is concerning, particularly for Redside Dace during summer. In addition, large flashiness values observed in the stream were comparable to those found in declining or extirpated Redside Dace populations in Greater Toronto Area streams. Stream temperatures in the Lake Huron tributaries appear to be within the range of values Redside Dace can tolerate. Sediment and total phosphorus (TP) load yields in Gully Creek were some of the highest found in southern Ontario. However, declines in sediment and nitrate-N concentrations were observed in the watershed, while total phosphorus remained stable. Concentrations of TP, sediment, and nitrate-N from the 1980s were compared to present day conditions in Stanley Tributary J, with a similar range of values observed between the two periods.

Practices that reduce nutrient and sediment movement in the uplands and headwaters benefit the habitat of aquatic species at risk as they prevent inputs of contaminants which would otherwise adversely affect the downstream habitat. Many of these same practices also help to minimize streamflow variability and high-flow events, conditions in which Redside Dace are sensitive. We are beginning to see positive impacts on small watersheds due to past BMP projects. However, further collaborative efforts are necessary to ensure the persistence of species at risk and their habitat in agricultural areas.

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1.0 Introduction

The Redside Dace (*Clinostomus elongatus*) is a small, colourful cyprinid species found in the pools and slow-flowing sections of small streams (McKee and Parker 1982, Novinger and Coon 2000). Due to recent declines and threats to remaining populations, the species has been designated as Endangered in the province of Ontario (OMNF 2009) and in Canada (COSEWIC 2017). Habitat degradation caused by agricultural activities has been identified as a threat facing Canadian Redside Dace populations; however, impacts affecting Redside Dace in agricultural settings have not been evaluated through rigorous investigation (RDRT 2010). The Redside Dace Recovery Strategy has identified agricultural development that causes declines in Redside Dace populations as a gap in the research (RDRT 2010). Populations of Redside Dace have been monitored in two small, agricultural Lake Huron tributaries, Gully Creek and Stanley Tributary J.

Intensive agricultural land use has been associated with increased flashiness and variability in flow conditions (Stanfield and Jackson 2011) and increases to nutrients and suspended sediment concentrations (Blann *et al.* 2009, King *et al.* 2015, Moore 2016). The development of surface and subsurface drainage systems to facilitate agricultural production throughout North America has significantly altered the hydrology of landscapes compared to historical conditions (Blann *et al.* 2009, Moore 2016). For instance, King *et al.* (2015) and Moore (2016) reviewed agricultural drainage literature and reported that tile drainage increases total water yield compared to untiled fields because it tends to increase the proportion of annual precipitation that reaches surface waters via subsurface (tile) flow. The increased contribution of runoff to streamflow can be expected to impair water quality in Redside Dace streams, as summer water temperatures and contaminant levels increase (O'Driscoll *et al.* 2010). Stream fishes, such as Redside Dace and similar species, are sensitive to changes in streamflow variability and high-flow events (Harvey 1987, Hill and Grossman 1987, Freeman *et al.* 2001, Craven *et al.* 2010, Reid and Parna 2017).

Agricultural practices are also known to affect nutrient and sediment inputs to adjacent surface water (Blann *et al.* 2009, King *et al.* 2015, Moore 2016). Nutrients and sediment are susceptible to loss from agricultural lands through surface runoff or subsurface (tile) drainage during precipitation events. High levels of suspended sediment can negatively affect aquatic species by clogging gills, impairing the quality of fish habitat, limiting the ability of 'sight feeders' to feed, reducing growth, and limiting disease tolerance (Kerr 1995). Agricultural nonpoint sources of phosphorus and nitrogen may also lead to excessive growth of aquatic plants in streams and cause dissolved oxygen concentrations to decrease to levels that cannot sustain some aquatic species (OMOEE 1994, CCME 2012). Some species of algae are known to be toxic to aquatic life.

Furthermore, stream temperature may be affected by agricultural land use practices, such as livestock grazing and removal of riparian vegetation or cover (Quinn *et al.* 1997, Nagasaka and Nakamura 1999, Borman and Larson 2003, COSEWIC 2017, Kovach *et al.* 2018). Rising stream temperatures that exceed the thermal tolerance of many aquatic species can negatively impact the species' populations (*e.g.,* Eaton and Scheller 1996, Mohseni *et al.* 1999, Kovach *et al.* 2018). Another consequence of increasing water temperature is a decline in dissolved oxygen levels.

Agricultural best management practices (BMPs) to stabilize flows and stream temperatures, and reduce nutrient and sediment concentrations have been undertaken in Gully Creek and Stanley Tributary J. An intensive monitoring program to evaluate stream health and BMPs was established in Gully Creek in 2010. Water monitoring occurred in Stanley Tributary J in the late 1980s and resumed in 2018.

1.1 Report Objectives and Format

This report summarizes the different approaches to evaluating water quality and quantity data collected from Gully Creek and Stanley Tributary J, two agricultural streams that provide habitat for the Endangered Redside Dace. The objectives of the project are to:

1) evaluate water quality (temperature, nutrients, sediment) in the watersheds;
2) evaluate water quantity (flashiness, streamflows, baseflows) in the watersheds; and
3) evaluate stewardship efforts and their capacity to improve stream conditions in the watersheds.

To address these project objectives, the remainder of the report is organized into three sections:

1) Site Selection and Methods;
2) Results and Discussion; and
3) General conclusions and next steps.

2.0 Watershed Monitoring

2.1 Site Selection

The monitoring stations are located in 'The Gullies' watersheds, a number of small parallel basins that drain mostly agricultural landscapes directly into Lake Huron (Table 1, Figure 1). Gully Creek is 14 km^2 in area, the largest in the North Gullies watersheds. Gully Creek is located north of the Town of Bayfield, Ontario. Currently, small residential areas are scattered throughout the watershed and the remaining land use is primarily agricultural with a considerable proportion of natural area for much of its length. Stanley Tributary J is a 6 km^2 watercourse in the South Gullies watersheds, located south of Bayfield. Currently, agriculture is more prevalent here than in Gully Creek, with a smaller proportion of natural areas in the watershed. Clay loam and sandy loam comprise the majority of soils for each watershed. In 1955, land use was evenly divided for row crops and hay and pastures; however, the ratio has changed noticeably since then, with more area devoted to row cropping. Natural areas have increased in both watersheds since 1955 due to farmland retirement and tree planting initiatives.

Table 1: Watershed size and land use (based on 1955, 1978, and 2018 cropping years) in each study watershed.

