Urbanization, long-term stream flow variability, and Redside Dace status in Greater Toronto Area streams

Scott M. Reid and Sarah Parna

Aquatic Research and Monitoring Section
Ontario Ministry of Natural Resources and Forestry
DNA Building, Trent University
2140 East Bank Drive
Peterborough, ON
K9J 7B8

2017

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3118

Fisheries and Oceans Canada
Pêches et Océans Canada

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la base de données Résumés des sciences aquatiques et halieutiques.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 900 de cette série ont été publiés à titre de Manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme Manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de Rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de Rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3118

2017

Urbanization, long-term stream flow variability, and Redside Dace status in Greater Toronto Area streams

by

Scott M. Reid and Sarah Parna

Aquatic Research and Monitoring Section
Ontario Ministry of Natural Resources and Forestry
DNA Building, Trent University
2140 East Bank Drive
Peterborough, ON
K9J 7B8

PDF version: Cat. No. Fs97-4/3118E-PDF ISBN 978-0-660-08457-2 ISSN 1488-5387

Correct citation for this publication:

Reid, S.M., Parna, S. 2017. Urbanization, long-term stream flow variability, and Redside Dace status in Greater Toronto Area streams. Can. Manuscr. Rep. Fish. Aquat. Sci. 3118: iv + 20 p.

TABLE OF CONTENTS

ABSTRACT

Redside Dace (*Clinostomus elongatus*) is a small, colorful cyprinid found in the pools and slow-flowing sections of small Ontario streams. As a result of recent declines and threats to remaining populations, the species has been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and the province of Ontario as Endangered. Habitat degradation caused by urban development is considered a primary threat. However, a clearer understanding of urban development impacts is still required to inform status assessments, and the degree to which the supply of suitable habitat meets current and future needs of the Redside Dace. In this study, hydrometric data for 6 Greater Toronto Area watersheds was used to characterize long-term (1966 to 2013) trends in stream flow condition (quantity and variability) for Redside Dace populations of differing conservation status. Compared to heavily urbanized watersheds where Redside Dace has been extirpated (Etobicoke and Mimico creeks), streams with healthy populations (East Humber River and Duffins Creek) were characterized by more stable spring and summer flows and greater contributions of groundwater. Over the assessment period, significant increases in flow variability and the magnitude of high flow events have occurred in watersheds where Redside Dace populations have declined. Significant declines in groundwater input to streamflow have also occurred in those watersheds where Redside Dace has been extirpated. Although the slopes of significant trends were generally lower, similar stream flow alterations were identified for the East Humber River, where the rate of human population growth has recently increased. Past research has linked changes in stream flow, similar to that observed in the Greater Toronto Area, to changes in channel morphology and water quality.

RÉSUMÉ

Le méné long (*Clinostomus elongatus*) est un petit cyprinidé coloré se trouvant dans les fosses et les sections à faible courant des petits cours d'eau de l'Ontario. À la suite des récents déclins et des menaces pesant sur les populations restantes, l'espèce a été jugée en voie de disparition par le Comité sur la situation des espèces en péril au Canada (COSEPAC) et la province de l'Ontario. La dégradation de l'habitat causée par le développement urbain est considérée comme une menace principale. Cependant, il faut encore mieux comprendre les impacts du développement urbain pour orienter les évaluations de l'état, ainsi que de la mesure dans laquelle les habitats appropriés disponibles répondent aux besoins actuels et futurs du méné long. Dans le cadre de cette étude, les données hydrométriques de six bassins hydrographiques de la région du Grand Toronto ont été utilisées pour caractériser les tendances à long terme (de 1966 à 2013) des conditions de débit des cours d'eau (quantité et variabilité) pour les populations de méné long ayant des statuts de conservation différents. Comparativement aux bassins hydrographiques très urbanisés où le méné long est disparu (ruisseaux Etobicoke et Mimico), les cours d'eau où se trouvent des populations saines (rivière East Humber et ruisseau Duffins) ont été caractérisés par des débits printaniers et estivaux plus stables et de plus grands apports en eau souterraine. Au cours de la période d'évaluation, d'importantes augmentations de la variabilité du débit et de l'ampleur des périodes de débit élevé se sont produites dans les bassins hydrographiques où les populations de méné long ont diminué. D'importants déclins des apports en eau souterraine au débit ont également eu lieu dans les bassins hydrographiques où le méné long a disparu. Même si les pentes des tendances importantes étaient généralement moins fortes, des modifications semblables du débit du cours d'eau ont été constatées dans la rivière East Humber, où le taux de croissance de la population humaine a récemment augmenté. Les recherches menées par le passé ont révélé un lien entre les modifications du débit, semblables à celles observées dans la région du Grand Toronto, et les modifications de la morphologie du cours d'eau et de la qualité de l'eau.

INTRODUCTION

Redside Dace (*Clinostomus elongatus*) is a small, colorful cyprinid found in the pools and slow-flowing sections of small streams with moderate gradient and riffle–pool sequences (McKee and Parker 1982; Novinger and Coon 2000). The species has a disjunct distribution across North America throughout the upper Mississippi River Drainage, Great Lakes Basin, Ohio River and upper Susquehanna River (Page and Burr 1991). As a result of recent declines and threats to remaining populations, the species has been assessed as Endangered in the province of Ontario (OMNRF 2016) and in Canada (COSEWIC 2007). Redside Dace is thought to be extirpated from almost half of the historically occupied watersheds in Canada, with many remaining populations in decline (COSEWIC 2007). Almost 80 percent of its Canadian distribution is located within the boundaries of the City of Toronto and adjacent municipalities. Habitat degradation caused by urban development activities is considered a primary threat facing Canadian Redside Dace populations (COSEWIC 2007), with local population sizes negatively affected by increasing amounts of upstream urban land-use (Poos et al. 2012). In the Greater Toronto Area, the human population is expected to grow by 37% by 2031 (MPIR, 2013), and therefore the stresses affecting remaining Redside Dace populations can be expected to increase.

