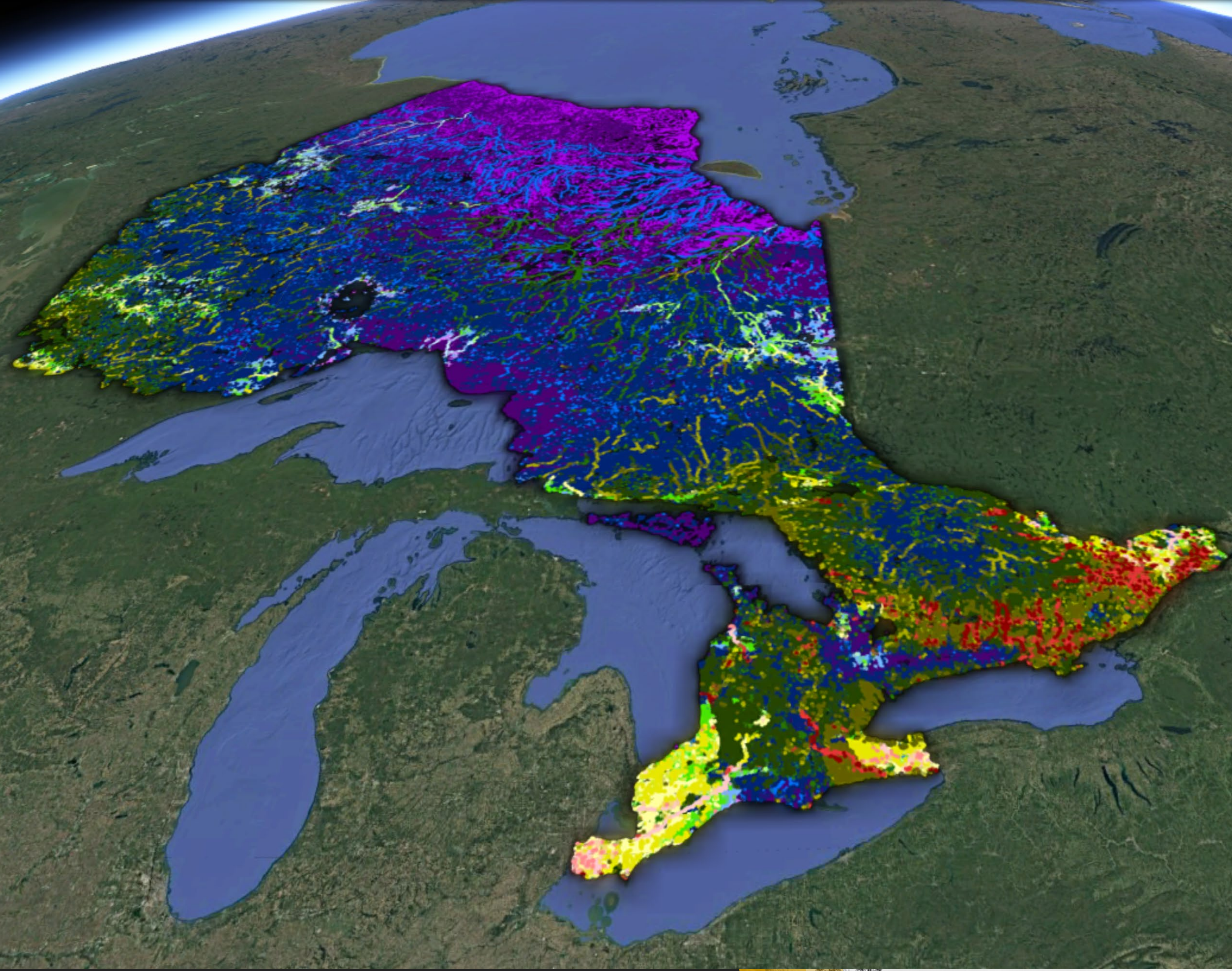

An aquatic ecosystem classification for Ontario's rivers and streams: Version 3

Technical Report TR-69
Science and Research Branch
Ministry of Natural Resources

Ontario

Science and Research Technical Report TR-69

An aquatic ecosystem classification for Ontario's rivers and streams: Version 3

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Science and Research Branch

Ministry of Natural Resources

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Abstract

The aquatic ecosystem classification (AEC) is a science-based tool used to group and classify Ontario's rivers and streams based on their physical attributes, such as water temperature, and watershed characteristics, such as upstream drainage area. The third version of the AEC provides improved spatial stream class coverage and other analytical enhancements. All versions of the AEC share the same underlying spatial source data (i.e., Ontario Integrated Hydrology from 2014). The Ministry of Natural Resources (MNR) is responsible for sustainably managing and deriving economic benefit from the fisheries and water resources in the estimated 500,000 km of Ontario's rivers and streams. The AEC reduces the complexity of these vast aquatic networks by using consistent and quantitative methods to build a standardized data foundation that helps MNR staff with landscape-scale planning and policy development.

Résumé

Une classification des écosystèmes aquatiques pour les rivières et les ruisseaux de l'Ontario : Version 3

La classification des écosystèmes aquatiques (CEA) est un outil scientifique utilisé pour regrouper et classer les rivières et ruisseaux de l'Ontario en fonction de leurs attributs physiques, comme la température de l'eau, et des caractéristiques du bassin hydrographique, comme l'aire de drainage en amont. La troisième version de la CEA offre une couverture améliorée des classes spatiales de ruisseaux ainsi que d'autres améliorations analytiques. Toutes les versions de la CEA partagent les mêmes données spatiales sous-jacentes (c.-à-d. les données hydrologiques intégrées de l'Ontario de 2014). Le ministère des Richesses naturelles (MRN) est chargé d'assurer la gestion durable des pêches et des ressources en eau dans les quelque 500 000 km de rivières et de ruisseaux de l'Ontario et d'en tirer des avantages économiques. La CEA réduit la complexité de ces vastes réseaux aquatiques à l'aide de méthodes uniformes et quantitatives qui permettent d'obtenir un ensemble de données normalisées qui aident le personnel du MRN à mener à bien les tâches de planification à l'échelle des paysages et d'élaboration des politiques.

Acknowledgements

Many people contributed to the development of the classification system including the AEC Technical Committee (Peter Uhlig, Mike McMurtry, Helen Ball, Steve McGovern, Kent Todd, Sandra Orsatti, Steve Leney, and Jason Borwick), staff from the Provincial Geomatics Services Centre, conservation authorities across Ontario, and the federal Department of Fisheries and Oceans; and especially Stephanie Melles, Sarah Parna, Kimisha Ghunowa, Paul Seelbach, Lizhu Wang, and Dan McKenney. We thank Robert Mackereth, Trevor Middel, Nolan Pearce, Scott Gibson, and Kyla Standeven for helpful reviews of previous version of this report. Funding for the AEC came from the then Ontario Ministry of Natural Resource's Far North Branch, the Canada-Ontario Agreement on Great Lakes Water Quality and Ecosystem Health, and Fish and Wildlife.

Contents

Preface

The aquatic ecosystem classification (AEC) groups and classifies Ontario’s rivers and streams into ecologically meaningful units. It is an ongoing project that will be updated and supplemented with additional information that can be used to better manage Ontario’s aquatic resources. The current version of the AEC, version 3, improves on previous versions and incorporates feedback from numerous stakeholder meetings. Refinements in AECv3 include modelling mean July stream temperatures for all streams in Ontario, adjusting the flow velocity classification, and improving lake influence estimates using more sophisticated analytical methods. All versions of the AEC are based on the same underlying spatial base data.

Getting involved

We have gained much insight and learned from participant feedback during many regional and local presentations about the AEC. We encourage AEC users to continue providing information about where the classification works well and where it does not. We would like to hear from you if you think a change in class designation is warranted and why. For example, if a stream is classified as warmwater in the AEC, but you are certain it is a coldwater stream from experience and have evidence, we would consider adjusting the AEC classification manually to reflect that knowledge. To submit comments, suggestions, or concerns about the AEC class assignments, please email the form included in the zipped Ontario GeoHub data packages (also provided in Appendix A of this report) to AEC@ontario.ca.

Glossary

Glossary of terms as used/defined in this report. Compiled and adapted from various sources.

Allochthonous: Organic matter entering a stream, lake, or ocean but derived from an adjacent terrestrial ecosystem.

Aquatic ecosystem classification (AEC): A consistent, science-based system of rules designed to group and classify Ontario's rivers and streams based on their physical attributes.

Autochthonous: Organic matter produced in an ecosystem (diatoms, algae, macrophytes).

Baseflow index (BFI): A metric quantifying the amount of groundwater contributing to stream flow, and key in defining the hydrology and thermal characteristics of streams which are fundamental to their ecology. BFI represents the ratio of groundwater to total stream flow.

Binning: Dividing continuous values (e.g., temperature) into discrete bins to reduce data complexity. Histograms are examples of a data binning method used to observe underlying distributions.

Bottom-up approach: Small spatial elements (e.g., interconfluence reaches) are aggregated to form larger spatial units (e.g., neighbourhoods, segments), which in turn are linked, sometimes through many levels, until a complete top-level system is formed.

Channel slope: Ratio of channel elevation change (from the upstream to downstream end of a reach) to reach channel length.

Confluence symmetry ratios (CSR): A unitless ratio of tributary upstream catchment area (UCA) over the mainstem river UCA.

Digital elevation model (DEM): A three-dimensional surface that approximates real-world terrain created using interpolation of contour and/or point elevation data.

Ectotherm: An animal that depends on external heat sources to maintain body temperature.

Edaphic: Characteristic of the geology and soil of a region including drainage and texture or chemical properties such as soil pH.

Fundamental spatial unit: In the AEC, this term refers to interconfluence reaches (between tributary junctions) including breaks at waterbody inlets and outlets.

Geodatabase: A proprietary (ESRI Inc.) file format used to organize and store digital geographic information. A geodatabase can contain multiple layers (e.g., points, lines, and polygons).

Growing degree days (GDD) >5 °C: A measure of accumulated thermal units above a threshold temperature (in this case 5 °C) for each day of the growing season. Growing degree days are a reliable predictor of organism growth and development, particularly ectotherms such as fish.

Habitat template: Results from the long-term pattern of physicochemical variability combined with the complexity and stability of the flow, thermal, and sediment regimes, and, theoretically, influences which combinations of behavioural, physiological, and life history characteristics constitute appropriate ecological strategies for persistence in that habitat.

Interconfluence reach: A section of stream between inflowing tributary streams of any size. Synonymous with the term reach.

Intermittent stream: A stream that flows only during certain times of the year (e.g., seasonally, rain or snow melt).

Lake influence: The influence a lake exerts on the temperature, flow, sediment, and nutrient regimes of reaches downstream of the outlet. For AECv3, lake influence refers to the influence on stream temperature.

Lentic: Of, relating to, or living in still fresh waters such as lakes, ponds, or swamps.

Lotic: Of, relating to, or living in flowing (i.e., actively moving) fresh water.

Neighbourhood: A grouping of reaches based on upstream catchment area rules such as confluence symmetry ratio (CSR).

Neighbourhood upstream catchment area ratio (NUCAR): A ratio calculated to determine when a stream segment is getting too large, i.e., the upstream and downstream drainage areas differ too much. In such segment, the reach affinity tool (RAFT) finds the largest tributary to create a break. It uses minimum and maximum reach UCAs inside each neighbourhood and calculates a ratio of the two UCAs called the Neighbourhood Upstream Catchment Area Ratio (e.g., NUCAR = 3,000 km^2/1,500 km^2 = 2.0).

Network Catchment Attribute Tool (NCAT): A custom MATLAB-based software application that automates the process of calculating the upstream catchment attributes from individual reach contributing area (RCA) attributes and assigning network metrics such as Strahler and Shreve order to the reaches.

Non-wadeable streams: Streams with an upstream catchment area >2,000 km^2. About 95% of the stream is boatable, and sampling methods designed for large rivers and lakes will apply.

Ontario Hydrographic Network (OHN): The official provincial data set delineating hydrographic features in Ontario (e.g., stream blue lines, waterbody polygons). The AEC is based on OHN data captured in 2014.

Ontario Integrated Hydrology (OIH): A data product that supports provincial-scale hydrological analyses. The OIH was created using a digital elevation model (DEM) and its derivative products (e.g., flow direction, flow accumulation) and hydrology features from the Ontario Hydrographic Network (OHN). The OIH was used to generate watershed boundaries at various scales. The AEC uses OIH data captured in 2014.

Perennial stream: A stream or river that has continuous flow in parts of its stream bed all year during years of normal rainfall.

Productivity region: The combination of growing degree day bands and predominant upstream ecozone. Nine AEC productivity regions delineate large areas of potential differences in stream biological productivity.

Reach: A section of stream between inflowing tributary streams of any size. Synonymous with the term interconfluence reach.

Reach Affinity Tool (RAFT): A network-aware computer program used to cluster (i.e., group) stream reaches into stream segments.

Reach contributing area (RCA): The lateral area of land contributing surface and subsurface flow of water, nutrients, and organic and inorganic materials to a stream reach independent of catchment size and upstream contributions. RCA is defined by the local topography.

Segment: A grouping of reaches that are considered relatively homogenous in hydrologic, limnologic, geomorphic, and biotic characteristics. Stream segments are considered appropriate spatial units for many types of fishery and water resource management decisions.

Semi-wadeable streams: Intermediate size streams (upstream catchment area ≥200 and <2,000 km^2) that are difficult to navigate and sample, requiring a mixture of wadeable and non-wadeable sampling methods.

Strahler order: Provides an indication of the size of a stream (e.g., first order streams are small headwaters and seventh order streams are large lowland rivers); see Strahler (1957).

Stream class: A group of streams characterized by their unique combination of thermal habitat, perennial turbidity, and flow velocity (e.g., a warm, turbid, and slow river).

Stream-lake network: A series of stream reaches and interconnecting lakes in a network.

Top-down approach: Starting at the largest spatial extent (e.g., regional) and dividing them into progressively smaller spatial units.

Turbidity: A measure of the degree to which water loses its transparency due to the presence of suspended particulates; the more total suspended solids in the water, the cloudier it appears and the higher the turbidity.