Watershed	Size (ha)	Year	Row Crops (%)	Hay/ Pasture (%)	Natural/ Roughland (%)[A]	Other (%)[B]
Gully Creek	1,427	1955	39.2	37.5	20.9	2.4
		1978	40.5	29.4	27.1	3.0
		2018	66.3	1.6	27.8	4.3
Stanley Tributary J	587	1955	41.7	44.3	9.6	4.4
		1978	64.2	17.2	14.5	4.1
		2018	72.0	6.8	17.7	3.5

[A] Includes riparian corridors, ditches, scrub land, woodlands and wetlands.
[B] Includes urban land, roads, pits, farmsteads, farm access roads, and ponds

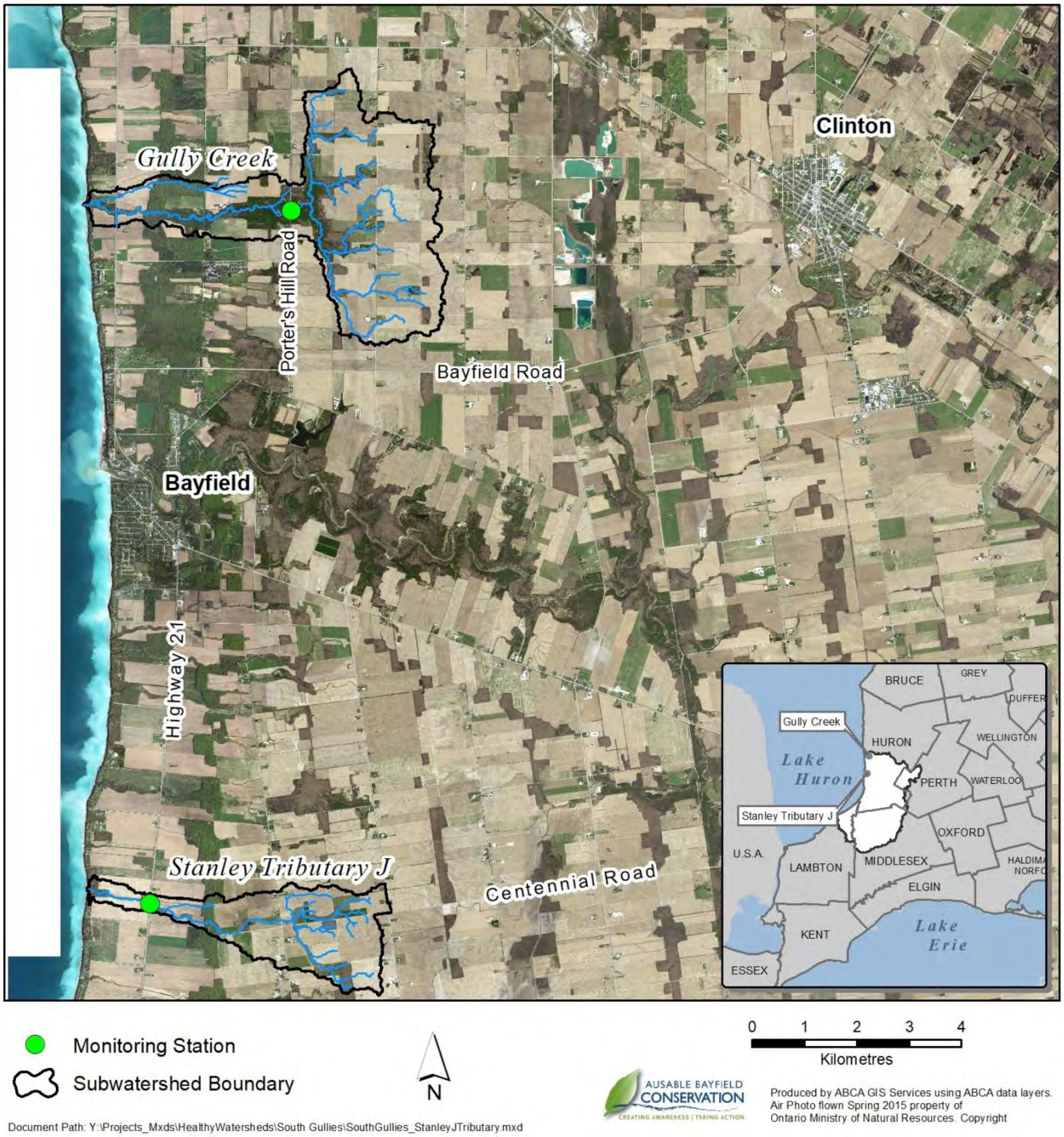

Figure 1: Location of the monitoring stations in the Gully Creek and Stanley Tributary J watersheds.

Water quality and quantity monitoring stations were selected to be as close to the headwaters as possible in each watershed, while maintaining accessibility to the stream. Headwaters are known to provide important habitat for Redside Dace (COSEWIC 2017). Stations were co-located with reliable flow gauging stations so that water quality results could be combined with stream discharge measurements for the computation of flow-weighted mean concentrations and loads (Figures 2 and 3).

Figure 2: An example of stream conditions at the Stanley Tributary J monitoring station (looking downstream) before and during an event.

Figure 3: An example of stream conditions at the Gully Creek monitoring station (looking downstream) before and during an event.

2.2 Field Methods

2.2.1 Water Quantity Monitoring

Water level (also referred to as water stage) data were collected sub-hourly at the stream gauges. At each station, a water level logger was used to measure water stage. This continuous record of stage was translated to stream discharge by applying a stage-discharge relationship (also called a rating curve). A rating curve was developed for each stream gauge by measuring the flow of the stream with a flow meter. For each measurement of discharge there is a corresponding measurement of stage. High and low stages and flows are particularly important for the development of the rating curve; however, it was unsafe to obtain manual measurements of flow in the streams when they were in peak-flow conditions. Instead, a theoretical equation related to the shape, size, slope, and roughness of the channel at the stream gauge was used to iteratively determine the stage-discharge relationship at higher stages and flows. This relationship differs between stream gauging stations and can also change over time at a specific station. More details on the water quantity monitoring methods can be found in Upsdell Wright *et al.* 2015a.

Mean daily discharge data were used for the period October 1, 2010 to September 30, 2018 for Gully Creek. Indices of flow quantity and variability were calculated for spring (May 1st to June 30th) and summer (July 1st to September 30th). The spring period includes the ranges of dates when Redside Dace are expected to spawn (McKee and Parker 1982, COSEWIC 2017). During the summer period, streamflow is reduced, and Redside Dace are largely confined to pools. The fall (October 1st to November 30th) and winter (December 1st to March 31st) periods were also examined, as stream fishes use overwintering habitat during these times. Stream baseflows, the dry-weather portion of streamflow usually attributed to groundwater discharge, were calculated using the Streamflow Analysis and Assessment Software 4.1 (SAAS) (Metcalfe and Schmidt 2016). The baseflow index (BFI), which is the ratio between baseflow and total streamflow, was also calculated. Measures of high flows and low flows were also determined according to Reid and Parna (2017). For instance, 10th and 90th flow exceedance values were evaluated as discharges that occur in the stream (or are exceeded) 10 and 90% of the time, respectively. Accordingly, 10th percentile flows represent high streamflow conditions, and 90th percentile flows represent low streamflow conditions.

Mean daily discharge values for Stanley Tributary J, measured between July 31 and December 31, 2018, were used to compare against hydrological indices from Gully Creek for the same period.

2.2.2 Water Quality Monitoring

Many water quality monitoring programs involve a random sampling strategy, whereby samples are collected on pre-determined days of the month. However, rain, rain-on-snow, and snowmelt events (herein referred to as events) are important because high concentrations of some pollutants, particularly sediment and phosphorus, are transported during these events (Upsdell Wright and Veliz 2013). The monitoring and modelling results in the Watershed Based Best Management Practices Evaluation study found that intermittent channels that form across the land contribute to poor water quality during storm events (Simmons *et al.* 2013). Further, practices to address rural water quality nutrient enrichment issues are undertaken to reduce the formation and/or the effects of these intermittent channels on the landscape. Therefore, water quality monitoring for this study included sample collection when water was running across the landscape in order to improve the accuracy of pollutant load estimates.