Urbanization is known to increase impervious surface area in a watershed (Paul and Meyer 2001). The increase in impervious surface reduces infiltration of precipitation and increases run-off causing multiple impacts on aquatic systems, including: reduced baseflow, increased frequency of high flow events, and increased variability in flow conditions (Klein 1979, Degasperi et al. 2009). Low flow (*i.e.* summer) rates may also increase due to wastewater inputs and run-off from urban irrigation (Paul and Meyer 2001). Common stream geomorphological responses to urbanization include increased bank erosion and channel incision, channel widening and changes to bed material size (either finer or coarser) (O'Driscoll et al. 2010). Endemic fish species, fluvial specialists, and species intolerant to poor water quality are especially vulnerable to the effects of urbanization (Meador et al. 2005). In Lake Ontario tributaries, the amount of impervious cover, especially in the upstream extent of watersheds has been shown to influence the distribution of stream salmonids and other sensitive coldwater species (Stanfield and Kilgour 2006, Stanfield et al. 2006). Altered stream hydrology and geomorphology associated with increased urbanization could therefore result in habitat loss for Redside Dace (COSEWIC 2007).

A high priority Redside Dace recovery action is to identify key factors (threats) associated with urban development that contribute to population declines (RDRT 2010). It is anticipated that this knowledge will improve the ability of resource managers to protect and enhance Redside Dace habitat through urban planning and the use of best management practices. A clearer understanding of the impacts of urban development is also required to inform assessments of population trajectories, and the degree to which supply of suitable habitat meets the current and future needs of the Redside Dace. In this study, hydrometric data for 6 Greater Toronto Area watersheds were used to characterize long-term (> 50 years) trends in stream flow conditions for Redside Dace populations with differing conservation status (*i.e.* extirpated, declining, and stable). Stream flow conditions were assessed using indices of flow quantity and variability.

METHODS

Forty-nine hydrometric gauge stations were identified in Greater Toronto Area watersheds that drain into Lake Ontario. Six hydrometric gauge stations were selected based on the knowledge of the recent population status of Redside Dace, whether long-term continuous stream flow data were available, and if flows were largely unregulated by reservoirs (Table 1). Population status was assigned based on information provided in Anderson (2002), COSEWIC (2007), Reid et al. (2008) and Poos et al. (2012). Stations were located in the following watersheds (population status in parentheses): Duffins Creek (stable), East Humber River (stable), Etobicoke Creek (extirpated), Lynde Creek (declining), Mimico Creek (extirpated), and Rouge River (declining). The surficial geology of studied watersheds is a complex mixture of glacial till and glacial lake deposits, with varying sediment textures (*i.e.* clay, silt, sand, and gravel) (Sharpe et al. 1997).

Mean daily discharge data for the period between 1966 and 2013 were obtained for each station from Water Survey of Canada (https://wateroffice.ec.gc.ca). For each station and year, indices of flow quantity and variability were calculated for the spring (May 1st to June 30th) and summer (July 1st to September 30th) periods. The spring period includes the range of dates when Redside Dace are expected to spawn (McKee and Parker 1982, COSEWIC 2007). During the summer period, streamflow is reduced, and Redside Dace are largely confined to pools. A season-based approach has been applied in past studies investigating altered flow regimes effects on stream fish young-of-year and juvenile fish abundance (Freeman et al. 2001, Craven et al. 2010). It is recognized that flow events with important consequences for channel morphology (and therefore stream habitat condition) can occur during late fall and spring snow-melt periods, but were not addressed in this study.

The following flow quantity measures were calculated using Streamflow Analysis and Assessment Software 3.0 (SAAS) (Metcalfe and Schmidt 2012): baseflow index (BFI) and the 10th and 90th percentile flow exceedance values. BFI is the ratio between baseflow and total stream flow. Baseflow is water which enters a stream from persistent, slowly varying sources, maintaining flow between precipitation events. 10th and 90th percentile flow exceedance values are discharges that occur in the stream (or are exceeded) 10 and 90% of the time, respectively. Accordingly, 10th percentile flows represent high stream flow conditions, and 90th percentile flows represent low stream flow conditions.

Two measures of stream flow variability were calculated: spread and the Richards-Baker Flashiness Index (R-B Index). Spread is a nonparametric analogue to the co-efficient of variation and independent of watershed size (Richards 1989). Spread was calculated as the interquartile range divided by the median daily flow value. A larger value indicates a more variable flow regime over the time period of interest. The R-B index was calculated using the following formula (Baker et al. 2004):

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

where q_i is the mean daily flow for a given date. A large value indicates more variability between dates.

The non-parametric Mann-Kendall trend test (Mann 1945, Kendall 1975) was used to determine whether individual flow indices had changed significantly over time in each watershed. Where trends were significant, the slope coefficient (Sens' slope) was calculated to describe the average rate of annual change. Prior to analysis, the risk of temporal autocorrelation inflating the significance of trends was assessed by examining autocorrelograms. Statistical tests were done using XLSTAT (Version 2015.5.01.23373). Flow variability trends were also visually assessed by plotting mean daily discharge versus year of record.

Watershed areas upstream of each station were delineated using the Ontario Flow Assessment Tool (OFAT 3) and the percentage of urban landcover in each of these areas was calculated using the Ontario Land Cover Compilation (OLCC) dataset (https://www.ontario.ca/data/ontario-land-cover-compilation-v20). OFAT 3 is available from the Ministry of Natural Resources and Forestry (https://www.ontario.ca/page/watershed-flow-assessment-tool). Urban landcover includes highways and roads, and residential, industrial, commercial and civic areas. The percent change in human population size was calculated using the closest census division and census data available from Statistics Canada (http://www12.statcan.gc.ca/census-recensement/index-eng.cfm).

RESULTS

Upstream watershed areas were between 68 and 205 km^2, and percent urban land cover between 5 and 88%. Percent urban land cover was highest for Etobicoke and Mimico creek watersheds, with much lower urban land cover in Duffins Creek and the East Humber River. Lynde Creek, Rouge River and East Humber River watersheds have experienced the largest recent increases in human population size (Table 1).

Median (calculated from 1966 to 2013 data) spring and summer baseflow (BFI) values were highest for the East Humber River and Duffins Creek, and lowest for Etobicoke and Mimico creeks (Table 2). Over the assessment period, significant declining trends in both spring and summer baseflow (BFI) were observed for Mimico and Etobicoke creeks. A decreasing trend in summer baseflow was also observed for East Humber River (Table 3).