Upstream contributing area (UCA): Total area of land draining to an outlet at the downstream end of a stream reach.

Virtual connector: Stream reaches that run through waterbody polygons to provide continuity of network flow and allow network analyses.

Wadeable streams: Streams with upstream catchment area <200 km^2. More than 95% of the stream can be waded. A diverse and well-established set of sampling methods are available.

Water conductivity: A measure of water's capability to pass electrical current, which is directly related to the concentration of chemical ions in the water (e.g., Ca^{++}, HCO_3^-). It also correlates with total dissolved solids (TDS) and the amount of nutrients in freshwater.

Work units: Watershed-based containers that partition the province-wide aquatic ecosystem classification's stream network data into manageable sub-units for analysis and distribution.

Introduction

The aquatic ecosystem classification (AEC) is a science-based tool designed to classify Ontario's rivers and streams based on their physical attributes such as water temperature and upstream drainage area. The main goals of the AEC are to: (1) provide a universal and consistent spatial framework for Ontario's flowing waters, (2) capture the ecological nature of rivers and streams, (3) simplify the complexity of streams across Ontario for understanding and management, and (4) validate the classification in collaboration with stakeholders. In this report, we detail the development of the AEC and review how and why the AEC was created. Practical guidance on applying the AEC to science, monitoring, and resource management is provided in Jones et al. (2025).

The Ministry of Natural Resources (MNR) is responsible for sustainably managing and deriving economic benefit from the fisheries and water resources in the estimated 500,000 km of rivers and streams in Ontario[1]. Ontario has an area of about 1 million square kilometres and much of it is remote and difficult to access. Before developing the AEC, we did not have a full inventory of the characteristics of Ontario's rivers and streams. We did not know what kinds of rivers we had and how they were distributed across the province. This information is vital for managing our flowing waters and their inhabitants as a natural resource, including monitoring them, reporting on their health, and assessing the effectiveness of our management actions.

Before the computer age, aquatic classification schemes relied on a combination of hand drawn watershed maps and terrestrial land classifications (Omernik 1987, Hawkins et al. 2000). In their synthesis, Hawkins et al. (2000) noted that landscape classifications accounted for more biotic variation than would be expected by chance, but that the amount of variation related to terrestrial features was minimal. They suggested that landscape-scale classifications have a role in initial stratification, but that a hierarchical classification based on reach- and larger-scale landscape features is needed to accurately predict the composition of freshwater communities. Modern geographic information systems (GIS) have allowed for increasingly powerful and sophisticated analyses of stream networks, changing the way we can perceive streams. Contemporary and historical classifications are predicated on the idea that the 'valley rules the stream' (Hynes 1975). The ecological characteristics of streams are strongly influenced by the characteristics of their catchments (i.e., the areas of land they drain and flow through). Landscape characteristics such as physiography, topography, climate, geology, and land cover determine thermal and flow regimes and nutrient and sediment dynamics. Using the AEC, we are now able to inventory our flowing waters from small headwaters to kilometre wide lowland rivers based on their landscape characteristics.

In 2013, we published a technical report outlining the theoretical basis for an aquatic ecosystem classification for Ontario's rivers and streams (Melles et al. 2013). We also conducted a client needs survey to determine the usefulness of an AEC and how it could be applied within the ministry (Melles et al. 2011). This survey and a literature review of classification systems world-wide (Melles et al. 2012, 2014) were used to guide the development of the AEC, including a new spatial data framework needed to classify all rivers

[1] The cumulative length of Ontario's streams is an estimate and an underestimation. See the *Simplifying the base data* section for additional information.

and streams in the province into ecologically relevant units at several hierarchically nested spatial scales.

The AEC is a hypothesis that aims to capture major ecological differences among streams in Ontario. Feedback gathered over many meetings with stakeholders from across the province indicates that the AEC classifies most streams correctly. The few incorrectly classified streams need to be scrutinized by those familiar with them, as they can be rare or unique in character (e.g., karst systems, groundwater springs) or have base data issues (e.g., inaccurate geological mapping). The AEC was built using a small set of landscape variables that strongly influence stream character. Many other variables could have been included, perhaps slightly improving predictive accuracy, but at the cost of reduced interpretability. No right or wrong number of stream classes exists. The number of classes is not scientifically defined but rather reflects management needs and geographic scales of interest. In general, higher complexity at small, local scales becomes problematic at regional scales as the number of classes increases beyond usefulness. A balance between local and regional scales is required. This dichotomy is why we used a hierarchical approach for classifying streams at different spatial scales. Like all hypotheses, ours will change and improve as we gain additional knowledge.

Potential uses of the classification

The AEC serves as a landscape-scale resource management tool for streams and rivers. It can be used in many ways to support policy and management decisions. Some relevant applications of the AEC are:

Provincial monitoring

- Providing a provincially consistent spatial framework for monitoring and reporting.
- Improving statistical sampling designs (e.g., stratification) resulting in greater power to detect change.
- Guiding site selection to ensure efficient use of time and money for coarse- and fine-scale monitoring and field inventories.
- Allowing extrapolation from data rich to data poor areas.

Conservation status

- Providing biologists with an understanding of the nature/ecology of streams across the province without needing to visit streams.
- Providing quantitative assessments of the health of populations (e.g., expected vs. observed brook occupancy or biomass).
- Understanding how human disturbances influence fish abundance and biodiversity (e.g., Jones et al. 2019).

- Contributing to the development of models predicting the distribution or abundance of invasive, at-risk, or highly valued species (e.g., brook trout; Thorn et al. 2016, Jones et al. 2020).

- Predicting locations of rare aquatic species (e.g., redside dace) to support reintroduction and restoration efforts.

Policy and guideline development

- Making guidelines more context dependent with criteria specific to stream types. For example, evaluation criteria for indicators like fish abundance can be tailored to specific stream classes.

Protected areas and land use planning

- Determining representation and uniqueness of aquatic features on the landscape.

- Helping assess the ecological integrity of streams across Ontario.

- Understanding ecological sensitivity and landscape capacity.

- Developing aquatic class parks.

Considerations when using the classification

- The AEC is a general habitat template, not a species-specific model.

- The AEC does not include very small, often temporary, streams. Although we recognize the value of these features, they are smaller than can be reasonably represented using provincial-scale base data (i.e., a 30 m digital elevation model). Streams in the AEC have a drainage initiation threshold of 1 km^2.

- In Northern Ontario, many small perennial streams are missing or in the wrong location because visually obstructive canopy cover combined with an irregular stream network pattern on Precambrian geology makes stereographic interpretation difficult.

- The AEC does not include identification of sub-reach habitat heterogeneity (e.g., pools, riffles). We recognize that heterogeneity exists at a scale below the AEC reach level, but provincial-scale base data does not support work at such a fine spatial scale.

- The AEC should be interpreted with caution in streams with considerable human influence such as highly urbanized streams and the tailwaters below dams – particularly with respect to bottom-draw dams that alter the thermal characteristics of streams.

- The classification does not directly include the influence of human development (e.g., urbanization, agriculture; see Jones et al. 2019). Unlike geology and stream size, human development changes quickly and would require frequent changes to the classification.

- Although the AEC groups stream reaches into discrete classes, the continuous nature of underlying abiotic variables remains. Some streams may be close to the class thresholds, leading to longitudinal “flip-flopping” between classes. See the user guidance document (Jones et al. 2025) for direction on evaluating the affinity of a reach to its assigned class.

- The AEC aims to achieve a high level of classification accuracy. However, some streams could be misclassified due to base data limitations (e.g., inaccurate surficial geology) and/or modelling uncertainty. Small streams are more affected by underlying base data errors (e.g., geological misclassification or spatial inaccuracy) than large rivers that encompass larger areas. Users can contribute to making corrections by sharing field observations via AEC@ontario.ca .

Spatial framework

The AEC aims to provide a consistent, standardized, data foundation for inventorying and analyzing Ontario’s streams. We recognized that achieving this goal would require us to design and build a new spatial data framework. This fundamental spatial framework is shared by all versions of the AEC. Development of the framework involved the following steps:

1. Dividing the province into watershed-based containers.

2. Simplifying and standardizing the stream network.

3. Building the *spatial framework* from the stream-lake network for all work units of the province using Arc Hydro.

4. Generating a *stream reach* inventory and summarizing reach landscape characteristics (e.g., geology, landcover, climate) at relevant spatial scales.

Work units

We divided the province into watershed-based containers called work units (Figure 1). These polygons divide the provincial AEC data into manageable sub-units for processing, analysis, and data distribution. The final AEC data set includes 43 work units.

WUID	Name	WUID	Name
1	Lake Erie - West	25	Harricanaw River
2	Lake Erie - East	26	Albany River
3	Lake Ontario - West	27	Kinosheo River
4	Lake Ontario - Central	28	Kapiskau River
5	Lake Ontario - Kawarthas	29	Attawapiskat River
6	Lake Ontario - East	30	Ekwan River
7	St. Lawrence River	31	Opinnagau River
8	Ottawa River - Lower	32	Sutton River
9	Ottawa River - Central South	33	Winisk River
10	Ottawa River - Central North	34	Shagamu River
11	Ottawa River - Upper	35	Severn River
12	Lake Huron - South	36	Hayes River - A
13	Lake Huron - Bruce Peninsula	37	Hayes River - B
14	Georgian Bay - South - Lake Simcoe	38	English River
15	Georgian Bay - Central	39	Bird River
16	Georgian Bay - North - Lake Nipissing	40	Manigotagan River - A
17	Lake Huron - Manitoulin Island	41*	Manigotagan River - B
18	Lake Huron - North	42	Bloodvein River - A
19	Lake Huron - North West	43	Bloodvein River - B
20	Lake Superior - East	44*	Pigeon River
21	Lake Superior - North East	45	Upper Berens River
22	Lake Superior - Lake Nipigon	46*	Poplar River - A
23	Lake Superior - North West	47*	Poplar River - B
24	Moose River		

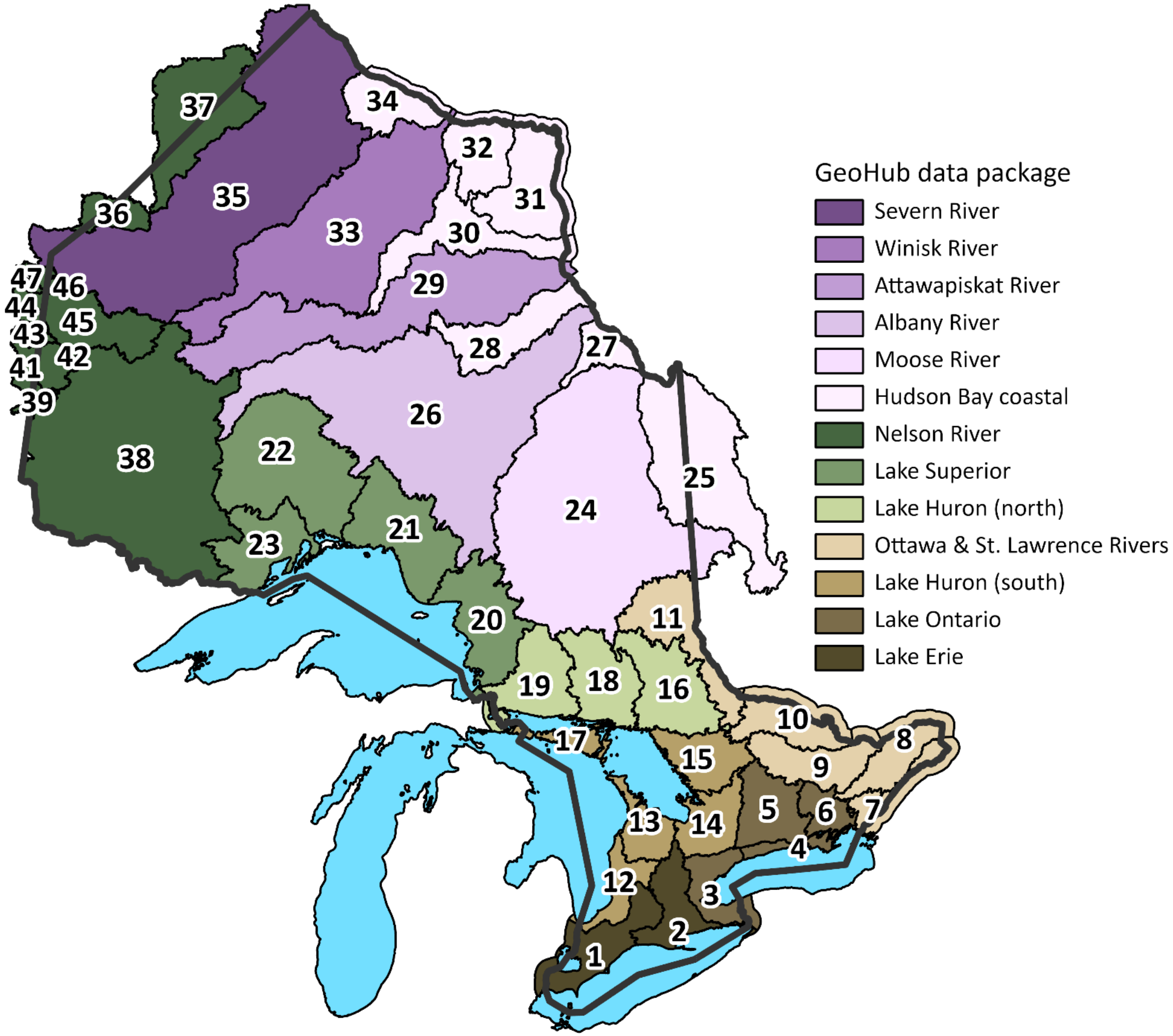


Figure 1. A map of the aquatic ecosystem classification (AEC) work units including their names, numeric identifiers, and Ontario GeoHub data package. Several small work units along the Ontario-Manitoba border could not be fully processed or were excluded later because Ontario Integrated Hydrology data for that work unit was not available or they were missing other fundamental base data. The excluded work unit names are highlighted in grey and denoted by an asterisk (*). The final AEC data set includes 43 work units contained within 13 data packages.