For the purposes of this study, water samples were collected year-round under both low-flow and high-flow conditions. Richards (1998) has shown that the 80th percentile of flow is an appropriate division for separating runoff events from low-flow periods for Lake Erie tributaries in Northwest Ohio. This study used the same approach. Continuous flow data from October 2010 to December 2019 were used to establish the low-flow conditions. A threshold was set at the 80th percentile of the continuous flow record for each of the sites to separate low-flow from event flow. Low-flow grab samples were collected monthly between October 2010, and March 2019. High-flow events were sampled with an ISCO automated sampler at each station. The ISCO samplers were set to trigger with a rise in water level and to collect samples throughout the hydrograph, attempting to capture samples at the onset of the event, mid-way up the rising limb of the hydrograph, at the peak, mid-way down the falling limb, and at the end of the event.

Water samples were analyzed for nutrients and suspended solids by the Ministry of the Environment, Conservation and Parks (MECP) laboratory in Etobicoke and ALS Laboratory in Waterloo.

More than 1,100 tributary water quality samples were collected between October 1, 2010, and March 15, 2019. It is important to recognize that a change in laboratory analysis method for total phosphorus occurred at MECP in November 2012.

In the study period (2010 to 2019), Gully Creek experienced 185 events, whereas only 18 events were documented in Stanley Tributary J in less than a year of monitoring (Table 2). Not all events were sampled. Some events were missed due to decisions made *a priori* about the size of the event, equipment malfunctions, and staffing issues. A more detailed account of the field methods for monitoring water quality is provided in Upsdell Wright *et al.* 2015a.

Table 2: Number of storm events and water quality samples for each watershed (October 2010 to March 2019).

Watershed	Water Years	Total Number of Events	Number of Events Sampled	Total Number of Samples
Gully Creek[a]	2011 - 2019	185	107	1,105
Stanley Trib. J[b]	2018 - 2019	18	7	26

[a] Incomplete flow record for 2019 water year.
[b] Incomplete flow record for 2018 and 2019 water year.

Additional water samples were collected in Stanley Tributary J during the period 1987 to 1989, as part of the Provincial Rural Beaches Strategy Program (RBSP). Up to 48 samples were collected during this program and analyzed for TP, TSS, and nitrate-N. Water quality results were compared to the 2018-2019 dataset; however, streamflow was not measured during the RBSP sampling period to directly compare loadings or flow-weighted mean concentrations.

Stream temperatures were measured sub-hourly at each gauging station. Mean daily temperature data was used for the period October 1, 2010 to September 30, 2018 for Gully Creek. Temperature values for Stanley Tributary J, measured between July 31 and December 31, 2018, were used to compare against thermal indices from Gully Creek for the same period.

2.3 Data Analysis Methods

For this report, both the monthly and annual flow-weighted mean concentrations and the loads have been summarized. Dickinson (in Upsdell Wright *et al.* 2015b) suggested that, if the focus of the study is on concentration targets or limiting ecological conditions, then concentration values are needed. However, if the focus of the study is on land use management or Great Lakes impacts, then load estimates are needed. Past water quality reports completed by the Ausable Bayfield Conservation Authority have reported findings as concentrations (see http://www.abca.on.ca/publications.php for past reports). However, calculating loads is important for comparing the contributions that are made from the different watersheds to Lake Huron.

Water quality indicator concentrations (nitrate-nitrogen, total phosphorus , and total suspended solids) from the grab and ISCO samples collected during the study period were converted to loads (mass per time), flow-weighted mean concentrations (FWMC) (mass per volume), and mass export loads (mass per watershed area). These computations help to remove the variability associated with event discharge and watershed size, respectively.

2.3.1 Mass Loads

Mass loads are the product of stream flow (volume per time) and concentration (mass per volume). A mass load (Equation 1) is a calculation of the total mass of a substance, usually expressed in kilograms, that is transported past a particular point on a stream or river over a given time period, often annually (Cooke 2000). In this study, monthly and annual loads were calculated.

Equation 1

$$\text{Mass Load (kilograms)} = \sum_{i=1}^{n} \frac{c_i + c_{int}}{2} q_j$$

Where,

n = total number of samples
i = number of a particular sample
c_i = concentration measured at the day and time of the ith sample
q_j = inter-sample mean flow
c_{int} = linearly interpolated concentration value between samples

2.3.2 Flow-Weighted Mean Concentrations

In a flow-proportionate sampling program, an individual water sample does not characterize the event or low-flow period. To estimate the average concentration, each sample must be weighted to represent a particular portion of the hydrograph (Equation 2; Cooke 2000). Flow-weighted mean concentrations (FWMC) are concentrations that are weighted by streamflow over a given period – in this study, the length of the month or water year. This computation allows for comparisons between streams with different flows or the same stream at different times.

Equation 2

$$\text{Flow-Weighted Mean Concentration (mg/L)} = \frac{Mass\ Load\ (kg)}{Total\ Stream\ Flow\ Volume\ (L)} \times 1000$$

2.3.3 Mass Export Loads

The total mass export load or unit-area load (Equation 3) is an estimate of the amount of the constituent that is lost per hectare of watershed for a given time period. This computation allows for comparisons between streams with different flows or the same stream at different times.

Equation 3

$$\text{Mass Export (kg/ha)} = \frac{Mass\ Load\ (kg)}{Watershed\ Area\ (ha)}$$

2.3.4 Stream Flashiness Index

Stream flashiness reflects how streamflow responds during runoff events, and includes factors, such as the magnitude and frequency of floods and low-flow periods and the rates of change of flow during those periods (Baker *et al.* 2004). Streams characterized as 'flashy' respond rapidly to precipitation events. Changes in land use (*e.g.,* conversion of forestland to cropland), land management practices (*e.g.,* improvements in agricultural drainage, adoption of conservation tillage, or implementation of structural BMPs), or hydrologic regimes largely influence how a stream will respond to precipitation events (Baker *et al.* 2004). The Richards-Baker (R-B) Stream Flashiness Index measures a stream's flashiness based on mean daily flows, and is calculated by dividing the sum of the absolute values of day-to-day changes in mean flow by total discharge during that time interval (Equation 4). A large value indicates greater streamflow variability between days.

Equation 4

$$\text{R-B Flashiness Index (dimensionless)} = \frac{\sum_{i=1}^{n} |q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$

Where,

q_i = mean daily streamflow on a given day (in m^3/s)

2.3.5 Spatial and Temporal Patterns

Loads are typically calculated annually and based on a water year (*e.g.*, October 1 to September 30). The United States Geological Survey uses a water year with an October 1 start date, as it is the time of year least likely to have major storm events on either side of that date. Use of this date is thought to avoid inflating or reducing the overall load for that year due to variations in major discharge events. For the purposes of the current study, to better understand baseline water quality conditions in each watershed, mass loads, flow-weighted mean concentrations, and mass export loads were calculated for the period between October 1, 2010, and September 30, 2018. Water quality was analyzed for nitrate-nitrogen (NO_3-N), total phosphorus (TP), total suspended solids (TSS), and stream temperature.