Median 10% exceedance values were highest for Etobicoke Creek. Median 90th percentile exceedance values were highest for Duffins Creek (Table 2). Over the assessment period, a significant increasing trend in the magnitude of both spring and summer high flow events (10th percentile exceedance) was observed for 5 of the 6 watersheds (Table 3). Slope was greater for extirpated and declining populations than for stable populations (Table 3, Figure 2). The magnitude of low flow events (90th percentile exceedance) also increased significantly in Etobicoke Creek, Lynde Creek and Rouge River and East Humber River. Mimico Creek showed a significant decline in summer low flow magnitude. Across all watersheds, spring flow exceedance values were greater than during the summer.

Median spring and summer values for measures of flow variability (R-B Index and Spread) were greatest for Etobicoke and Mimico creeks, intermediate for Lynde Creek and Rouge River, and lowest for Duffins Creek and East Humber River. Except for Duffins Creek, summer flow variability was higher than during the spring (Table 2). Over the assessment period, increasing summer flow variability was observed for all watersheds except Duffins Creek (Figure 3). Slope of trend lines corresponded with Redside Dace status, with greater slopes being observed at extirpated and declining locations compared with stable locations.

Within each year, Duffins Creek and East Humber River flows were largely stable from mid-spring through late fall (Figures 4a and 4b). Alternatively, there was greater variability (i.e. frequency of high flow events) throughout the year in Etobicoke and Mimico creeks. Over the assessment period, the occurrence of summer and fall high flow events in Lynde Creek and Rouge River has increased.

DISCUSSION

Significant long-term stream flow alterations consistent with increasing urbanization are evident in locations from which Redside Dace have been extirpated (Mimico Creek and Etobicoke Creek) and where they are in decline (Lynde Creek and Rouge River). In urbanized areas, stormwater controls (i.e. stormwater management ponds, wetlands, and storage tanks) are present in only 28% of the Etobicoke and 31% of the Mimico watersheds (TRCA 2016). The East Humber River population (considered stable) also indicates alterations consistent with urbanization, although the alteration is slightly less severe. This corresponds with census data which, based on change in human population size, indicates that the East Humber River has undergone recent rapid urbanization. In the Rouge and East Humber watersheds, most of the urban areas have stormwater controls in place (TRCA 2016). Duffins Creek is considered a stable Redside Dace population and has not demonstrated any significant changes in streamflow over time. Differences among our study watersheds and observed changes over recent decades are consistent with studies of other urbanizing watersheds in North America (Moscrip and Montgomery 1997, Roy et al. 2005, White and Greer 2006, DeGasperi et al. 2009, O'Driscoll et al. 2010). Variation in Redside Dace distribution and population size has been related to the amount of impervious land-cover within sub-watersheds (Parish 2004, Poos et al. 2012). Results from this study indicate that measures of stream flow variability can also inform assessments of Redside Dace population status, habitat condition and threats to recovery and survival.

Redside Dace inhabit slow moving sections of streams with a mixture of overhanging grasses and shrubs, and pool and riffle habitats. Pools are used as resident habitat while riffles are used for spawning. Common stream channel responses to urbanization-related changes to stream hydrology include increased channel dimensions and decreased complexity of instream habitats (O'Driscoll et al. 2010). These alterations would be expected to reduce the amount and quality of pool and riffle habitats necessary to support key life history processes. There has been limited research documenting changes to Redside Dace habitat in response to increased urbanization. Parrish (2004) found Greater Toronto Area stream sites with Redside Dace to have smaller channel widths and smaller wetted width to depth ratios than those sites without Redside Dace, and steeper gradients between the bottom end of pools and the top end of riffles. Alternatively, Reid et al. (2008) failed to identify expected differences in the amount of deep pool habitat and fine sediments between historical and currently occupied stream sites in the Greater Toronto area. In those urbanized watersheds without Redside Dace, the contribution of groundwater to spring and summer streamflow is low and declining. The increased contribution of runoff to stream flow can be expected to impair water quality in Redside Dace streams, as summer water temperatures and contaminant levels will increase (O'Driscoll et al. 2010).

In addition to impacts on stream habitat, altered flow regimes may also have negative direct impacts on stream fishes. Survivorship of young-of-the-year of Rosyside Dace (sister species, *Clinostomus funduloides*) has been negatively correlated to high flow events after the reproductive period (Freeman et al. 1998). Craven et al. (2010) also reported young-of-the-year fish density in warmwater streams to be negatively correlated to flow variability during the rearing period. Due to their small size and limited swimming ability, larval and young-of-year stream fish are highly vulnerable to displacement during high flows (Harvey 1987). Redside Dace typically occupy small home ranges, and demonstrate a strong affinity for pools (Poesch and Jackson 2012). Hill and Grossman (1987) documented that high flows were capable of displacing Rosyside Dace downstream from home ranges. In urbanizing watersheds, high flow events associated with storm events could further negatively affect Redside Dace populations by disrupting the typical movement patterns of individuals, and displacing individuals downstream to stream reaches with poorer habitat quality.

Protection and rehabilitation goals for Ontario Redside Dace populations include: 1) the protection of water quality and stream hydrology; and, 2) to rehabilitate degraded Redside Dace habitats in areas adjacent to occupied reaches (RDRT 2010). Flow alterations that arise from increasing urbanization will make stream rehabilitation a challenge, as hydrology strongly influences stream geomorphology (Paul and Meyer, 2001). This highlights the importance of best management practices to mitigate against the impacts of development through sub-watershed planning, storm water management and low impact development strategies (Olding et al. 2004, MNR, 2011). Strategies that reduce fine sediment loading, and maintain the connection to the adjacent floodplain can counteract the effect of increased flashiness of flows on stream channel morphology (Annable et al. 2012). Additionally, remedial actions taken to preserve summer baseflow and enhance groundwater infiltration (Grebel et al. 2013) could mitigate the negative impact of elevated water temperatures and contaminant loading from surface runoff on Redside Dace populations.