Simplifying the base data

The spatial framework for the AEC was developed from two foundational data sets: the Ontario Integrated Hydrology (OIH) raster data set, which has a cell size of 30 m, and the Ontario Hydro Network (OHN) vector data from 2014. Information from these two data sets was combined to generate a stream network with a uniform catchment area-based headwater initiation threshold of 1 km² (i.e., all 1st order streams have catchment areas ≥1 km²). Simplification serves three purposes:

- Standardizing stream network density: The OHN data is captured at various scales across Ontario (1:10,000 in the south, 1:20,000 in the near north, and 1:50,000 in the Far North of Ontario) resulting in different stream densities (i.e., km·km^2) and assigned stream orders (Hansen 2001). Using a uniform stream initiation threshold of ≥1 km² across the province during the stream network creation process provides a consistent stream density and stream order.

- Reducing network complexity: This reduction decreases complexity of the final network, increasing data processing and display speeds. While very small streams excluded during simplification may be the focus of some management efforts, the available base data (i.e., 30 m DEM) does not support such fine scale analyses. Given a pressing need and accurate high-resolution base data, the AEC framework could be extended to accommodate finer scales in some areas of the province.

- Reducing uncertainty of stream intermittency: In southern Ontario, small streams that are often intermittent and ephemeral (i.e., temporary) are mapped abundantly because open agricultural lands visually expose even the smallest of ravines to the cartographer. Many of these streams are in actively ploughed farm fields and these tiny streams may only flow for a few weeks each year. In Northern Ontario, many small perennial streams are missing or in the wrong location because dense forests obscure stream channels. Although we recognize that temporary streams are abundant, understudied, vulnerable, and contribute greatly to the ecological integrity of stream networks (McDonough et al. 2011, Buttle et al. 2012), the variable nature of temporary streams in terms of flow and temperature requires a different classification approach that is not possible using current base data. We recognize that some perennial streams will have smaller catchment areas (<1 km^2) particularly those associated with spring upwellings.

The stream reach lines inherit the zig-zag raster nature of the OIH source data (i.e., the 30 m step pattern seen in Figure 2A). This zig-zag pattern increases the lengths of the initial reach lines compared to their OHN equivalent blue lines. To reduce this discrepancy, we simplified the reach lines with the Douglas-Peucker algorithm. This simplification brings line geometry and lengths closer to the mapped OHN blue lines. However, the simplified lengths tend to slightly underestimate OHN line lengths because streams meander more in reality than their simplified equivalents (Figure 2). This simplification process and the 1 km^2 catchment initiation threshold means that analyses using the AEC stream network will consistently underestimate true stream length on the ground.

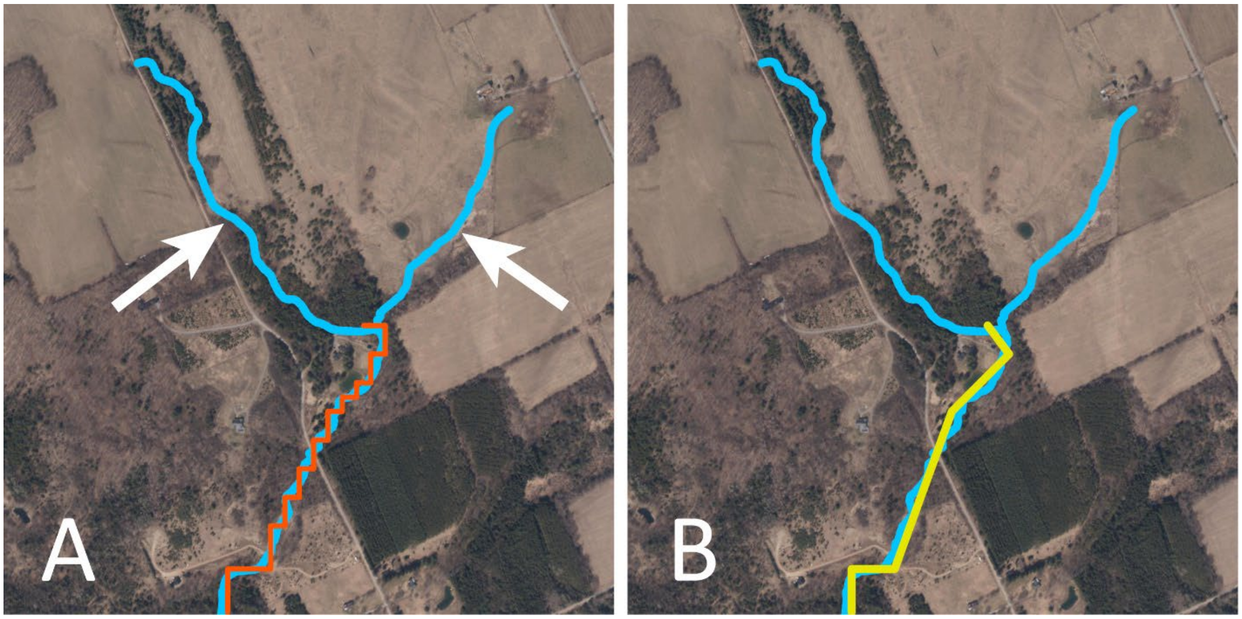


Figure 2. Comparisons of the Ontario Hydrographic Network (OHN) mapped blue lines and their processed aquatic ecosystem classification (AEC) equivalents. In panel A, the orange "stepped" line shows the Ontario Integrated Hydrography (OIH) equivalent of the OHN mapped blue lines used to create the AEC base data. The OIH and OHN lines generally overlap well because the OIH data was created using the OHN. The arrows identify OHN lines that were excluded from the AEC stream network because their upstream catchment areas are less than 1 km^2. Panel B shows the simplified AEC lines (yellow) in context of the original OHN lines (blue). The length of the AEC reach (yellow) is less than its equivalent OHN reach (blue), which is the case for most reaches across the province. The 1 km^2 exclusion threshold and the shorter simplified AEC lines are the reason any analysis using the AEC data will consistently underestimate true stream length on the ground.

Stream reaches

We used Arc Hydro (Maidment 2002) to create the fundamental spatial framework for the AEC. Using the simplified stream network, Arc Hydro generates spatial units called *links* – sections of stream bounded by tributary confluences (i.e., interconfluence reaches; Figure 3A). We refer to links as stream *reaches* in the context of the AEC. Across Ontario, lakes and streams are interconnected in a series of alternating lentic (still water) and lotic (flowing water) reaches and, as a result, it is impossible to understand streams without also incorporating lakes (Jones 2010). To incorporate lakes, we combined the interconfluence link raster generated by Arc Hydro with attributes from the OHN data. The OHN data differentiates line features representing real streams from virtual connectors that provide flow continuity through waterbodies. We intersected the link raster with a rasterized version of the OHN virtual connectors to generate an enhanced link raster that included waterbody inlet/outlet breaks. We substituted this enhanced lake-interconfluence link raster for the interconfluence link raster during further processing. An example of the final lake-interconfluence link layer is shown in Figure 4. Ontario has roughly 410,000 real stream reaches (total length ~475,000 km) and ~300,000 virtual connectors to provide flow continuity through waterbodies.

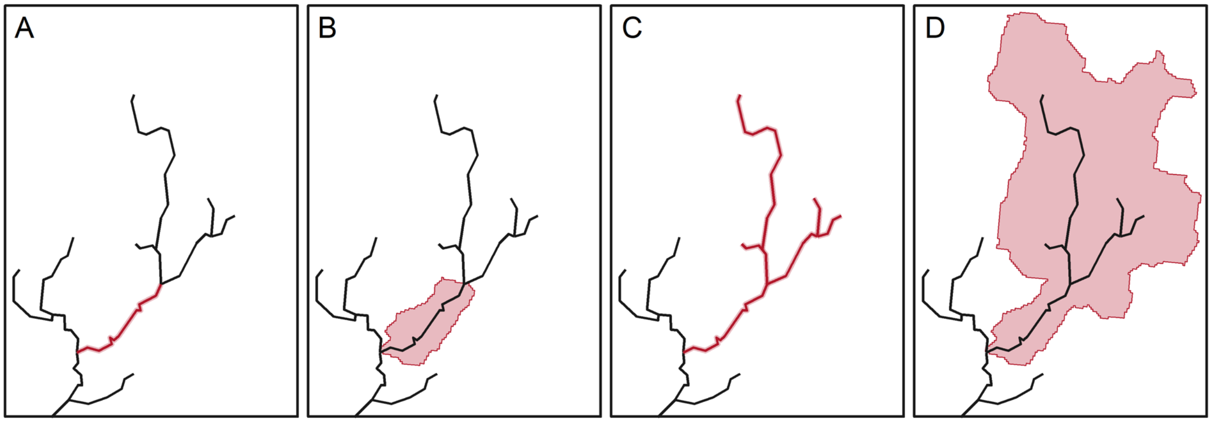


Figure 3. The four spatial scales used to inventory landscape variables in the aquatic ecosystem classification: (A) reach channel (RCh), (B) reach contributing area (RCA), (C) upstream channel (UCh), and (D) upstream catchment area (UCA).

Additional geoprocessing steps performed on the finalized lake-interconfluence link raster using Arc Hydro included delineating reach contributing areas, assigning unique reach identifiers, and generating network components (e.g., to and from node fields). The network components make it possible to perform network analyses, while the unique identifiers allow joining spatial data with tabular data (e.g., landscape attribute tables).

Using the Arc Hydro geodatabases, we generated a large inventory of landscape and network attributes for each of the 710,000 reaches in Ontario across four scales of collection (Figure 3). Reach channel (RCh) and reach catchment area (RCA) attributes were calculated using ArcGIS Zonal Statistics toolboxes. To automate the calculation of upstream catchment attributes from individual reach data and assign network metrics such as Strahler and Shreve order (Horton 1945, Strahler 1952) to the reaches, we developed a custom MATLAB-based application called Network Catchment Attribute Tool (NCAT). The final attribute count for each reach was more than 1,000 fields across several dozen data categories (e.g., climate, geology, landcover).

Stream class components

The AEC stream classes are composed of three attributes: thermal habitat, perennial turbidity, and stream flow velocity. These continuous variables are discretized into categories (i.e., binned) and combined to form 20 stream classes (figures 5, 6; Table 1). Thermal class assignment is based on a probabilistic approach described in detail below. Perennial turbidity and flow velocity are discretized using thresholds that allow us to form ecologically meaningful groupings that can be easily interpreted. However, group membership (i.e., affinity) diminishes near the thresholds. For example, reaches with channel slopes of 0.01% and 0.14% would both be classified as slow because they fall below the slow/fast cutoff of 0.15%. However, the reach with a channel slope of 0.01% will flow much slower than the reach with a channel slope of 0.14%. These caveats around class affinity also apply to the turbidity class. Only real reaches are classified. Virtual connectors (i.e., lakes and shorelines) and out-of-province reaches are not assigned a class.

The variables used in the classification (thermal habitat, perennial turbidity, and stream flow velocity) represent the main drivers of aquatic community composition. Although additional variables could be incorporated into the AEC classes, it would increase complexity and create many more class combinations, negating the goal of creating succinctly meaningful classes. Additional variables are also likely to be highly correlated with those already included in the classification. Nevertheless, the AEC provides extended class codes that provide information about other variables of ecological interest including: (1) potential biological productivity, (2) Strahler order, and (3) whether stream temperature is influenced by upstream lakes. The AEC extended class is composed of the primary stream class plus these additional factors (Figure 7).

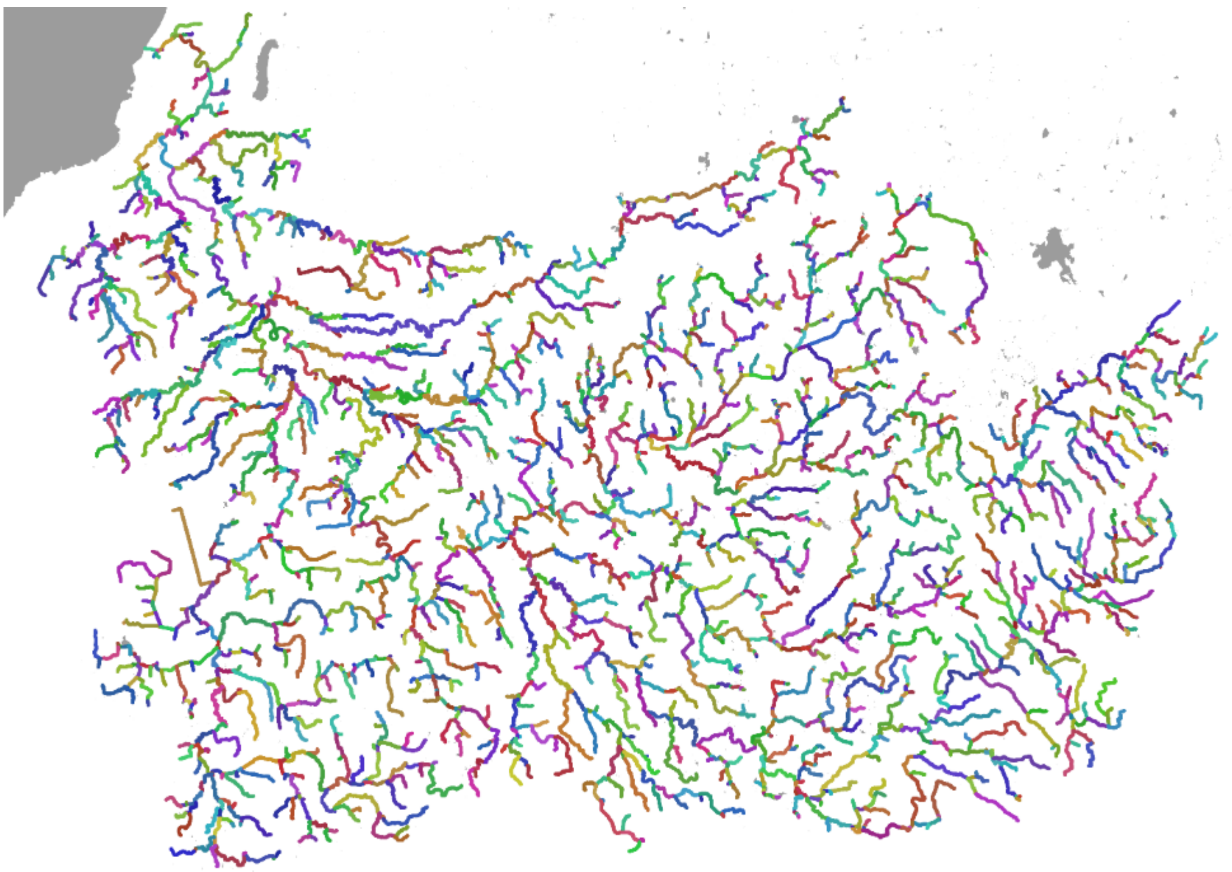
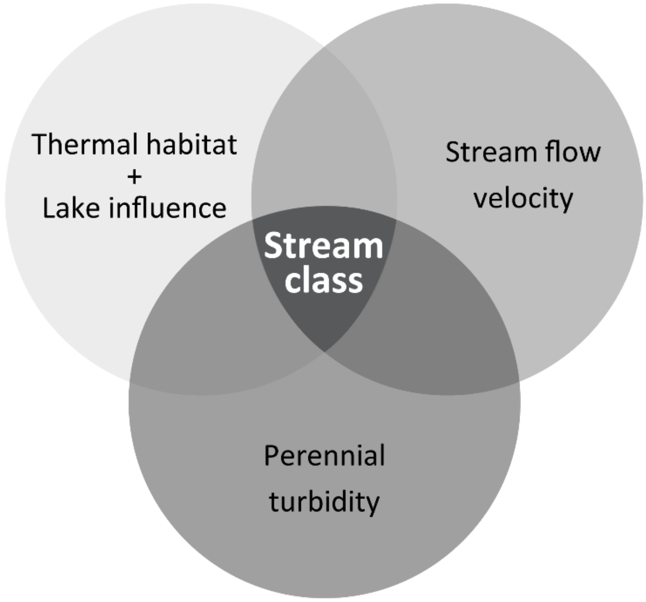


Figure 4. The 2,957 reaches of the Saugeen River watershed in southwestern Ontario. Different colours represent individual stream reaches.