Annual pollutant transport is typically defined by seasonal changes, in which greater loads occur during large, infrequent storm events (usually during winter and spring) and smaller loads occur during smaller, more frequent storm events and low-flow periods (usually during fall and summer). In a given year, it is not uncommon for 80 to 90 percent of total loads to occur during only 10 to 20 percent of the time (Richards 1998). For this reason, pollutant loads, stream temperature, and streamflow yields were determined for individual seasons to assess patterns across each stream during the study period.

2.3.6 Trends in Monthly Water Quality and Quantity Data

Regression analyses were performed to evaluate trends in water quality and quantity data for each watershed during the current study period. The non-parametric Mann-Kendall trend test (Mann 1945, Kendall 1975) and Sen's slope estimation (Sen 1968) were used to evaluate the trends in monthly streamflow and baseflow indices, flow-weighted mean concentrations, and stream temperature. Some of the strengths of a Mann-Kendall trend test is that it does not require the datasets to be normally distributed and the results are not impacted by the magnitude of extreme values (as with linear regression trend tests). A one-tailed trend test was performed to determine the strength of the trend based on direction of the slope of the regression line (*i.e.*, improving trend, no trend, declining trend). A trend was found to be statistically significant when the magnitude of the change was large relative to the variation of the data around the trend line (*i.e.,* $p<0.05$). Monthly values were used instead of annual values to limit the effect of outliers and to retain inter-annual variability.

The average rate of change (%) in monthly water quality and quantity values was determined based on Sen's slope coefficient using Equation 5.

Equation 5

$$\text{Average monthly rate of change (\%)} = \left(\frac{Sen's\ slope\ coefficient, \beta_1}{Intercept\ of\ regression, \beta_0}\right) \times 100\%$$

2.3.7 Stewardship Efforts in Gully Creek and Stanley Tributary J

As the majority of land area in the Gully Creek and Stanley Tributary J watersheds is used for agriculture, many stewardship opportunities relate to implementing agricultural best management practices (BMPs). An agricultural BMP is a practical approach to conserving a farm's soil and water resources while maintaining productivity. Typical BMPs include farmland retirement, field windbreaks, tree planting, land management practices (*e.g.,* winter cover crops and residue management, conservation tillage or no tillage, fertilizer and manure management), erosion control structures, and cropland drainage. Conservation tillage is a system whereby more than 30% of the soil surface is covered with crop residue after planting, whereas conventional tillage systems leave less than 30% crop residue on the fields.

Previous research has highlighted the importance of implementing agricultural BMPs to improve stream conditions (*i.e.,* stream hydrology and water quality). For instance, Bittman and Veliz (2018a, b) found that uncovered fields in the non-growing season were more likely to generate surface runoff when compared to fields that were planted in cover crops. In addition, a hay field that was previously cropped was monitored in Gully Creek, resulting in the elimination of a concentrated flow path and reducing overland water flow from the field to the creek (Upsdell Wright *et al.* 2013). Since flow yield from fields is one of the leading drivers of stream loads, mitigating or reducing flows across the landscape is essential. Land management BMPs, such as cover crops and conservation tillage practices have been found to reduce surface runoff and peak discharge during events, particularly during the non-growing season or intercropping period (Brill and Neal 1950, Zhu *et al.* 1989, Dabney 1998, Veum *et al.* 2009, Yu *et al.* 2016, Singh *et al.* 2018). Reductions in surface runoff are due in part to increased field infiltration rates as a result of planting cover crops (McVay *et al.* 1989, Kaspar *et al.* 2001, Singh *et al.* 2018). By reducing total runoff or peak runoff rates in the non-growing season, there is potential to minimize stream erosion thereby reducing nutrient and sediment concentrations and loads (Brill and Neal 1950, Zhu *et al.* 1989, Sharpley and Smith 1991, Dabney 1998, Singh *et al.* 2018).

Tile drainage is used extensively in much of Huron County and facilitates infiltration and decreases surface runoff; however, soils with preferential flowpaths (*i.e.,* large cracks or macropores) may contribute significantly to streamflow when tiles are present (Sheler 2013, King *et al.* 2015). Tile drains have been found to contribute most of the annual water exported from agricultural fields, particularly during the non-growing season (Tan *et al.* 2002, Macrae *et al.* 2007, Van Esbroeck *et al.* 2016). King *et al.* (2015) and Moore (2016) reviewed agricultural drainage literature and reported that tile drainage increases total water yield because it tends to increase the proportion of annual precipitation that reaches surface waters via subsurface (tile) flow. Nutrient and sediment concentrations are typically lower in field tiles compared to surface runoff; however, mass loads tend to be larger due to the increase in water yields reaching surface waters (Pease *et al.* 2018). A grassed ditch in Gully Creek was monitored to evaluate its effectiveness in improving water quality and habitat for the Redside Dace (Upsdell Wright *et al.* 2013). It was found that the ditch acted as a filter to reduce average sediment and total phosphorus concentrations during runoff events. Water and sediment control basins (WASCoBs) have also been evaluated at two fields in and adjacent to the Gully Creek watershed (Bittman and Veliz 2018a, b). The results of the investigation showed significant reductions in the peak flows into and out of the berm, likely resulting in a decline in downstream flashiness. Evidence of improvements in water quality was associated to holding back surface water runoff by the WASCoB.

Due to the complexity of climate and hydrologic conditions, a Soil and Water Assessment Tool (SWAT) was developed for Gully Creek to determine the effectiveness of BMP implementation. The University of Guelph's Watershed Evaluation Group (WEG 2018) reported reductions of flow, TP, TSS, and total nitrogen (TN) loads as a result of implementing water and sediment control basins (WASCoBs) and land management BMPs, such as cover crops and conservation tillage.

3.0 Results and Discussion

3.1 Nutrient and Sediment Concentrations

In Gully Creek, annual flow-weighted mean TP and nitrate-N concentrations exceeded concentrations that are considered to protect aquatic life and minimize eutrophication: The Provincial Water Quality Objective for TP is 0.03 mg/L, while the Canadian Environmental Quality Guideline for nitrate-N is 2.93 mg/L. A previous analysis of phosphorus and nitrogen in Gully Creek showed that concentrations exceeded the standards the majority of the time, even under low-flow conditions (Upsdell Wright and Veliz 2013). Agricultural nonpoint sources of phosphorus and nitrogen may lead to excessive growth of aquatic plants in streams and cause dissolved oxygen concentrations to decrease to levels that cannot sustain some aquatic species (OMOEE 1994, CCME 2012). Some species of algae are known be toxic to aquatic life.

Annual total phosphorus concentrations ranged from 0.15–0.67 mg/L in Gully Creek between October 1, 2010 and September 30, 2018. Flow-weighted mean concentrations for nitrate-N ranged from 3.56–6.17 mg/L, while total suspended sediment concentrations ranged from 134–614 mg/L.

For direct comparison between Gully Creek and Stanley Tributary J, flow-weighted mean concentrations were calculated for the period July 31 to December 31, 2018. During this period, mean concentrations of TP and nitrate-N were the same for both watersheds (0.15 mg/L and 8 mg/L, respectively), while mean sediment concentrations were 56 mg/L in Gully Creek and 42 mg/L in Stanley Tributary J.