REFERENCES

Anderson, J.J. 2002. Status of Redside Dace, *Clinostomus elongates*, in the Lynde and Pringle Creek watersheds of Lake Ontario. Canadian Field-Naturalist 116:76-80.

Annable, W.K., C.C. Watson, and P.J. Thompson. 2012. Quasi-equilibrium conditions of urban gravel-bed stream channels in south Ontario, Canada. River Research and Applications 28:302-325.

Baker, D. B., Richards, R. P., Loftus, T. T., and J.W. Kramer. 2004. A new flashiness index: characteristics and applications to Midwestern rivers and streams. Journal of the American Water Resources Association 40:503-522.

COSEWIC. 2007. COSEWIC assessment and update status report on Redside Dace *Clinostomus elongatus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 54pp.

Craven, S.W., J.T. Peterson, M.C. Freeman, T.J. Kwak, and E. Irwin. 2010. Modeling the relationships between flow regime components, species traits, and spawning success in warmwater streams. Environmental Management 46:181-194.

DeGasperi, C. L., Berge, H. B., Whiting, K. R., Burkey, J. J., Cassin, J. L., & Fuerstenberg, R. R. 2009. Linking hydrologic alteration to biological impairment in urbanizing streams of the Puget lowland, Washington, USA. JAWRA Journal of the American Water Resources Association. 45: 512-533.

Freeman, M.C., M.K. Crawford, J.C. Barret, D.E. Facey, M.G. Flood, J. Hill, D.J. Stouder and G.D. Grossman. Fish assemblage stability in a southern Appalachian stream. Canadian Journal of Fisheries and Aquatic Sciences 45:1949-1958.

Freeman, M.C., Z.H. Bowan, K.D. Bovee, and E.R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11:179-190.

Grebel, J.E., S.K., Mohanty, A.A. Torkelson, A. B. Boehm, C. P. Higgins, R. M. Maxwell, K. L. Nelson, and D.L. Sedlak. 2013. Engineered Infiltration Systems for Urban Stormwater Reclamation. Environmental Engineering Science 30:437-454.

Harvey, B. C. 1987. Susceptibility of young-of-the-year fishes to downstream displacement by flooding, Transactions of the American Fisheries Society 116:851-855.

Hill, J., and G. D. Grossman. 1987. Home range estimates for three North American stream fishes. Copeia 1987:376-380.

Kendall, M. G. 1975. Rank Correlation Methods. Griffin, London, UK.

Klein, R. D. 1979. Urbanization and stream quality impairment. Water Resources Bulletin 15: 948-963.

Mann. H. B. 1945. Nonparametric tests against trend. Econometrica 13:245–259.

McKee, P.M., and B.J. Parker. 1982. The distribution, biology, and status of the fishes *Campostoma anonalum*, *Clinostomus elongates*, *Notropis photogenis* (Cyprinidae), and *Fundulus notatus* (Cyprinodontidae) in Canada. Canadian Journal of Zoology 60:1347-1358.

Meador, M. R., J. F. Coles, and H. Zappia. 2005. Fish assemblage responses to urban intensity gradients in contrasting Metropolitan areas: Birmingham, Alabama and Boston, Massachusetts. American Fisheries Society Symposium 47:409-423.

Metcalfe, R. A. and B. Schmidt. 2012. Streamflow Analysis and Assessment Software (version 3): Reference Manual. Ontario Ministry of Natural Resources and Forestry.

Ministry of Natural Resources (MNR). 2011. DRAFT Guidance for Development Activities in Redside Dace Protected Habitat. Ontario Ministry of Natural Resources, Peterborough, Ontario. ii+42 pp.

Ministry of Public Infrastructure Renewal. 2013. Growth plan for the Greater Golden Horseshoe, 2006. Office Consolidation 2013. Toronto.

Moscrip, A. L, and D. R. Montgomery. 1997. Urbanization, flood frequency, and salmon abundance in Puget lowland streams. Journal of the American Water Resources Association 33:1289-1297.

MPIR (Ministry of Public Infrastructure Renewal). 2004. Places to grow: better choices, brighter future. Queen's Printer for Ontario, Toronto, Ontario. 55 pp.

Novinger, D.C. and T.G. Coon 2000. Behavior and Physiology of the Redside Dace, Clinostomus elongatus, a Threatened Species in Michigan. Environmental Biology of Fishes 57: 315-326.

O'Driscoll. M., S. Clinton, A. Jefferson, A. Manda, and S. McMillan. 2010. Urbanization effects on watershed hydrology and in-stream processes in the southern United States. Water 2:605-648.

Olding, D.D., T.S. Steele and J.C. Nemeth. 2004. Operational monitoring of urban stormwater management facilities in Richmond Hill, Ontario. Water Quality Research Journal of Canada 39:392-405.

Ontario Ministry of Natural Resources and Forestry (MNRF). 2016. Species at Risk in Ontario (SARO) List. Available from http://www.ontario.ca/environment-and-energy/species-risk-ontario-list [accessed September 8 2016].

Page, L.M. and B.M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. The Peterson Guide Series, vol. 42. Houghton Mifflin Company, Boston, MA.

Parish, J. 2004. Redside Dace Recovery Strategy fluvial geomorphology study. Report prepared for the Redside Dace Recovery Team by Parish Geomorphic. 22 p. + app.

Paul, M. J., and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333-365.

Poesch, M.S. and D.A. Jackson. 2012. Impact of species-specific dispersal and regional stochasticity on estimates of population viability in stream metapopulations. Landscape Ecology 27:405-416.

Poos, M., Lawrie, D., Tu, C., Jackson, D. A., and N.E. Mandrak. 2012. Estimating local and regional population sizes for an endangered minnow, Redside Dace (*Clinostomus elongatus*), in Canada. Aquatic Conservation: Marine and Freshwater Ecosystems 22: 47-57.

Redside Dace Recovery Team (RDRT). 2010. Recovery Strategy for Redside Dace (*Clinostomus elongatus*) in Ontario. Ontario Recovery Strategy Series. Prepared for the Ontario Ministry of Natural Resources, Peterborough, Ontario. vi + 29 pp.