Stream class	Thermal habitat	Perennial turbidity	Flow velocity
CDCF	Cold	Clear	Fast
CDCS			Slow
CDTF		Turbid	Fast
CDTS			Slow
CCCF	Cold-cool transitional	Clear	Fast
CCCS			Slow
CCTF		Turbid	Fast
CCTS			Slow
CLCF	Cool	Clear	Fast
CLCS			Slow
CLTF		Turbid	Fast
CLTS			Slow
CWCF	Cool-warm transitional	Clear	Fast
CWCS			Slow
CWTF		Turbid	Fast
CWTS			Slow
WMCF	Warm	Clear	Fast
WMCS			Slow
WMTF		Turbid	Fast
WMTS			Slow

Figure 5. The three fundamental aquatic ecosystem classification (AEC) stream attributes and the 20 stream classes that are created by combining the discretized categories of these continuous attributes.

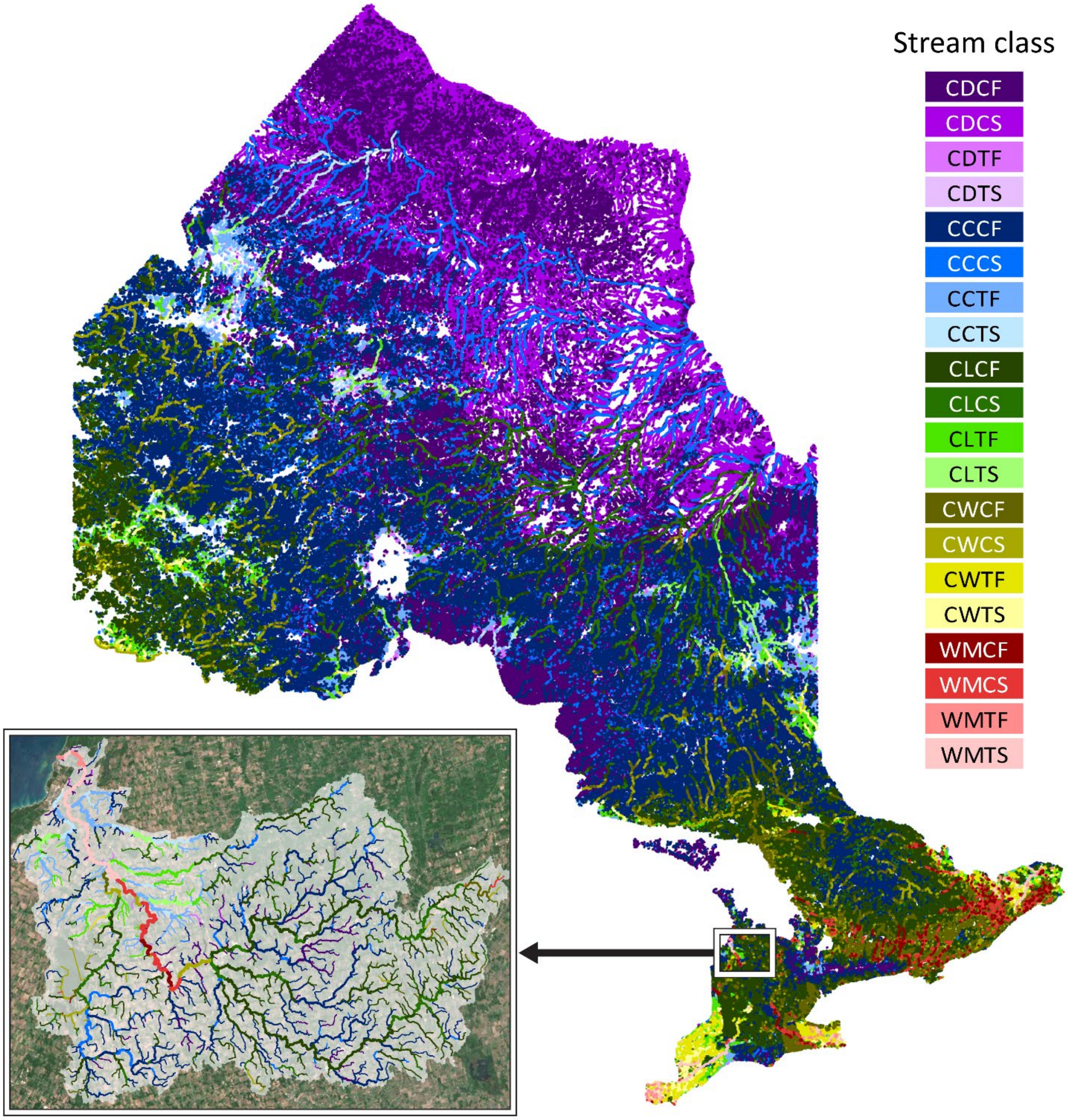


Figure 6. Distribution of the 20 aquatic ecosystem stream classes across Ontario. The inset shows the Saugeen River watershed in southwestern Ontario, where increasing line thickness corresponds with increasing Strahler stream order.

Table 1. Counts and measures of the 20 aquatic ecosystem stream classes in the province of Ontario.

Stream class	Thermal class	Turbidity class	Velocity class	Reaches (#)	Stream length (km)	% of total length
CDCF	Cold	Clear	Fast	80,897	95,230	20.0
CDCS			Slow	86,267	113,447	23.9
CDTF		Turbid	Fast	2,879	4,042	0.9
CDTS			Slow	643	723	0.2
CCCF	Cold-cool transitional	Clear	Fast	99,327	101,403	21.3
CCCS			Slow	49,448	51,167	10.8
CCTF		Turbid	Fast	8,479	11,872	2.5
CCTS			Slow	4,166	5,851	1.2
CLCF	Cool	Clear	Fast	29,431	29,016	6.1
CLCS			Slow	20,726	23,281	4.9
CLTF		Turbid	Fast	4,935	7,266	1.5
CLTS			Slow	3,579	5,470	1.2
CWCF	Cool-warm transitional	Clear	Fast	4,811	6,386	1.3
CWCS			Slow	6,376	9,155	1.9
CWTF		Turbid	Fast	1,689	2,646	0.6
CWTS			Slow	2,623	4,957	1.0
WMCF	Warm	Clear	Fast	569	826	0.2
WMCS			Slow	1,187	1,661	0.3
WMTF		Turbid	Fast	109	128	0.03
WMTS			Slow	487	777	0.2

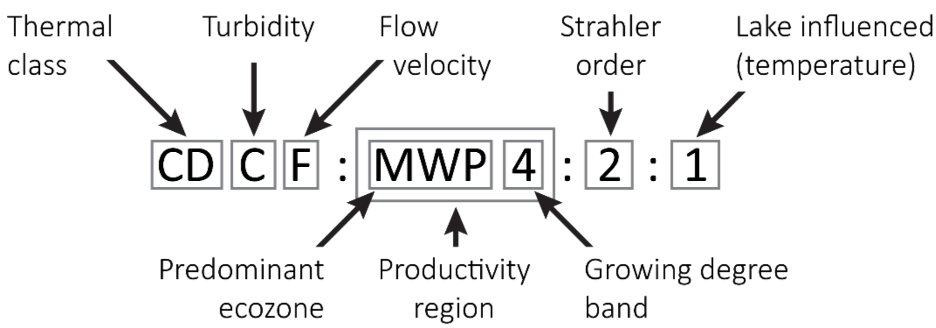


Figure 7. The components of the aquatic ecosystem classification (AEC) extended class code for a single reach. The stream class is CDCF (thermal class = cold; turbidity = clear; stream flow velocity = fast), the productivity region is MWP4 (Mixedwood Plains (MWP) ecozone; growing degree day band 4 or 1500–1900 degree days), the Strahler stream order is 2, and temperature is influenced by upstream lakes (encoded as 1; if the reach was not influenced by lakes this value would be 0). The individual classification components are described in more detail in the following sections.

Thermal habitat

Water temperature has been described as a master variable and an ecological resource due to its influence on aquatic ecosystems (Brett 1971, Magnuson et al. 1979, Hannah and Garner 2015). Water temperature plays a key role in several physical, chemical, and biological processes including nutrient cycling, ice dynamics, and the metabolism, growth, survival, and timing of life history events for fishes (Prowse 2001, Caissie 2006, Webb et al. 2008, Hasnain et al. 2010). Spatial and temporal variation in water temperature constrains the distribution and abundance of aquatic organisms in lotic systems (Vannote et al. 1980). As a result, a robust understanding of water temperature dynamics is essential to manage and sustain ecological integrity in rivers and streams.

Water temperature varies spatially within a stream (longitudinally, laterally, and by depth) and temporally (annually, seasonally, daily). Although fish have temperature preferences, and their general distribution is largely shaped by average summer temperature, thermal tolerances and behavioral adaption make it possible for fish to inhabit a wide range of temperatures (Reynolds 1979, Biro 1998). As such, fish can inhabit streams several degrees warmer than their preferred temperature. The amount of excess heat a fish can tolerate depends on a variety of factors such as duration of exposure, availability of food resources, and their ability to find cooler patches of water (e.g., groundwater seeps). Although high temperatures during the summer months might cause fishes to seek cooler water, temperature is not a limiting factor through the remainder of the year and fish can move freely throughout the stream network or into neighbouring lakes. In winter, fish may move to exploit warmer overwintering habitats. Spatiotemporal variability and the adaptive potential of fishes make it challenging to develop a single classification for stream temperature. Considering thermal seasonality, where peak summer temperatures are generally most limiting, it seems logical to base the AEC's thermal classes on July water temperature (i.e., the period of the year where the peak of the stream thermograph occurs across Ontario).

In the AEC, mean July water temperatures were modelled using linear mixed models (Sutton et al. 2024). Individual models were developed for the Mixedwood Plains (MWP) ecozone and the combined Ontario Shield and Hudson Bay Lowland (OSD & HBL) ecozones based on preliminary evidence that the relationship between stream temperature and covariates of interest (e.g., air temperature) varied with stream size, climate, and geology. The OSD & HBL were further divided into small stream (UCA ≤700 km^2) and large river (UCA >700 km^2) models based on findings that water temperatures increasingly correlated to air temperatures as catchment size increased. As a result, mean July water temperatures and the AEC thermal classes are based on the combined output of three separate, non-overlapping temperature models.

Most predictive models provide predictions based on limited data collected within a single year or for a 30-year climatic average, providing little understanding of interannual variability. Point-in-time sampling methods (e.g., Stoneman and Jones 1996; Chu et al. 2009) are also vulnerable to misclassification due to interannual variation in air temperatures. A more robust approach is to use multiple years of data to generate a probability distribution and determine the likelihood that a stream falls within a given class (e.g., over 10 years of data, only 2 years (20%) had stream temperatures >19 °C). In the AEC, thermal classes are assigned by evaluating the affinity of each reach to three core thermal classes: cold (<18.5 °C), cool (18.5–21.5 °C), and warm (>21.5 °C). If a reach falls within a class >80% of the time, it is assigned to that class, while all other reaches are assigned to a cold-cool or cool-warm transitional class (Figure 8). For AECv3, class assignment is based on annual mean July stream temperatures predictions generated over the 30-year period from 1981 to 2010. Only real (i.e., non-virtual connector) reaches were assigned a thermal class (Figure 9). Refer to Jones and Schmidt (2019a) and Jones et al. (2021) for a detailed overview of the development and application of this probabilistic approach.

Stream temperatures are sensitive to climatic and hydrologic variability (e.g., whether a summer was cool and wet or warm and dry). Indeed, Jones and Schmidt (2018) found that average July stream temperature variation averaged 3.5 °C, ranging from 1.2 to 7.6 °C, among 78 streams in Ontario. As such, a stream classified as cold or cold-cool might occasionally reach temperatures exceeding 21.5 °C (i.e., the threshold for the warmwater class). Class membership probabilities are stated in the AEC to provide an understanding of expected interannual variability. Higher class membership probabilities suggest lower interannual variation. For example, a reach with a 90% probability of being cold should have a July average stream temperature exceeding 18.5 °C just 10% of the time (i.e., one in every ten years). In southern Ontario, cold class streams are generally small headwater streams that are very cold even during the hottest years, while warm class streams are either larger rivers or smaller streams draining the clay plains of southwestern Ontario. Thermal regimes can be complex and challenging to interpret, and we refer readers to Jones and Schmidt (2019) for an in-depth overview of stream temperature classifications and thermal regime interpretation.