Water quality data collected in Stanley Tributary J during the Rural Beaches Strategy Program (RBSP) between 1987 and 1989 was compared to recent data collected in 2018 and 2019 (Figure 4). Although median concentrations were generally higher in 2018-2019, without streamflow information from the RBSP, it may not be possible to directly compare water quality data between programs. Of interest, however, is that the range of nutrient and sediment concentrations were comparable between sampling programs.

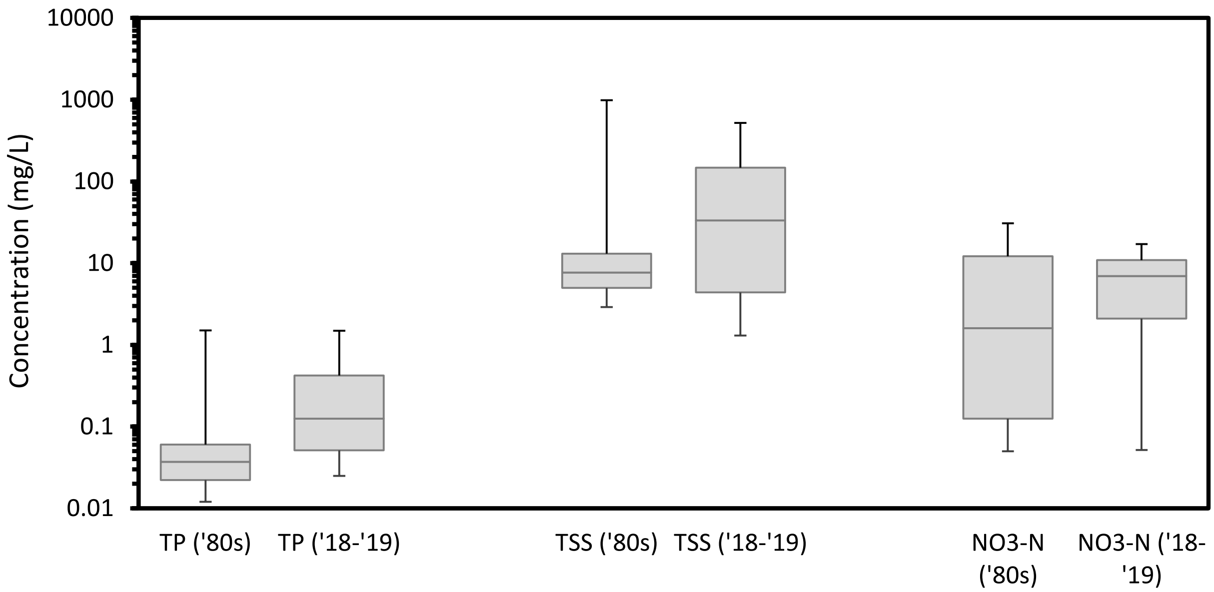

Figure 4: Comparison of water quality concentrations during the Rural Beaches Strategy Program (1987-1989) and the Habitat Stewardship Program (2018-2019). Whiskers represent the minimum and maximum concentration values, lower and upper limits of the boxes represent the 25th and 75th percentiles, and the horizontal line inside each box represents the 50th percentile.

3.2 Nutrient and Sediment Loads

Between October 1, 2010 and September 30, 2018, total phosphorus mass export loads in Gully Creek were higher than the range of values found in other streams in Southwestern Ontario (Table 3). The mean TP export load for Gully Creek was 2.10 kg/ha, ranging from 0.83 kg/ha during the 2013 water year to 4.36 kg/ha during the 2011 water year.

Table 3: Summary of annual total phosphorus mass export loads in agricultural, urban, and forested tributary catchments in Southwestern Ontario.

Land Use Type	Area	Mean (and Range) of TP Export Coefficient (kg/ha/year)	Reference
Agricultural	Gully Creek	2.10 (0.83 to 4.36)	This report
Agricultural	Southwestern Ontario	(0.10 to 1.50)	PLUARG 1978
Agricultural/Urban/Forest	Lake Simcoe Tributaries	0.36 (0.08 to 2.21)	LSRCA 2010
Agricultural	Southwestern Ontario	0.92 (0.20 to 1.89)	OMOE 2012
Agricultural/Urban	Hamilton, Ontario	0.87 (0.14 to 1.40)	Long *et al.* 2015

Sediment mass export loads ranged from 769–4,042 kg/ha in Gully Creek, which is relatively high compared to historical data from other streams in southern Ontario (160–1,810 kg/ha, in Dickenson and Green 1988; 62–520 kg/ha, OMOE 2012).

In addition, Gully Creek generated nitrate-N loads between 23–51 kg/ha.

For direct comparison between Gully Creek and Stanley Tributary J, mass export loads were calculated for the period July 31 to December 31, 2018. Nutrient and sediment mass export loads in Gully Creek were at least double those found in Stanley Tributary J. For instance, mass export loads for TP, TSS, and nitrate-N were 0.44 kg/ha, 160 kg/ha, and 24 kg/ha, respectively in Gully Creek, and 0.21 kg/ha, 60 kg/ha, and 12 kg/ha, respectively in Stanley Tributary J. Mass export loads were larger in Gully Creek primarily due to differences in drainage area (1,427 ha in Gully Creek versus 587 ha in Stanley Tributary J) and higher water yield (2,876 m^3/ha in Gully Creek versus 1,421 m^3/ha in Stanley Tributary J). Another possible explanation for the disparity in water yield is that the rating table (method to convert water level to discharge) for Stanley Tributary J was not as developed compared to Gully Creek, which may underestimate streamflow calculations.

3.3 Stream Temperatures

Between October 1, 2011 and September 30, 2018, median stream water temperatures in Gully Creek were 7.9°C (range = 0.1°C to 22.8°C). Median summer water temperatures were 17.3°C (range = 11.0°C to 22.8°C), while median spring temperatures were 13.7°C (range = 6.3°C to 20.8°C). Median water temperatures in Stanley Tributary J were 19.7°C (range = 12.1°C to 23.0°C) in August and September, 2018. During the same period, median water temperatures were lower in Gully Creek, at 17.8°C (range = 11.5°C to 20.7°C), likely reflecting greater groundwater inputs and riparian vegetation. Maximum water temperature for both sites was below the upper limit of 24°C suggested for Redside Dace (McKee and Parker 1982).

3.4 Trends in Water Quantity and Water Quality

Monthly water quality and stream hydrology measures were determined to detect trends in Gully Creek, between October 1, 2010 and September 30, 2018. Statistically significant trends in four of the six hydrology measures was observed (Table 4, Figure 5, Appendix A). Overall, streamflows remained stable during the study period (*i.e.,* no trend could be detected at a significance level of 0.05), though significant increases were detected during summer.

Table 4: Summary of annual water quality and quantity trends based on monthly data.