Reid, S.M., Jones, N., and G. Yunker. 2008. Monitoring Redside Dace in Ontario streams: evaluation of single pass electrofishing and rapid habitat assessment. North American Journal of Fisheries Management 28:50-56.

Richards, R.P. 1989. Measures of flow variability for Great Lakes tributaries. Environmental Monitoring and Assessment 12:361-377.

Roy, A. H., M.C. Freeman, B.J. Freeman, S. J. Wenger, W.E. Ensign, and J.L. Meyer. 2005. Journal of the North American Benthological Society 24:656-678.

Sharpe, D.R., P.J. Barnett, T.A. Brennand, D. Finley, G. Gorrell, H.A.J. Russell, and P. Stacey. 1997. Surfical geology of the Greater Toronto and Oak Ridges Moraine area, Southern Ontario: Geological Survey of Canada, Open File 3062, Scale 1:200,000.

Stanfield, L.W., and B.W. Kilgour. 2006. Effects of percent impervious cover on fish and benthos assemblages and in-stream habitats in Lake Ontario Tributaries. In: Hughes, R.M., Wang, L., Seelbach, P.W. (Eds.), Landscape Influences on Stream Habitats and Biological Assemblages: American Fisheries Society, Symposium, 48. Bethesda Maryland, pp. 577–599.

Stanfield, L.W., Gibson, S.F., and J.A. Borwick. 2006. Using a landscape approach to identify the distribution and production of tributary habitats for juvenile salmonids in Lake Ontario. Tributaries. In: Hughes, R.M., Wang, L., Seelbach, P.W. (Eds.), Landscape Influences on Stream Habitats and Biological Assemblages: American Fisheries Society, Symposium, 48. Bethesda Maryland, pp. 607–621.

Toronto Region Conservation Authority (TRCA). 2016. Watershed Report Cards. Available from https://trca.ca/conservation/watershed-management/watershed-report-cards [accessed September 8 2016].

White, M.D. and K.A. Greer. 2006. The effects of watershed urbanization on the stream hydrology and riparian vegetation of Los Penasquitos Creek, California. Landscape and Urban Planning 74:125-138.

Table 1. Characteristics of watersheds upstream of Greater Toronto Area hydrometric gauging stations used to assess long-term stream flow variability in Redside Dace streams.

Watercourse and Station Code	Drainage Area (km^2)	% Urban Cover (2002)	Percent Population Increase (2001 to 2011)
Mimico Creek, 02HC033	67.8	88.3	1.6
Etobicoke Creek below QEW, 02HC030	205.0	61.3	8.0
Rouge River near Markham, 02HC022	181.3	50.2	44.6
Lynde Creek near Whitby, 02HC018	100.3	17.2	39.6
Duffins Creek above Pickering, 02HC019	93.5	22.4	1.8
East Humber River near Pinegrove, 02HC009	190.9	5.2	58.4

Table 2. Median (range) values for 5 indices of stream flow quantity and variability. Indices were calculated for spring (May 1 to June 30) and summer (July 1 to September 30) periods using hydrometric data (1966 to 2013) from 6 Greater Toronto Area watersheds with differing Redside Dace population status.

		Extirpated		Declining		Stable	
Index	Season	Etobicoke	Mimico	Lynde	Rouge	East Humber	Duffins
Spread	Spring	3.91 (11.1)	5.39 (19.9)	1.56 (6.4)	1.96 (6.5)	1.28 (3.0)	0.90 (3.1)
	Summer	7.40 (10.7)	8.56 (45.2)	2.00 (7.5)	3.11 (12.0)	1.38 (5.4)	0.58 (4.9)
RBI	Spring	0.78 (0.8)	0.89 (0.6)	0.38 (0.9)	0.46 (0.7)	0.25 (0.5)	0.23 (0.7)
	Summer	0.93 (0.7)	1.02 (1.1)	0.45 (0.7)	0.55 (0.8)	0.27 (0.7)	0.18 (0.7)
BFI	Spring	0.28 (0.4)	0.23 (0.3)	0.49 (0.6)	0.41 (0.4)	0.51 (0.5)	0.69 (0.5)
	Summer	0.22 (0.3)	0.17 (0.4)	0.49 (0.6)	0.34 (0.5)	0.57 (0.5)	0.78 (0.5)
10^{th} percentile exceedance	Spring	3.56 (21.5)	1.65 (5.1)	1.15 (7)	2.37 (10.3)	1.71 (6.2)	1.35 (3.1)
	Summer	2.93 (6.3)	1.27 (7)	0.65 (5.8)	0.65 (5.8)	0.69 (6.4)	0.88 (2.8)
90^{th} percentile exceedance	Spring	0.41 (0.7)	0.15 (0.2)	0.25 (1.0)	0.33 (1.0)	0.36 (0.8)	0.61 (0.4)
	Summer	0.29 (0.4)	0.09 (0.2)	0.15 (1.0)	0.24 (2.6)	0.21 (0.4)	0.52 (0.5)

Table 3. Summary of results from Mann-Kendall trend tests for 5 indices of stream flow quantity and variability. Indices were calculated for spring (May 1 to June 30) and summer (July 1 to September 30) periods using hydrometric data (1966 to 2013) from 6 Greater Toronto Area watersheds with differing Redside Dace population status.

		Extirpated		Declining		Stable	
Index	Season	Etobicoke	Mimico	Lynde	Rouge	East Humber	Duffins
Spread	Spring	n.s.	↑ (0.069)	n.s.	n.s.	n.s.	n.s.
	Summer	n.s.	↑ (0.089)	↑ (0.03)	↑ (0.037)	↑ (0.026)	n.s.
RBI	Spring	n.s.	↑ (0.004)	n.s.	↑ (0.004)	↑ (0.002)	n.s.
	Summer	↑ (0.006)	↑ (0.004)	↑(0.004)	↑(0.006)	↑ (0.003)	n.s.
BFI	Spring	↓ (-0.003)	↓(-0.003)	n.s.	n.s.	n.s.	n.s.
	Summer	↓ (-0.002)	↓(-0.003)	n.s.	n.s.	↓ (-0.004)	n.s.
10^{th} percentile exceedance	Spring	↑ (0.103)	↑ (0.078)	↑ (0.031)	↑ (0.054)	↑ (0.026)	n.s.
	Summer	↑ (0.041)	↑ (0.032)	↑ (0.013)	↑ (0.047)	↑ (0.017)	n.s.
90^{th} percentile exceedance	Spring	↑ (0.006)	n.s.	↑ (0.005)	↑ (0.011)	↑ (0.005)	n.s.
	Summer	↑ (0.003)	↓ (0.0007)	↑(0.002)	↑(0.006)	↑ (0.002)	n.s.