July Mean Temperature (°C)	Class Membership Probability			Thermal Class
	Cold (≤ 18.5 °C)	Cool (18.5–21.5 °C)	Warm (≥ 21.5 °C)	
15.0	1.00	0.00	0.00	Cold
15.5	1.00	0.00	0.00	
16.0	1.00	0.00	0.00	
16.5	0.99	0.00	0.00	
17.0	0.97	0.03	0.00	
17.5	0.89	0.11	0.00	
18.0	0.73	0.27	0.00	Cold-Cool
18.5	0.50	0.50	0.00	
19.0	0.27	0.73	0.00	
19.5	0.11	0.89	0.01	Cool
20.0	0.03	0.94	0.03	
20.5	0.01	0.89	0.11	
21.0	0.00	0.73	0.27	Cool-Warm
21.5	0.00	0.50	0.50	
22.0	0.00	0.27	0.73	
22.5	0.00	0.11	0.89	Warm
23.0	0.00	0.03	0.97	
23.5	0.00	0.01	0.99	
24.0	0.00	0.00	1.00	
24.5	0.00	0.00	1.00	
25.0	0.00	0.00	1.00	

Figure 8. An overview of the thermal classification framework from Jones et al. (2021). Thermal class is determined by the probability of membership to a given core class (cold, cool, or warm). Class membership occurs when the probability exceeds a threshold, in this case p=0.8. When a reach fails to meet this threshold, it is assigned to a transitional class (illustrated by grey bands). See Jones and Schmidt (2019a) and Jones et al. (2021) for a detailed overview of this framework.

The influence of lakes on stream temperature

Throughout much of Ontario, lakes and rivers are connected in an alternating series of lentic and lotic reaches. The AEC provides mean July water temperature predictions for stream reaches (stream model; Sutton and Jones 2024) and lake surface waters (lake model; Bachmann et al. 2019). Rapid and predictable changes occur downstream of lakes. Streams flowing out of lakes (lake outlets) are often warmer than inflowing streams (Figure 10) because solar radiation warms the lake surface waters – think of lakes as large rivers with little riparian shade. Warm surface waters are transported some distance downstream from the outlet before the stream returns to an equilibrium with the surrounding landscape (e.g., due to cold groundwater seeping in through the stream bed). In the simplest terms, lake influence will attenuate quickly in small streams with small drainage areas (e.g., 5 km^2), whereas attenuation may take several kilometres for larger rivers because of the large volume of warmed lake water compared to groundwater contributions. We estimated the attenuation distance below all lake outlets using a metric called the Lake Effect Index for Temperature (LEI_T; Allerton unpublished). Values of LEI_T

range from zero to one, where zero denotes no lake influence and one denotes the maximum amount of influence right at the outlet. To simplify interpretation, we developed a binary classification using the LEI_T values to indicate whether a reach is lake influenced ($LEI_T \geq 0.1$) or not ($LEI_T < 0.1$). This threshold was used because we did not want very small LEI_T values (e.g., 0.001) to unduly flag a reach as being lake influenced when, despite having non-zero LEI_T, the influence has declined to the point of being insignificant.

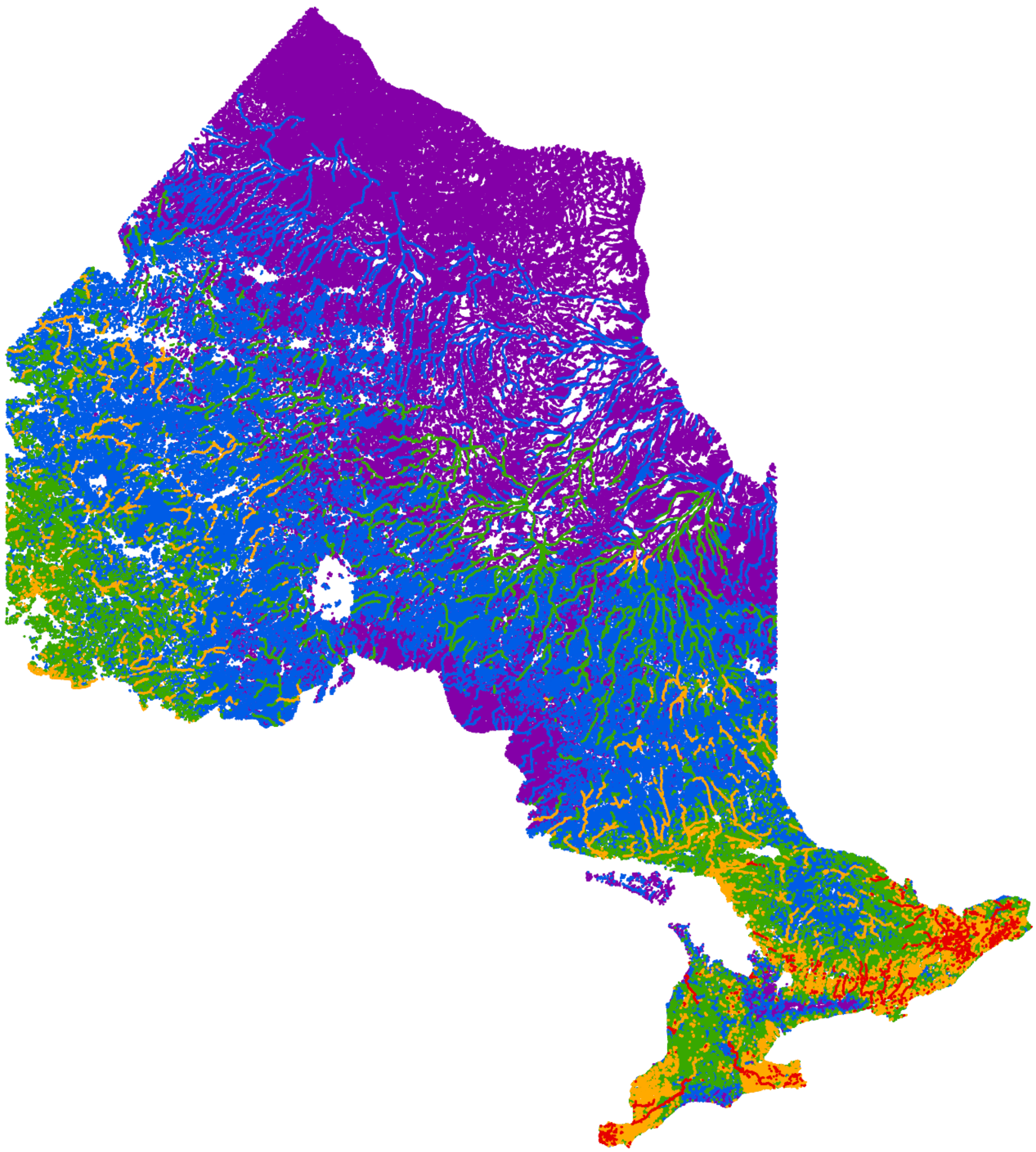


Figure 9. The spatial distribution of the five water temperature classes assigned based on the statistical distribution of 30 years of predicted mean July stream temperatures for each stream reach. The three core thermal classes are cold (purple), cool (green), and warm (red) with two transitional classes of cold-cool (blue) and cool-warm (orange).

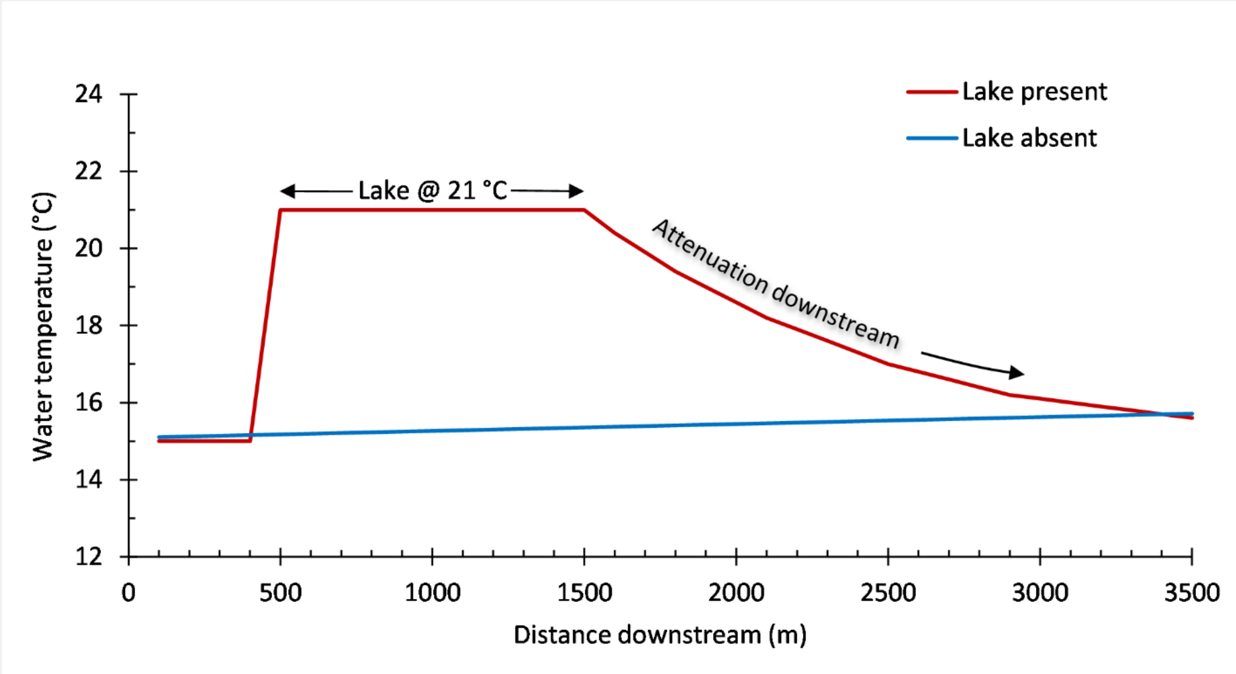


Figure 10. Two hypothetical examples showing longitudinal changes in water temperature with (red) and without (blue) a lake. The lake increases water temperatures relative to the inflowing stream. The outflowing stream starts at the temperature of the lake surface and then decreases downstream until water temperature returns to an equilibrium with the surrounding landscape. The stream without a lake shows a small increase in water temperature typical of many streams as they increase in size.

In July, stream water temperatures at a lake outlet will match the lake surface temperature and then decrease downstream. However, in the AEC, mean July stream temperatures are modelled and predicted without accounting for the influence of lakes. As such, the assigned thermal class may be inaccurate for lake influenced reaches. In turn, we developed a symbology scheme that provides users with an understanding of where lakes may influence stream temperature (Figure 11). Lake influenced reaches are shown as dashed lines, and a point estimate of the lake surface temperature is provided at the lake outlet. All lake surface temperature estimates are classified using the same probabilistic approach used to classify stream reaches and symbolized using the same colour symbology used for the stream temperature predictions.

An upstream waterbody may not always influence the temperature of a reach downstream. The temperature dynamics of larger rivers (upstream catchment area >700 km^2) are mainly driven by air temperature and solar radiation just like lakes, meaning that lakes have little to no warming effect on these rivers. As such, these reaches are not considered to be lake influenced and they are not assigned a dashed symbology. Conversely, in some cases a lake may be too small to exert an influence on downstream reaches. This situation happens when the lake (or pond) has an area to upstream catchment area ratio less than 0.002 (i.e., <1/500). For example, a 0.1 km^2 pond with a UCA of 100 km^2 has a ratio of 0.001 and would not influence downstream temperatures.

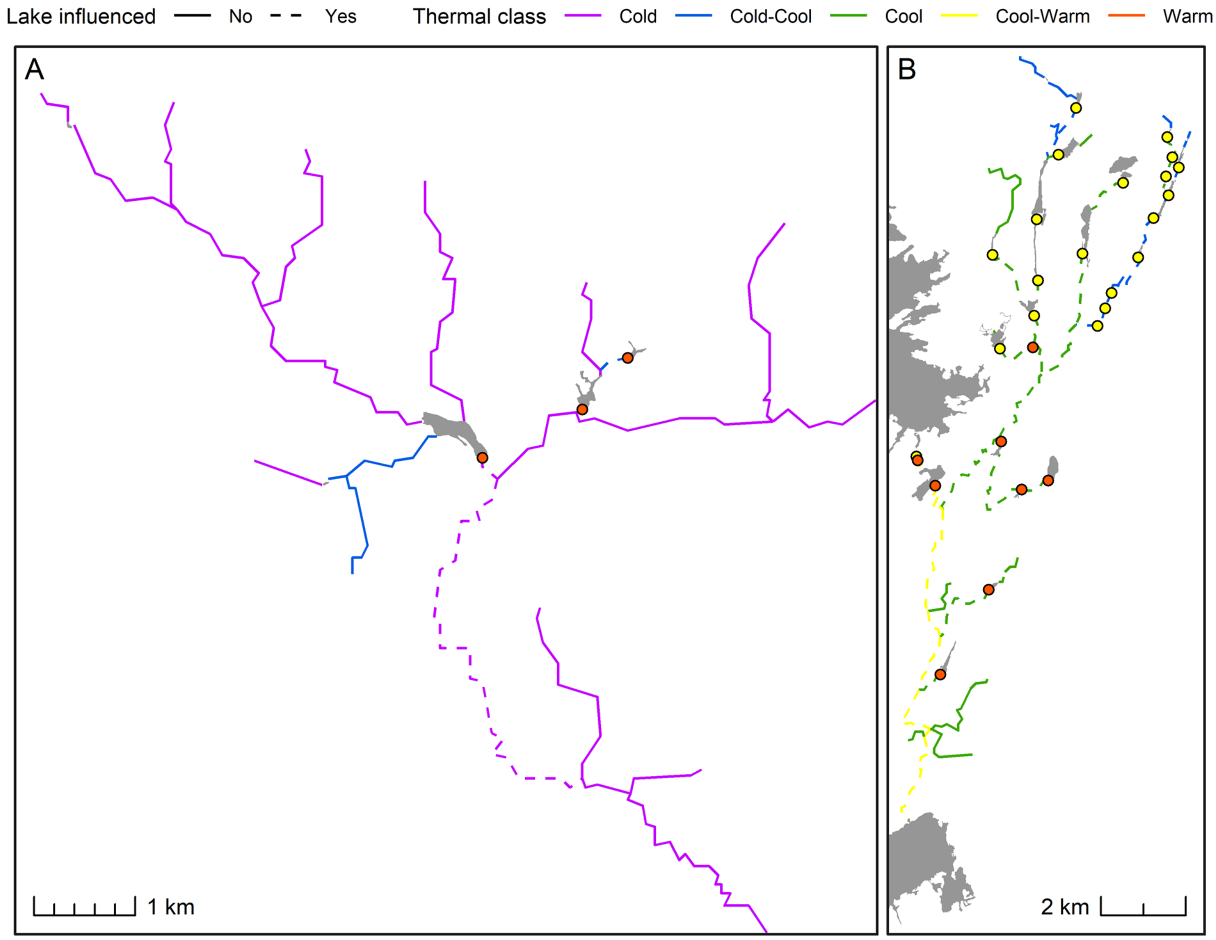


Figure 11. Examples of lake influence in (A) a small headwater stream and (B) a larger tributary. The lake surface temperature at the outlet (coloured points) is typically much warmer than the predicted stream temperature. Predicted stream temperatures below lake outlets (dashed line) should be interpreted with caution and likely fall somewhere between the predicted lake outlet and stream temperatures. In some cases, waterbodies will be too small to exert an influence on streams downstream of the outlet (e.g., the pond in upper left of panel A). In other cases, many sequential lakes lead to a continuous zone of lake influence (panel B).