Station	Rate of Change (%/year)									
	Streamflow Yield	**Baseflow Yield**	**RBI**	**BFI**	**10%**	**90%**	**TP**	**NO_3-N**	**TSS**	**Water Temp.**
Gully Creek	n.s.	↑ (14)	↓(-5)	↑ (6)	n.s.	↑ (10)	n.s.	↓(-3)	↓(-7)	n.s.
Stanley Tributary J	–	–	–	–	–	–	–	–	–	–

*****Arrow denotes direction of trend with the relative change (derived from Sen's slope estimation) in brackets, n.s. indicates a non-significant trend, while a horizontal dash represents insufficient data for trend analysis. RBI is the stream flashiness index, BFI is the baseflow index, 10% is the 10^{th} percentile exceedance, 90% is the 90^{th} percentile exceedance, TP is total phosphorus, NO_3-N is nitrate-nitrogen, TSS is total suspended solids, and Water Temp. is stream temperature.

Median spring and summer baseflow (BFI) values in Gully Creek were 0.56 and 0.51 (Appendix B), similar to the East Humber River in the Greater Toronto Area (GTA), where a stable population of Redside Dace exists (Reid and Parna 2017). BFI values were only 0.16 for Stanley Tributary J in August and September, 2018, which is similar to values reported for Mimico Creek in the GTA, a system where Redside Dace are considered extirpated (Reid and Parna 2017). Low BFI values may be an indication of minimal groundwater and subsurface (tile) inputs. Baseflow yields increased by approximately 14% per year (p=0.0067) in Gully Creek relating to significant increases during summer and fall. An overall increasing trend in BFI was detected (6% per year, p=0.0041), but no trends were found in any individual season. The magnitude of low-flow events (90^{th} percentile exceedance) increased by up to 10% per year (p=0.0126), largely due to increases during the summer and fall periods.

Median spring and summer stream flashiness (RBI) values in Gully Creek were 0.29 and 0.38, slightly higher than the values reported for stable GTA populations, but less than the values described for declining GTA populations (Reid and Parna 2017). RBI values were 0.77 for Stanley Tributary J in August and September, 2018, which is similar to the declining and extirpated populations in the GTA (Reid and Parna 2017). Stream flashiness decreased by 5% per year (p=0.0029) in Gully Creek, driven by decreases in RBI during spring and fall. Since 2010, a number of large erosion control projects (e.g., WASCoBs) were implemented, comprising more than 15% of the watershed area, which might explain the change in stream flashiness. The magnitude of high-flow events (10^{th} percentile exceedance) remained stable during the study period. For instance, 10^{th} percentile exceedance values did not show a trend, even during individual seasons.

Statistically significant trends were determined for two of the four water quality measures. Overall, significant reductions in nitrate-N concentrations (3% per year, p=0.0270) and sediment concentrations (7% per year, p=0.0266) were detected in Gully Creek. Declines in sediment were driven largely during the fall period, whereas no seasonal trends were determined for nitrate-N. Total phosphorus concentrations remained stable during the study period.

Likewise, water temperatures remained stable in Gully Creek between October 2011 and September 2018. This finding may not be surprising given the considerable groundwater inputs and amount of riparian vegetation for much of its length which helps to moderate stream temperatures. When looking at individual seasons, no trends in water temperatures were detected.

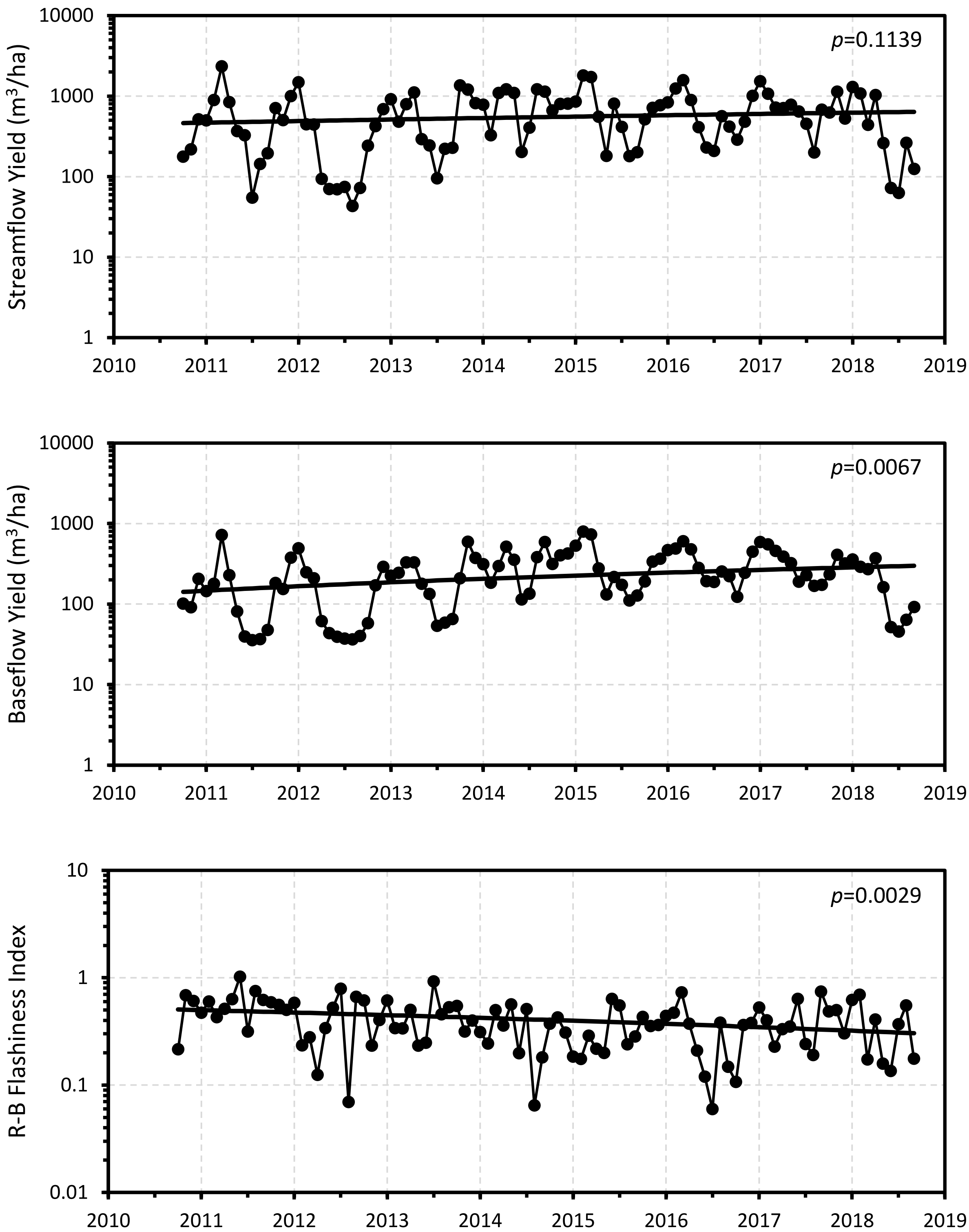

Figure 5: **An example of water quantity trends in monthly flashiness, and streamflow and baseflow yields for Gully Creek (October 2010 to September 2018).**