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

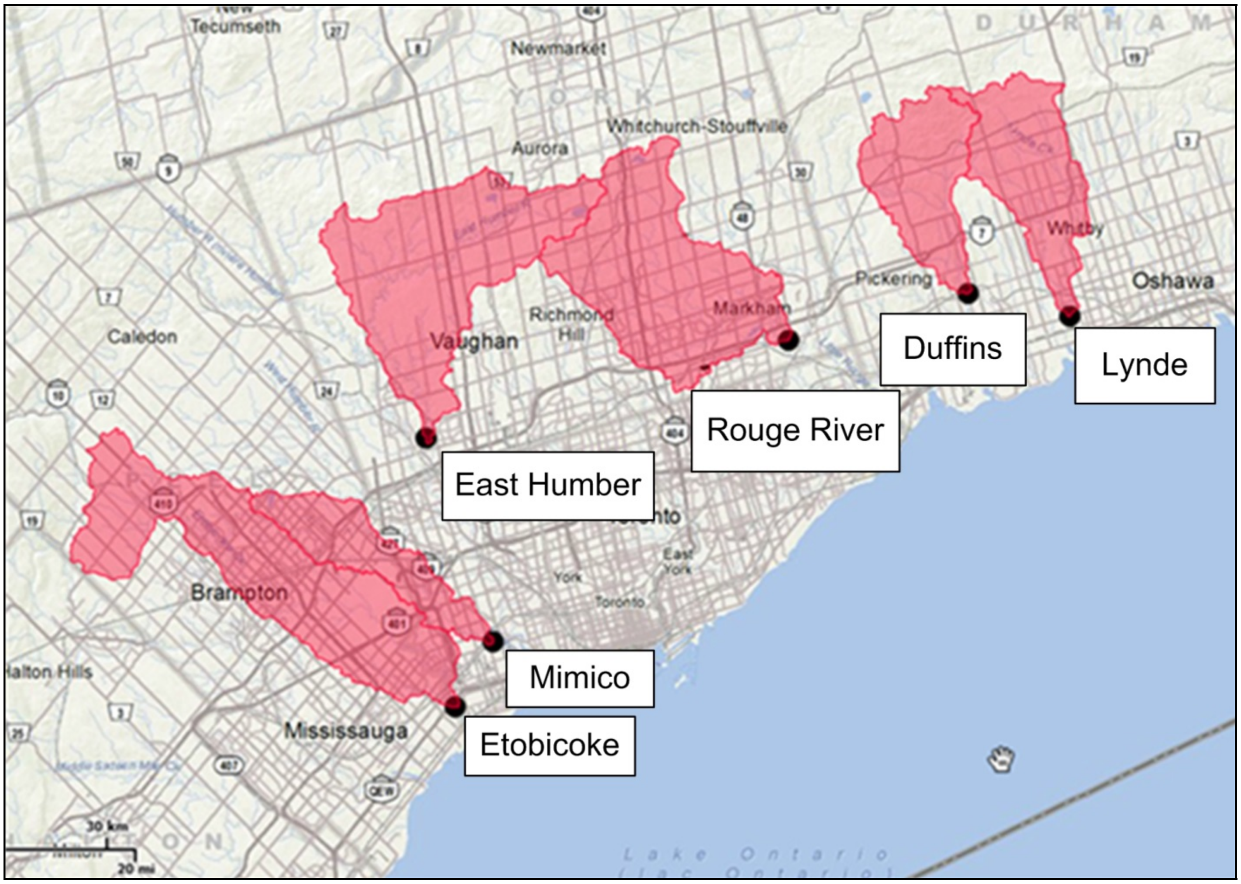

Figure 1. Locations and upstream watersheds of the 6 Greater Toronto Area hydrometric gauge stations used to assess stream flow variability in Redside Dace streams.