The influence of dams on stream temperature

Dams may influence stream temperature below their outlets depending on their design and the size of their reservoir. Top-draw dams will influence stream temperature like a lake as discussed above. Large bottom-draw dams, whose reservoirs stratify, usually discharge water from colder waters. This discharge results in cooler stream temperatures below the dam during the summer months. In contrast, warm water (~4°C) at the bottom of the reservoir is discharged during the winter months, resulting in warmer downstream temperatures, which reduces the annual range of stream temperatures. Similar to the influence of lakes, these effects attenuate with distance downstream from the dam until the effect becomes negligible. The influence of dams was not incorporated into the AEC and reaches downstream of large dams may be misclassified.

The influence of urbanization on stream temperature

Urbanized areas can artificially increase stream temperature because impervious surfaces (e.g., paved parking lots) and stormwater management ponds produce warm run-off during summer storms. In urbanized streams, temperatures can pulse very quickly giving stream biota no time to seek refuge in cooler parts of the stream network. Conversely, leaking water mains and storm sewer lines can be a source of increased "groundwater" contributions that can have a cooling effect on streams. The location of the urbanized area in relation to the stream determines the strength of effects. Like lakes and dams, the thermal effects of urbanization attenuate with distance downstream. Highly urbanized reaches (UCA urbanization >25% and/or RCA urbanization >50%) were excluded from the data set during temperature model development and reaches from urbanized areas may be misclassified.

Perennial turbidity

Stream turbidity (i.e., clarity or cloudiness) relates to its productivity (e.g., autotrophic vs. heterotrophic energy sources) and its invertebrate and fish community characteristics (e.g., sauger/mooneye/catfishes vs. trout/charr; Ryan 1991; Kerr 1995; Henley et al. 2000). Limited light penetration in turbid streams means the primary sources of energy are driven by more allochthonous (i.e., imported from external) sources of organic matter. In the context of the AEC, streams classified as turbid are turbid for most of the year, even during summer low flow periods. Perennial turbidity is largely a function of very fine inorganic glaciolacustrine (i.e., clay) deposits underlying the stream channel because surface run-off is not a factor during low flows. Stained waters from tannins released by decaying plant matter in wetlands are not considered in the AEC in terms of turbidity (Flotemersch et al. 2024).

To understand how turbidity relates to landscape factors, we launched a field campaign to measure turbidity using a portable turbidity meter (LaMOTTE Instruments) with 0, 10, and 100 Nephelometric Turbidity Units (NTU) standards and a Secchi tube. We also used turbidity data from the Ontario Provincial Water Quality Monitoring Network. Clay content of surficial geology was theorized to correlate with perennial low-flow turbidity in Ontario. We quickly learned of issues with the base data geology layers. The Surficial Geology of Southern Ontario (MRD128) data has good detail because it is mapped at a fine scale of 1:50,000, but it lacks full provincial coverage and the geology type found underlying most stream valleys is "modern alluvial deposits", which is ambiguously defined to include clay, silt, sand, gravel, and organic materials. Therefore, every stream channel is categorized with the same vague sediment texture description. This lack of clear definition makes modelling using this data impossible (Schmidt and Jones 2022). The quaternary geology data (1:1,000,000; Barnett 1991) has full provincial coverage but some of its geology types do not have homogeneous sediment textures (i.e., gradients of varying clay content are said to occur within a single polygon). For example, St. Joseph Till, extending along the coast of Lake Huron from Sarnia to Southampton, is composed of a silt to silty clay matrix, with clay content that increases southward. Streams at the north end of St. Joseph Till tend to be clearer than streams near Sarnia yet they are described as having the same geology type. Another example is Tavistock Till, which occurs primarily in three large polygons near Chatham-Kent, London, and Shelburne. This geology type is composed of a sandy silt to silt matrix and silty clay matrix in the south and has moderate to high carbonate content in the north, with clast content decreasing from moderate to poor northward. Streams south of Chatham-Kent are turbid, while those in the north are clearer despite their association with the same Tavistock Till. This heterogeneity limits the ability to model turbidity using this data because the variable degree of clay content within a single geology type can not be assumed to produce uniform turbidity levels. Ultimately, we learned that turbidity can not be accurately modelled due to the inconsistent description of sedimentary clay content.

We modified the quaternary geology data to reduce the heterogeneity by splitting some polygons according to the spatial descriptions of their clay content. For example, the St. Joseph Till polygon was split into a northern and a southern polygon, where the southern polygon was categorized as having enough clay content to produce turbidity, while the northern polygon was deemed to not produce turbidity. This approach resulted in a new binary geology layer (i.e., either turbidity producing or not) with full provincial coverage. We then determined the percentage of turbidity producing clay geology underlying the upstream channels of the stream network contributing to each reach (Figure 3C).

Instead of statistical modelling, we developed a manual classification that was iteratively evaluated until errors were few. We used aerial and satellite imagery to examine the turbidity of hundreds of streams and rivers, particularly in remote areas of the province. Interpreters were trained on a set of known turbid and non-turbid streams. We focused on imagery captured from June to September to capture summer low flow conditions. For each stream, we examined factors that may drive turbidity including drainage area, turbidity producing geology underlying the upstream channels (i.e., in the 30 m raster of the Ontario integrated hydrology). We also considered other more localized sources of turbidity including lakes that can produce turbidity through wave action (e.g., Abitibi), and bioturbation (e.g., carp, beavers, cattle) as this can persistently increase turbidity levels in streams (Adámek and Maršáalek 2013). We noticed that as upstream catchment area increased, percentage of upstream clay geology required to produce turbidity decreased. Ultimately, for a reach to be classified as turbid (Figure 12), the combined proportion of turbidity producing clay geology underlying the upstream channel must exceed upstream catchment area dependent thresholds (Table 2).

Table 2. Drainage areas and their associated values for clay geology types in the stream channel used in the aquatic ecosystem classification in Ontario.

Upstream catchment area (km^2)	Estimated % clay geology underlying the upstream channel required to produce low flow turbidity
<500	≥10
500–5,000	≥8
5,000–50,000	≥6
>50,000	≥4

We recognize that many rivers are seasonally turbid (spring and fall), and some are temporarily turbid in response to summer rainstorm events. Many rivers in agriculture areas may have artificially high turbidity levels due to soil erosion and indirectly through nutrient additions that promote primary production of phytoplankton. These rivers are often a khaki green colour during low flow conditions in the summer and, as mentioned earlier, bioturbation can also be a source of turbidity unrelated to geology. The AEC does not attempt to capture these additional turbidity sources and therefore it may not perform well where they are present.

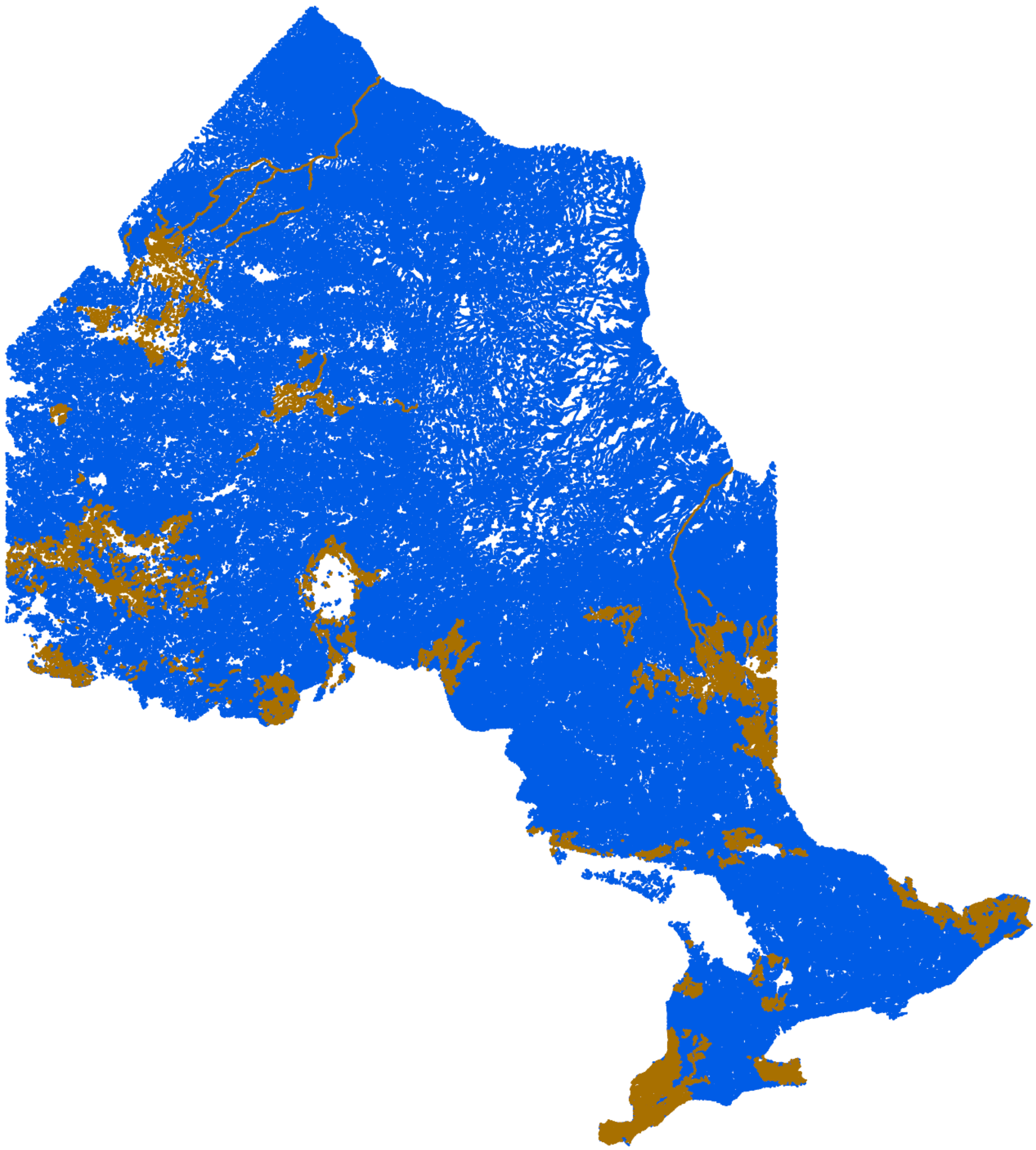


Figure 12. The classified perennial turbidity of streams in Ontario. Streams with blue symbology are typically clear during the summer low flow period, while those symbolized as brown are perennially turbid, even during low flows.

We obtained turbidity data between 2000–2021 from the Ontario Provincial Water Quality Monitoring Network to compare to our binary turbidity classification. Only measurements from June to August were used to calculate summary metrics to avoid larger flows that result in turbidity not indicative of low flow conditions. This coarse time filter does not rule out summer rainstorm events because stream flow was not measured at the place and time of turbidity measurement. We considered streams and rivers with summer turbidity values greater than 10 NTU to be turbid, which was about 0.6 m on the Secchi (Xu et al. 2019; Figure 13).