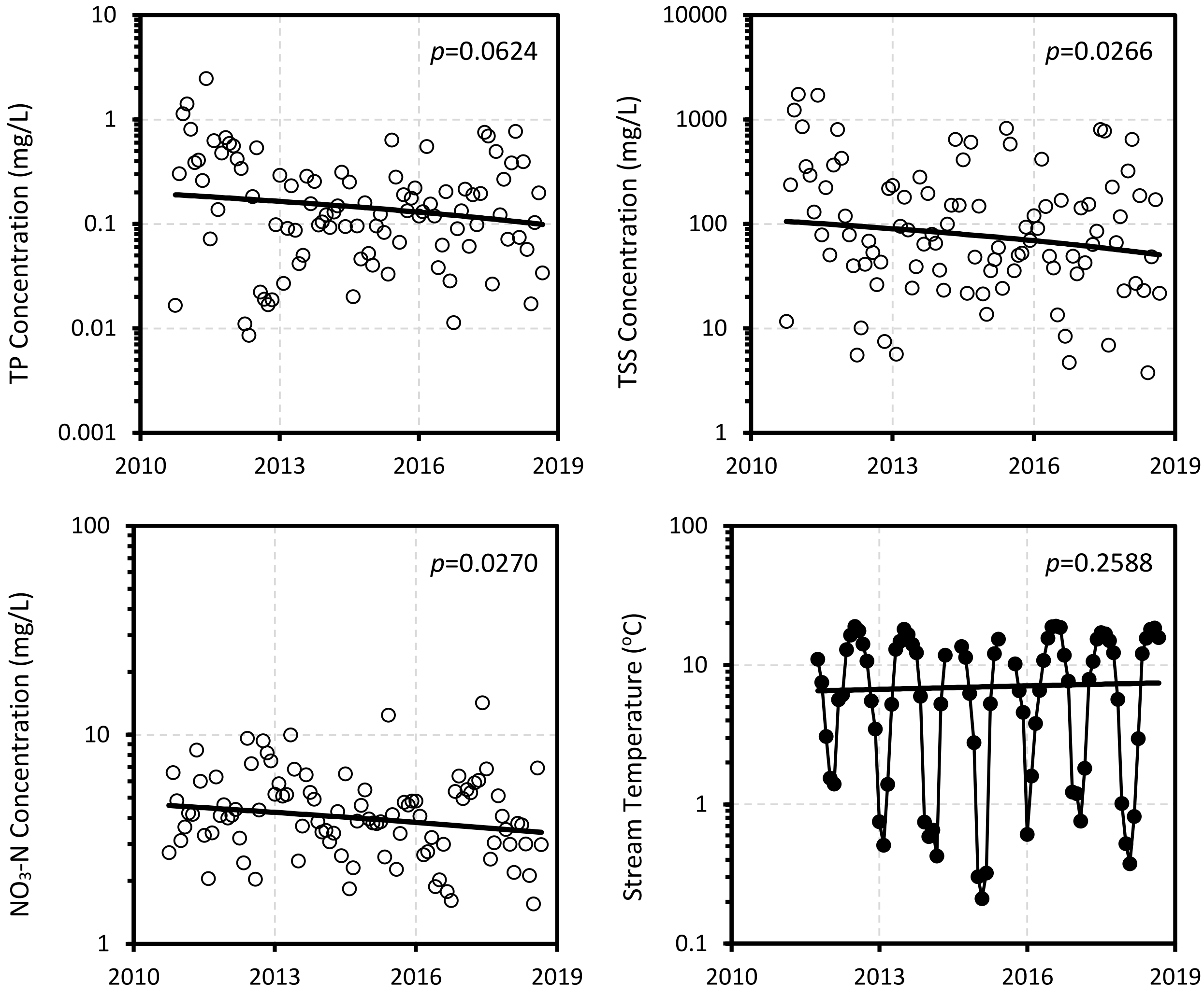

Figure 6: An example of water quality trends in monthly flow-weighted mean concentrations and stream temperatures for Gully Creek (October 2010 to September 2018). Note: A change of laboratory analysis method for total phosphorus occurred in November 2012 at the Ministry of the Environment and Climate Change.

3.5 Stewardship Efforts in Gully Creek and Stanley Tributary J

Windshield surveys of farmland in 2018 found that 2.1% of cropland area was planted in cover crops in Gully Creek, whereas no cover crops were reported for Stanley Tributary J (Table 5). Past research has indicated that the non-growing season is a vital period to have cover on the fields to help prevent surface runoff and nutrient and sediment losses (*e.g.,* Bittman and Veliz 2018a, b).

Minimal tillage or no tillage practices were common in both watersheds (51.2% in Stanley Tributary J and 69.1% in Gully Creek). Conservation tillage practices were not determined in Stanley Tributary J, while 10% of cropland was devoted to this practice in Gully Creek. Conventional tillage practices were more common in Stanley Tributary J at 37.3% of cropland area, while only making up 16.1% of the area in Gully Creek.

Table 5: Summary of land management practices in Gully Creek and Stanley Tributary J in 2018. Note: Percentages do not add up to 100%.

Station	BMP				
	Cover crop	Permanent Cover	No-Till	Conservation Tillage	Conventional Tillage
Gully Creek	2.1	1.6	69.1	10	16.1
Stanley Tributary J	0	8.3	51.2	0	37.3

The use of cover crops, conservation tillage, and tile drainage should be investigated further to improve our understanding of BMP adoption and its impact on water quality and quantity with existing monitoring data in the 'Gullies' watersheds.

During 2018 windshield surveys of farmland, it was noted that livestock (cattle) had unrestricted access to streamwater in the Stanley Tributary J watershed. Livestock access to watercourses can lead to erosion and impact water quality. For instance, research by Vidon *et al.* (2008) and Line *et al.* (2016) determined that cattle grazing in watercourses changed stream water quality, documenting substantial increases in total phosphorus and sediment. Exclusion fencing has been suggested to effectively improve water quality under these conditions (Line *et al.* 2016).

Agricultural BMPs have not been as widely adopted in Stanley Tributary J as they have been in Gully Creek. However, over the last 15 years, approximately 12 hecatres of farmland has been retired in the watershed, along with the planting of 1000s of trees as windbreaks and riparian cover.

Between 2007 and 2019, a total of 115 agricultural BMPs were implemented in Gully Creek (Table 6). Two projects were completed in 2018-2019, including 50 acres of cover crops planted in a field and 400 metres of trees planted for a windbreak. The remaining projects cover the majority of the watershed, but have been concentrated in the headwaters to effectively improve downstream water quantity and quality, and Redside Dace habitat.

Table 6: Agricultural best management practice implemented in the Gully Creek watershed (2007 to 2019).

BMP Type	Number of Projects	Area Affected (if applicable)
Streamside Restoration	1	50 m
Riparian Tree Planting	1	300 m
Water and Sediment Control Basins (WASCoBs)	48	930 ac
Wetland	2	1 ac
Grassed Waterway	2	167 m
Fragile Land Retirement	5	4.5 ac
Fragile Land Retirement – Windbreaks	5	1200 m
Fragile Land Retirement – Vegetative Cover	1	5.4 ac
Manure Storage Upgrade	2	
Manure Amendments	4	305 ac
No Tillage Implemented	6	1068 ac
Conservation Tillage Implemented	4	333 ac
Cover Crops Implemented	14	450 ac
Precision Agriculture Implemented[a]	14	900 ac

Nutrient Management Implemented	5	89 ac
Residue Management	1	141 ac
Total BMPs	**115**	

[a]Includes GPS systems, yield monitors, auto-steer equipment, and variable rate applicators.