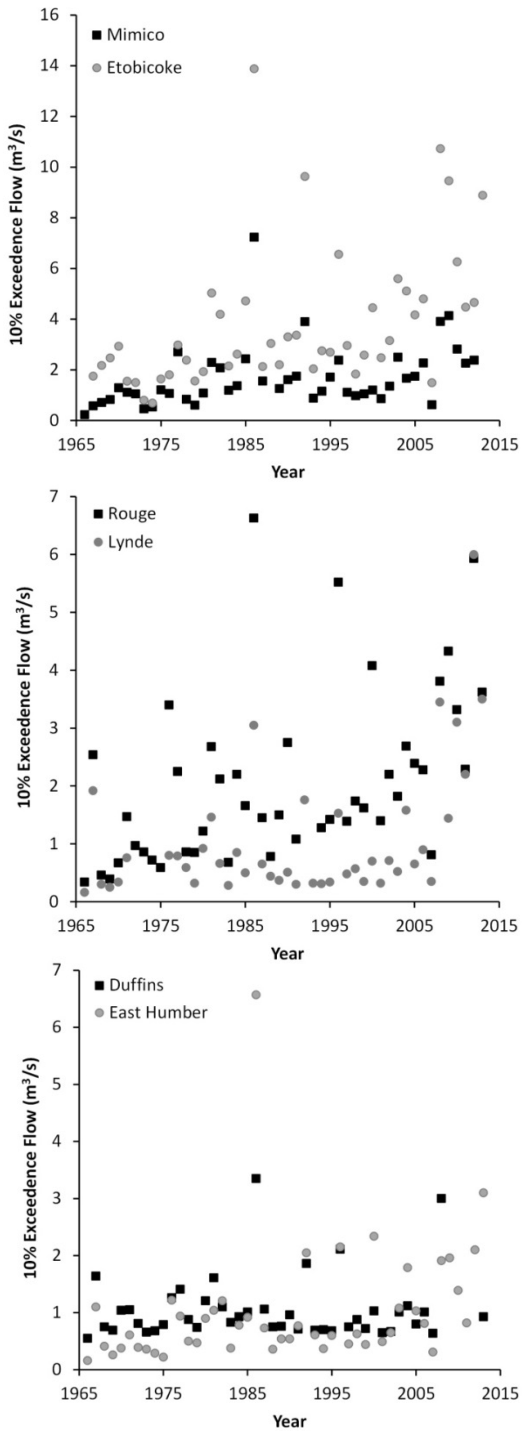

Figure 2. Comparison of long-term (1966-2013) trends in summer high flow events (10th percentile exceedance flows) among Greater Toronto Area watersheds with differing Redside Dace population status. Extirpated: Etobicoke and Mimico creeks; Declining: Lynde Creek and Rouge River; Stable: Duffins Creek and East Humber River.

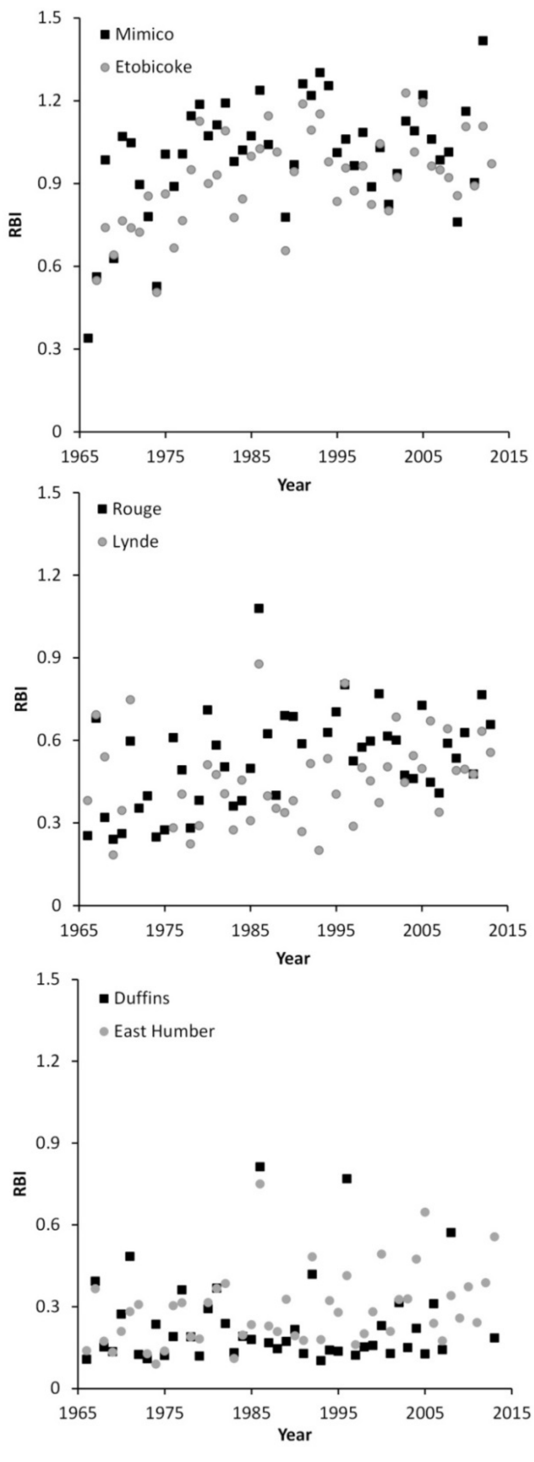

Figure 3. Comparison of long-term (1966-2013) trends in summer stream flow variability (RBI, Richards-Baker Flashiness Index) among Greater Toronto Area watersheds with differing Redside Dace population status. Extirpated: Etobicoke and Mimico creeks; Declining: Lynde Creek and Rouge River.