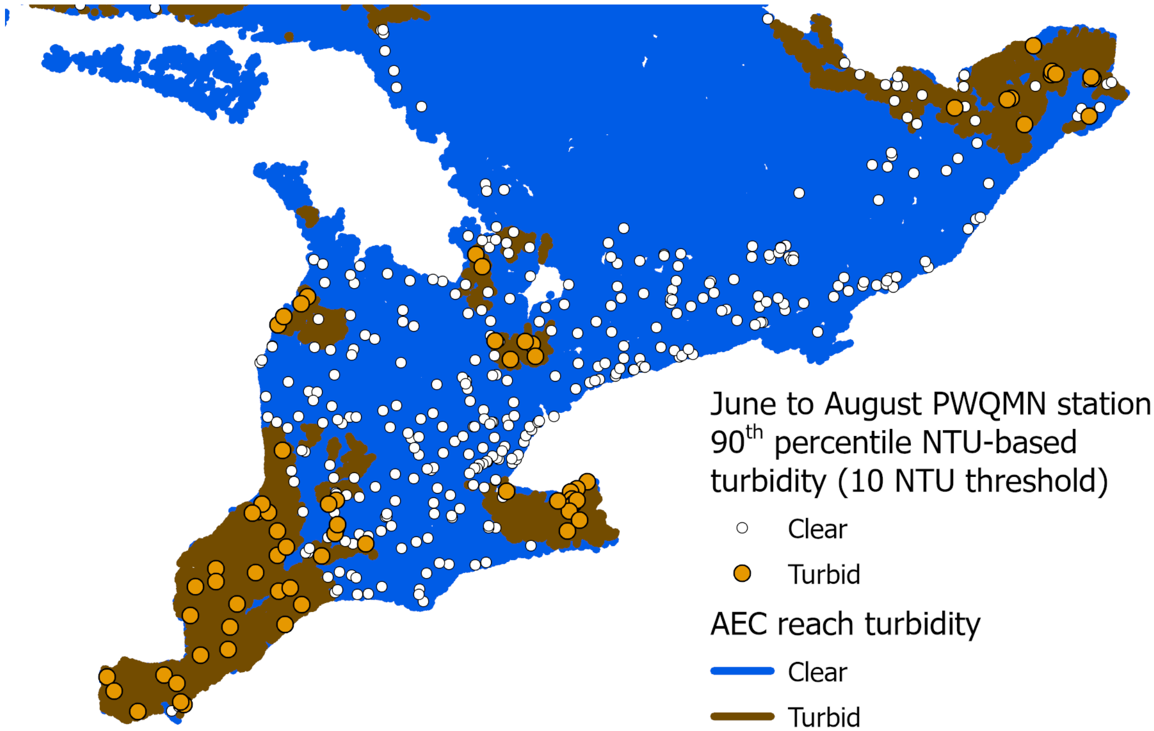


Figure 13. Ontario Provincial Water Quality Monitoring Network (PWQMN) stations classified as either clear or turbid by comparing the 90th percentile of turbidity for measurements from June to August for the years 2000 to 2021 against a threshold of Nephelometric Turbidity Units (NTU) ≥ 10. The map of southern Ontario shows the classified PWQMN stations in relation to the geology based AEC stream classes representing perennial turbidity.

Stream flow velocity

Stream channel slope is a determinant of potential flow velocity (i.e., current), which affects all organisms in running waters. Flow velocity defines sediment size and food delivery, and is a direct physical force acting on organisms. Channel slopes were calculated as rise over run along the length of each reach based on the 30 m Ontario Integrated Hydrology DEM. Flow velocities were categorized as slow (channel slope <0.15%) or fast (channel slope ≥0.15%) moving (Figure 14; Knighton 1998). This threshold was meant to differentiate streams with beds dominated by sands and finer sediments from those with larger sediments such as gravel and coarser sediments (Hjulström 1935). This categorization is a generalization that averages within-reach differences (e.g., fast riffles, slow pools) that are assumed to occur along most reaches because of geomorphological processes operating at scales below that of the AEC reach. We acknowledge that using average reach slope will misrepresent sudden elevation changes (e.g., waterfalls) within a reach. For example, the average channel slope of the Niagara River is just 0.011% excluding the drop at Niagara Falls, but 0.204% (~20x greater) when the falls are included. Like the temperature and turbidity classes, the flow velocity classes are imposed onto a continuum. As a result, channel slopes close to the fast/slow threshold of 0.15% have less affinity to their velocity class and should be implicitly interpreted as transitional.

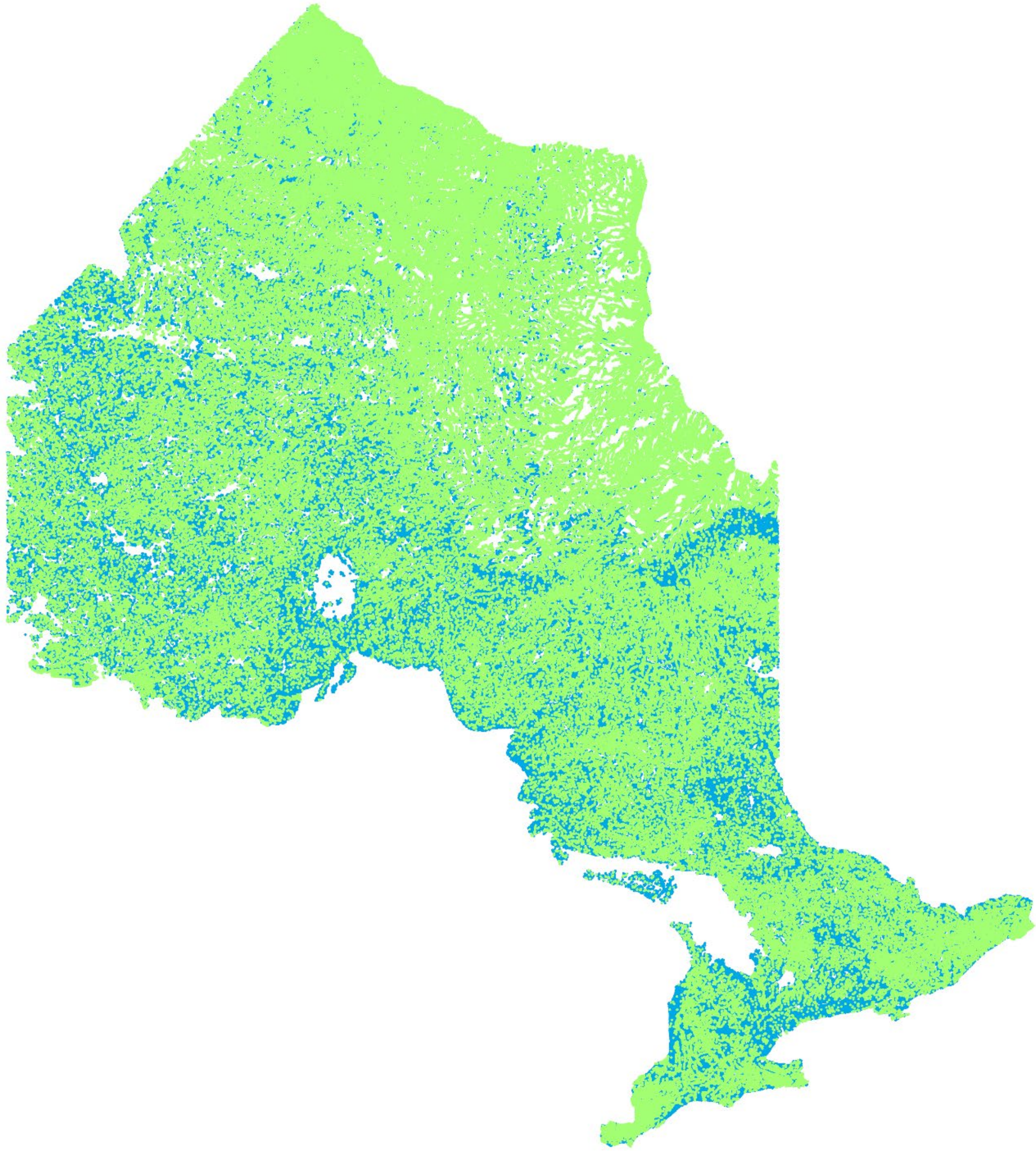


Figure 14. Flow velocity of Ontario streams categorized as slow (green; channel slopes <0.15%) or fast (blue; channel slopes ≥0.15%).

Hierarchical ecological units

The AEC is a hierarchical system where the stream reaches are aggregated into larger units called segments using size neighbourhoods and a reach's stream class. The segments are placed into a broader landscape context using productivity regions.

The complexity of Ontario's stream network is immense and must be reduced to be understood effectively. As a result, we developed a custom application called the Reach Affinity Tool (RAFT; Schmidt and Jones 2020). The RAFT is a network-aware application that clusters stream reaches into larger segments. Segments are assumed to have similar habitat templates and, as such, support similar ecological communities. RAFT was based on the Valley Affinity Search

Technique (VAST) software developed by researchers at the University of Michigan (Brenden et al. 2008). Reaches were grouped into segments through the following steps:

- Each reach was assigned to one of twenty *stream classes* by combining its assigned thermal habitat, perennial turbidity, and stream flow velocity classes.

- Adjacent (i.e., flow connected) reaches were grouped into larger *neighbourhoods* using a set of stream size similarity rules.

- *Segments* were created by combining the *neighbourhood* identifiers with the 20 *stream classes*. Each segment was assigned a unique *segment* identifier.

- *Reaches* were grouped into broader geo-climatic *productivity regions* to provide broad-scale context for the reach-scale *stream classes*.

Stream neighbourhoods

Abrupt changes in the volume of flow, temperature, and sediment at tributary confluences along the length of a stream are addressed by calculating the ratio of the tributary upstream catchment area (UCA) to the mainstem UCA. This ratio is called the confluence symmetry ratio (CSR) for which a value of 1 indicates that both reaches have the same area. As tributary size decreases, CSR approaches zero. Four rules are applied to determine stream neighbourhoods using CSR values (Figure 15). For a practical example of neighbourhoods in a landscape context see Figure 16.

1. Stream reaches between the lower and upper CSR (e.g., 0.25–0.50) are joined into a neighbourhood because they have similar sizes and thus potentially similar ecological characteristics (Figure 15i).

2. If the CSR is below a lower threshold (e.g., <0.25), a tributary is considered too small to affect the main channel (Figure 15ii). In this scenario, the main channel neighbourhood remains uninterrupted while the tributary becomes part of another neighbourhood. The rationale is that a small tributary should not become part of the mainstem neighbourhood because they likely have different channel morphology (e.g., riparian shading, bankfull width).

3. Conversely, when the CSR at a confluence exceeds the upper threshold (e.g., >0.5), a new neighbourhood is initiated beginning with the reach directly downstream of the confluence (Figure 15iii). The reasoning is that the combined volume of water in the downstream channel increases enough to change channel morphology (e.g., channel width, shading, temperature, riparian influence).

4. Subsequently, a fourth rule is applied that prevents large mainstem river neighbourhoods from becoming too large. The mainstems of higher Strahler order rivers have large drainages and few tributaries are large enough relative to these mainstem rivers to split the neighbourhood based on the upper CSR threshold (Figure 15iii). Many small tributaries joining the mainstem cause an increase in flow volume without abrupt changes in stream character (Figure 15ii). The larger the mainstem grows, the less likely

that a tributary will be large enough to cause a split, so large portions of the river are likely to be grouped into a single neighbourhood. This result is problematic because stream reaches at the upstream end of the neighbourhood might have a bankfull width of 25 m (i.e., UCA=1000 km^2), whereas reaches at the downstream end might be 50 m wide (i.e., UCA=2000 km^2) and therefore the reaches of this neighbourhood should not be considered ecologically homogeneous. As a result, neighbourhoods with an unacceptably wide range of reach UCAs need to be divided using a neighbourhood upstream catchment area ratio (NUCAR; Figures 17–19).

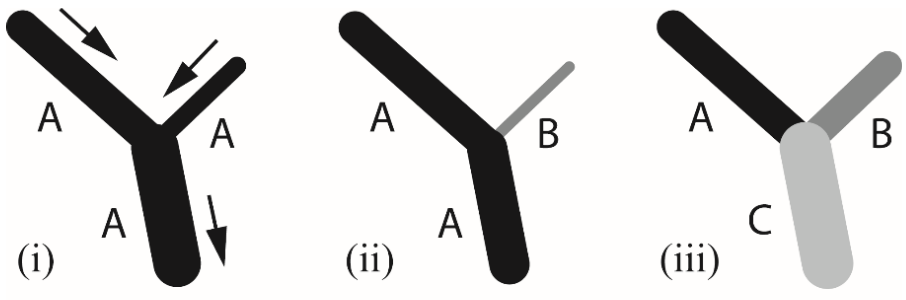


Figure 15. Schematic representation of the rules applied while grouping stream reaches into neighbourhoods using the confluence symmetry ratio (CSR). Arrows indicate the direction of stream flow. In (i), the tributary is neither too small nor too large compared to the main stem (e.g., CSR=0.3), allowing all three reaches to be assigned to the same neighbourhood A. In (ii), the tributary is too small (e.g., CSR=0.1) to cause a split in neighbourhood A and the tributary is assigned to a new neighbourhood B. The tributary in (iii) is large enough (e.g., CSR=0.9) to cause a split in neighbourhood A, initiating a new neighbourhood C with the tributary being assigned to a new neighbourhood B.

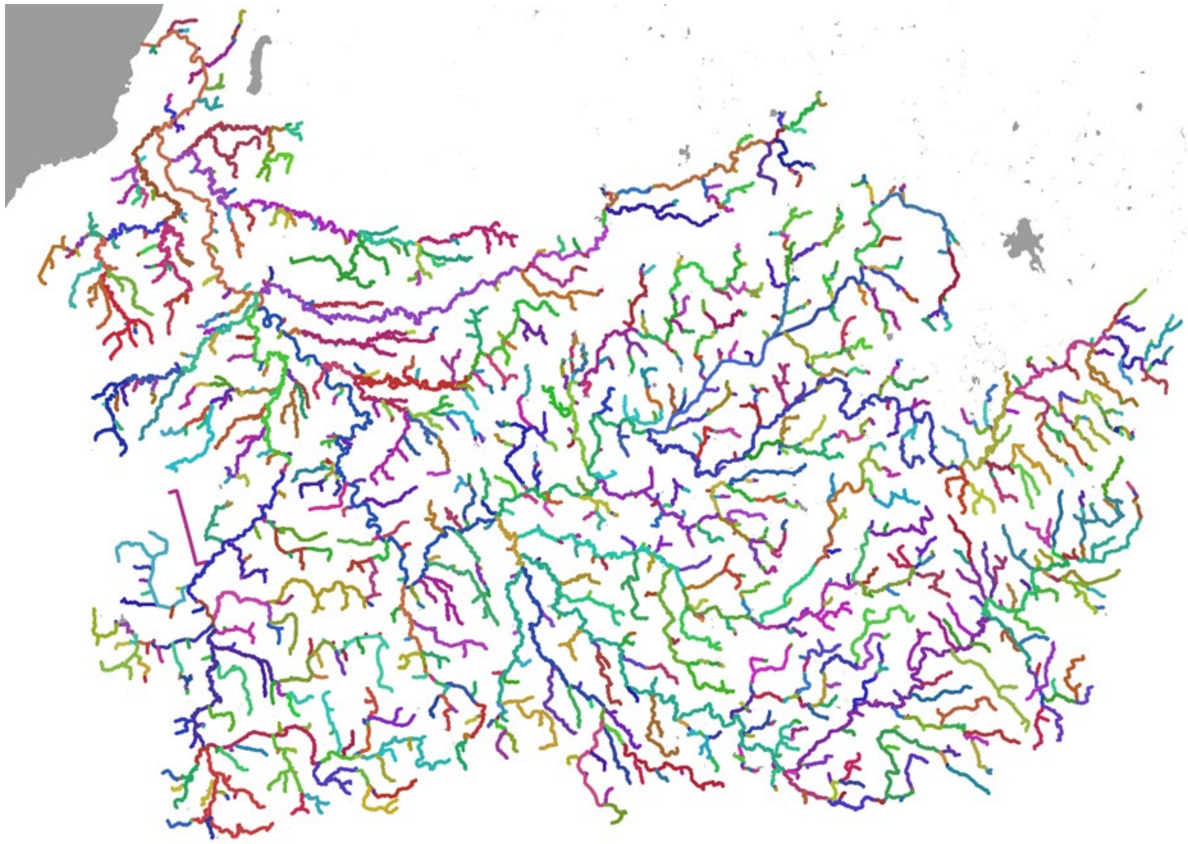


Figure 16. The 1,818 neighbourhoods of the Saugeen River watershed in southwestern Ontario. Different colours represent individual neighbourhoods.