4.0 Conclusions

This report has provided technical staff from the Ausable Bayfield Conservation Authority with the opportunity to summarize the water quantity and quality data that has been collected in two agricultural streams that provide habitat for the Endangered Redside Dace. Water quantity and quality monitoring has been undertaken since 2010 for Gully Creek, and the summer of 2018 for Stanley Tributary J.

According to population studies, the Gully Creek and Stanley Tributary J populations of Redside Dace are considered stable (COSEWIC 2017). Long-term goals for the recovery of Ontario Redside Dace populations include protection and restoration of their habitat (RDRT 2010). Since 2007, 115 best management practices (BMPs) have been implemented in Gully Creek, while several projects have been completed in the Stanley Tributary J watershed.

Results from Reid and Parna (2017) suggest that minimal changes in streamflow variability during the spring and summer months is an indication of stable Redside Dace populations in Greater Toronto Area (GTA) streams. This finding is consistent with the current study. However, some of the changes in streamflow observed in Gully Creek (*e.g.,* increasing baseflows, decreasing stream flashiness) may benefit the species. For instance, increasing baseflows in Gully Creek may help to improve Redside Dace habitat, particularly during the summer low-flow period. Agricultural BMPs, particularly water and sediment control basins, have been associated with reductions in peak flows and improvements to water quality (Bittman and Veliz 2018a, b). Further, a decrease in stream flashiness in Gully Creek may improve aquatic habitat by reducing erosion of the stream bed and bank. Although there was limited data available, the low level of baseflows in Stanley Tributary J is concerning, particularly for Redside Dace during summer. In addition, large flashiness values observed in Stanley Tributary J were comparable to those found in declining or extirpated Redside Dace populations in the GTA. Stream temperatures in the Lake Huron tributaries appear to be within the range of values Redside Dace can tolerate. Since 2011, stream temperatures in Gully Creek were found to be stable. Sediment and total phosphorus (TP) load yields in Gully Creek were some of the highest found in southern Ontario. However, declines in sediment and nitrate-N concentrations were observed in the watershed, while total phosphorus remained stable. Concentrations of TP, sediment, and nitrate-N from the 1980s were compared to present day conditions in Stanley Tributary J, with a similar range of values observed between the two periods.

Practices that reduce nutrient and sediment movement in the uplands and headwaters benefit the habitat of aquatic species at risk as they prevent inputs of contaminants which would otherwise adversely affect the downstream habitat. Many of these same practices also help to minimize streamflow variability and high-flow events, conditions in which Redside Dace are sensitive. We are beginning to see positive impacts on small watersheds due to past BMP projects. However, further collaborative efforts are necessary to ensure the persistence of species at risk and their habitat in agricultural areas.

4.1 Next Steps

In summary, continued monitoring of watershed data and Redside Dace populations in Gully Creek and Stanley Tributary J, would provide water managers and biologists with better approaches to understand stream conditions and aquatic habitat over time. Dissolved oxygen measurements should be collected in the streams to help assess the quality of aquatic habitat. Further implementation of best management practices should continue, particularly in Stanley Tributary J, to improve and restore stream habitat for the Redside Dace. Finally, Redside Dace surveys should continue in other lakeshore tributaries to verify the presence or absence of the species.

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Appendix A: Water Quantity Trends

Table A-1: Summary of results from Mann-Kendall trend tests for six indices of streamflow quantity. Indices were calculated for fall (October 1 to December 31), winter (January 1 to March 31), spring (May 1 to June 30), and summer (July 1 to September 30) periods using hydrometric data (2010 to 2018) from Gully Creek.

Water Quantity Index	Season	Trend
Streamflow Yield	Fall	n.s.
	Winter	n.s.
	Spring	n.s.
	Summer	↑ (28.589)
Baseflow Yield	Fall	↑ (27.745)
	Winter	n.s.
	Spring	n.s.
	Summer	↑ (20.861)
RBI	Fall	↓ (-0.028)
	Winter	n.s.
	Spring	n.s.
	Summer	↓ (-0.039)
BFI	Fall	n.s.
	Winter	n.s.
	Spring	n.s.
	Summer	n.s.
10th Percentile Exceedance	Fall	n.s.
	Winter	n.s.
	Spring	n.s.
	Summer	n.s.
90th Percentile Exceedance	Fall	↑ (0.009)
	Winter	n.s.
	Spring	n.s.
	Summer	↑ (0.006)

*Arrow denotes direction of trend with Sen's slope estimation in brackets, n.s. indicates a non-significant trend.

Appendix B: Streamflow Quantity and Variability Indices

Figure B-1: Median (and range) values for 6 indices of streamflow quantity and variability. Indices were calculated for fall (October 1 to December 31), winter (January 1 to March 31), spring (May 1 to June 30), and summer (July 1 to September 30) periods using hydrometric data (2010 to 2018) from Gully Creek.

Index	Season	Gully Creek
Streamflow Yield (m^3/ha)	Fall	677 (177 to 1361)
	Winter	904 (326 to 2344)
	Spring	276 (69 to 1094)
	Summer	205 (43 to 1215)
Baseflow Yield (m^3/ha)	Fall	265 (58 to 590)
	Winter	341 (144 to 790)
	Spring	147 (39 to 353)
	Summer	101 (36 to 586)
RBI	Fall	0.40 (0.11 to 0.69)
	Winter	0.42 (0.17 to 0.73)
	Spring	0.29 (0.12 to 1.02)
	Summer	0.38 (0.06 to 0.93)
BFI	Fall	0.42 (0.15 to 0.60)
	Winter	0.42 (0.20 to 0.63)
	Spring	0.56 (0.12 to 0.84)
	Summer	0.51 (0.24 to 0.90)
10th Percentile Exceedance (m^3/s)	Fall	0.43 (0.13 to 1.18)
	Winter	0.82 (0.18 to 2.46)
	Spring	0.16 (0.03 to 0.83)
	Summer	0.15 (0.02 to 0.70)
90th Percentile Exceedance (m^3/s)	Fall	0.12 (0.02 to 0.25)
	Winter	0.13 (0.06 to 0.38)
	Spring	0.06 (0.02 to 0.14)
	Summer	0.04 (0.01 to 0.27)

Appendix C: Water Quality Trends

Table C-1: Summary of results from Mann-Kendall trend tests for 4 indices of water quality. Indices were calculated for fall (October 1 to December 31), winter (January 1 to March 31), spring (May 1 to June 30), and summer (July 1 to September 30) periods using water quality data (2010 to 2018) from Gully Creek.

Water Quality Index	Season	Trend
Total Phosphorus	Fall	n.s.
	Winter	n.s.
	Spring	n.s.
	Summer	n.s.
Nitrate-Nitrogen	Fall	n.s.
	Winter	n.s.
	Spring	n.s.
	Summer	n.s.
Total Suspended Solids	Fall	↓ (-31.349)
	Winter	n.s.
	Spring	n.s.
	Summer	n.s.
Water Temperature	Fall	n.s.
	Winter	n.s.
	Spring	n.s.
	Summer	n.s.

*Arrow denotes direction of trend with Sen's slope estimation in brackets, n.s. indicates a non-significant trend.