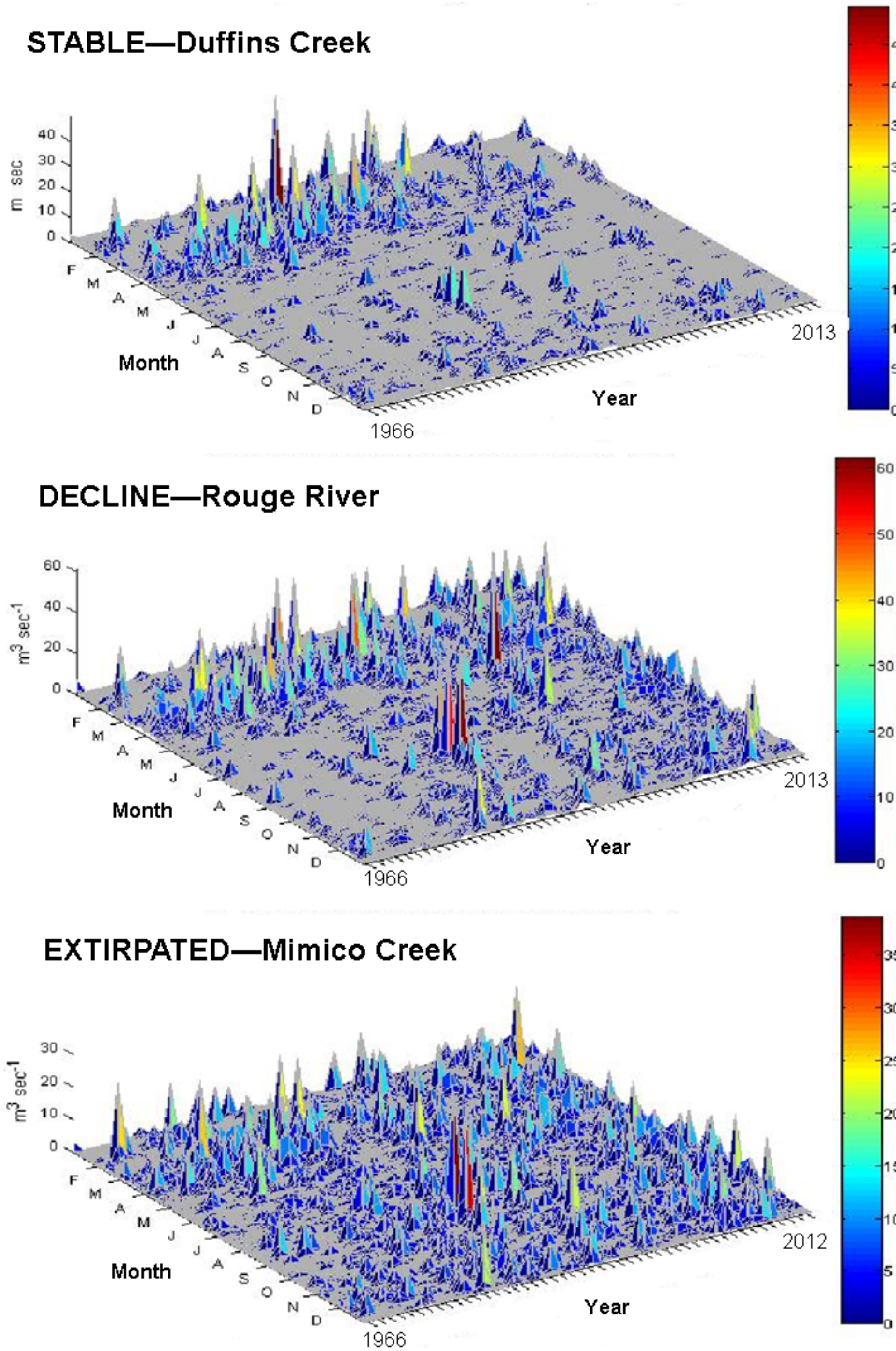

Figure 4a. Comparison of monthly and annual (1966-2013) variation in daily discharge measurements for 3 Greater Toronto Area watersheds, representing differing Redside Dace population status. Hydrometric gauging station data was obtained from Water Survey of Canada.

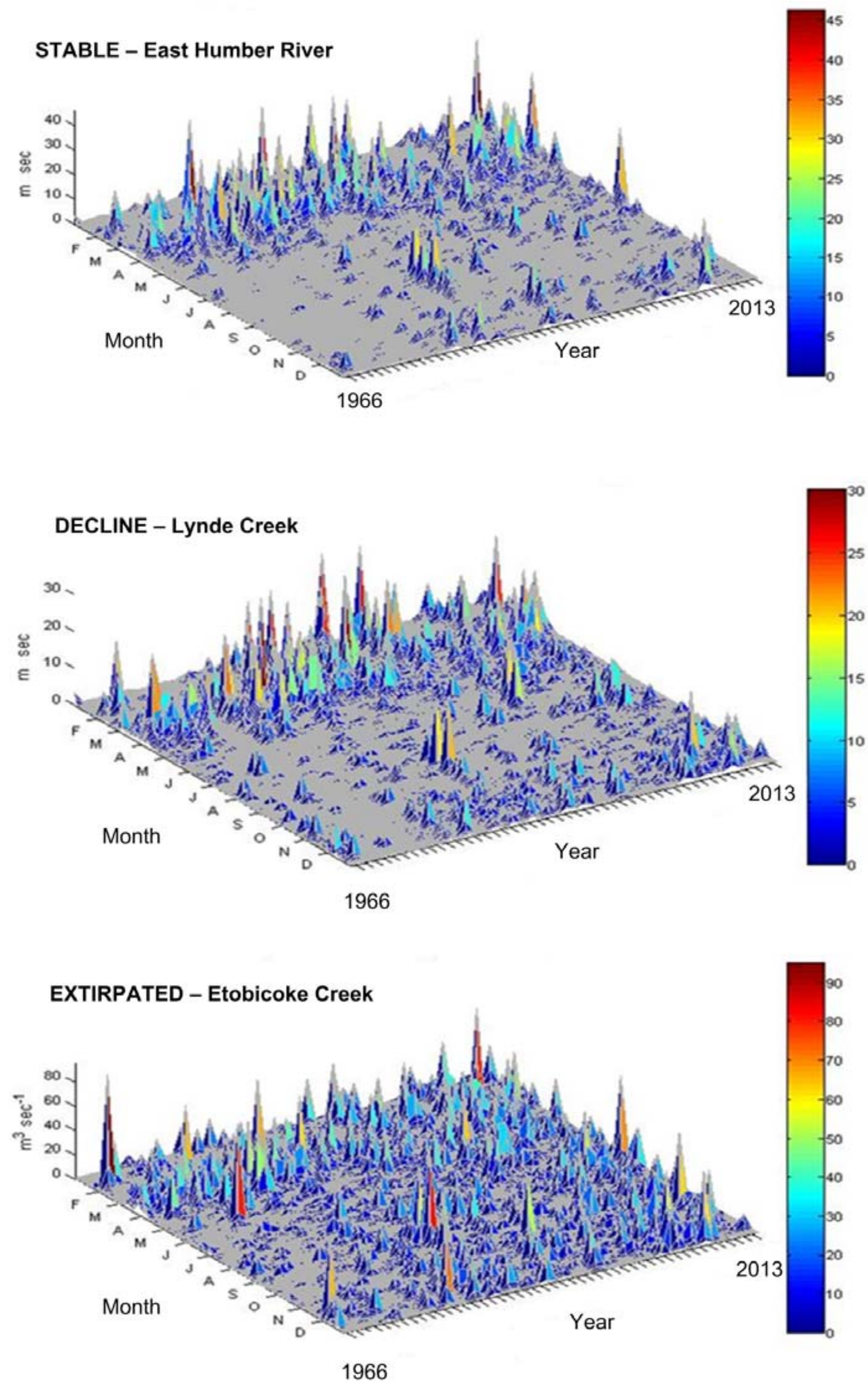

Figure 4b. Comparison of monthly and annual (1966-2013) variation in daily discharge measurements for 3 Greater Toronto Area watersheds, representing differing Redside Dace population status. Hydrometric gauging station data was obtained from Water Survey of Canada.