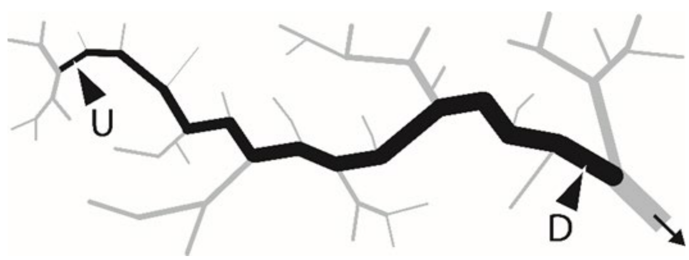


Figure 17. The black line illustrates a hypothetical neighbourhood defined by the confluence symmetry ratio rules within a network. The neighbourhood is composed of multiple reaches starting with upstream reach U having a UCA of 150 km^2 and a furthest downstream reach D which has a UCA of 350 km^2 (Neighbourhood Upstream Catchment Area Ratio (NUCAR) = 350 km^2/150 km^2 = 2.33). None of the small tributaries flowing into this neighbourhood were large enough to produce a split according to the CSR size rules yet the stream has more than doubled in UCA. This neighbourhood exceeds the upper NUCAR threshold of 2.0 as it is passed to the NUCAR processing algorithm. The arrow indicates the direction of stream flow.

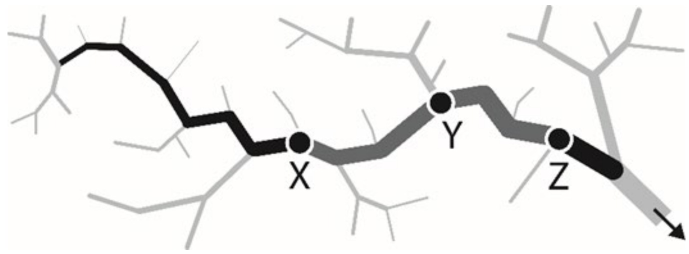


Figure 18. Using the upper and lower Neighbourhood Upstream Catchment Area Ratio (NUCAR) thresholds, Reach Affinity Tool (RAFT) creates a temporary window within the neighbourhood, which is searched for the largest tributary. In this example the upper NUCAR threshold of 2.0 is exceeded at a very small tributary at confluence Z and the lower NUCAR threshold of 1.5 is exceeded at confluence X, thus defining the extent of the search window (illustrated by the medium grey line between confluence X and Z). RAFT then finds the largest confluence within the search window at confluence Y.

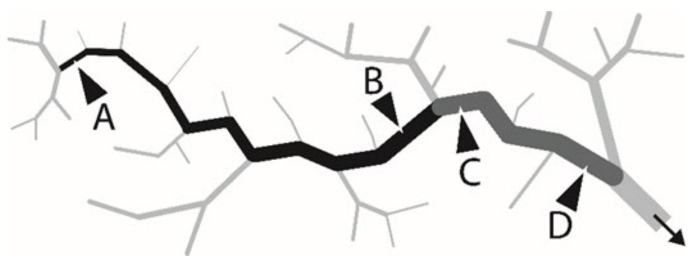


Figure 19. In this example, the Reach Affinity Tool splits the neighbourhood into two new neighbourhoods at the largest confluence it has found using the Neighbourhood Upstream Catchment Area Ratio (NUCAR) window. The two new neighbourhoods are illustrated as the black line between reach A and B and the medium grey line between reach C and D. The entire NUCAR process is repeated until all neighbourhoods within the processing extent fall below the upper NUCAR threshold (i.e., no neighbourhoods will have reaches that double in UCA).

Stream segments

The segments are created by spatially overlaying the neighbourhoods with the reach classes. The result is ecological units whose reaches are similar in size (i.e., upstream catchment area) and character (i.e., thermal habitat, perennial turbidity, and flow velocity) (Figure 20). The reaches in a segment do not have to be spatially contiguous (i.e., directly upstream or downstream of one another), but they must be within a single neighbourhood's boundaries. A neighbourhood can contain multiple segments (Figure 21).

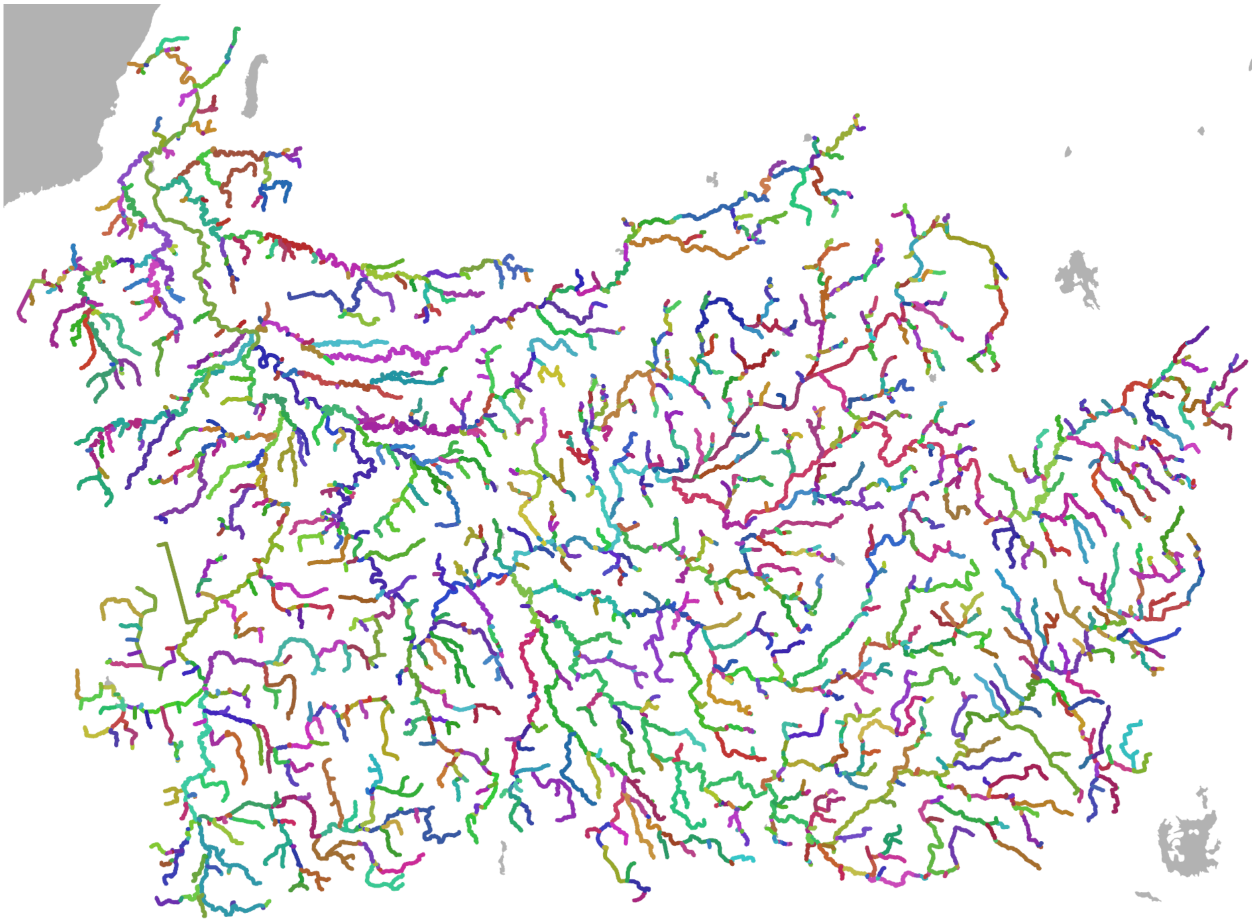


Figure 20. The 2,140 segments of the Saugeen River watershed in southwestern Ontario. Different colours represent individual segments.

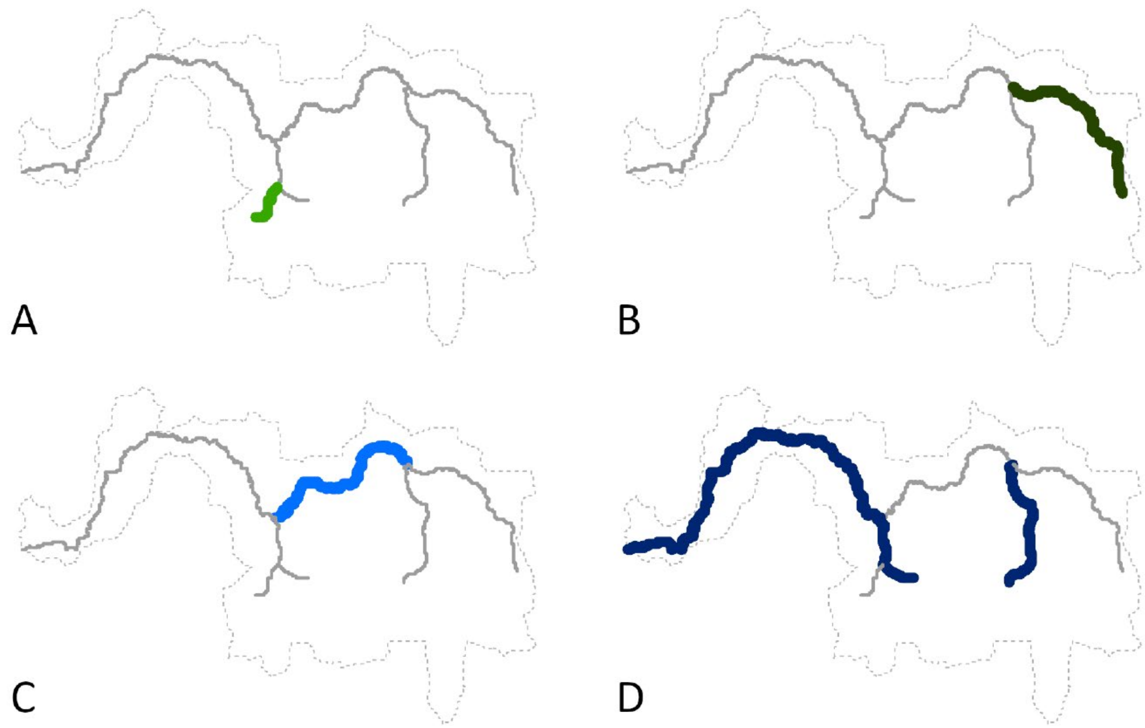


Figure 21. An example of a single neighbourhood (unique AEC identifier N13.497) within the Saugeen River watershed in southwestern Ontario, where the dashed polygon represents its sub-watershed (i.e., combined reach contributing areas). The thick coloured lines represent the four stream classes contained within this neighbourhood. They are: (A) CLCS, (B) CLCF, (C) CCCS, and (D) CCCF. The neighbourhood identifier and stream class are combined to form the unique segment identifier. For example, the identifier for the segment shown in D (dark blue lines) combines the neighbourhood identifier N13.497 with the stream class CCCF to form the unique segment identifier S13.497.CCCF (note that they do not have to be spatially contiguous). This approach assigns each reach to a segment, where each segment is composed of reaches with similar upstream catchment area, thermal habitat, perennial turbidity, and stream flow velocity.

Productivity regions

Regions constitute the highest levels of the classification hierarchy in the AEC and are based on expectations of aquatic productivity. Unlike the bottom-up approach that aggregates the reaches into larger segment units, productivity regions are developed using a top-down approach, where ecozones are subdivided into smaller region units. Productivity is a key aspect of flowing waters with respect to fish harvest and ecosystem resilience. In lakes, productivity has three principal influences: morphometric (shape/dimension), edaphic (soil/geology), and climatic factors (Ryder 1965, Welcomme et al. 1989). It is difficult to generalize about the morphometry of streams and rivers across Ontario; however, the potential of the fluvial environment to produce biota can be estimated by combining growing degree days and conductivity, broadly akin to the morphoedaphic index (MEI) developed by Ryder (1965). The relationship between MEI and productivity also likely holds true for flowing waters, wherein channel length, drainage basin area, or total floodplain area are more relevant measures than river depth (Welcome et al. 1989).

Ontario's ecozones are defined in large part by the differences in their surficial geology types, and the geology drives the amount and type of dissolved solids found in a stream. They are a key source of nutrients needed by aquatic organisms to grow and develop. We use water conductivity as a surrogate measure for the amounts of dissolved solids (e.g., Ca^{2+}, Mg^{2+}, PO_4^{3-}). We compiled a large set (5,624 points) of conductivity measurement points from several provincial data sources (e.g., Provincial Water Quality Monitoring Network, Canadian Aquatic Biomonitoring Network) and applied ecozone specific natural ranges to reduce influence of human activity (e.g., road salt) or marine inundated lands. We used the remaining values to calculate average conductivity for each ecozone (Figure 22). Average water conductivity values for the ecozones are 571, 69, and 138 µS for Mixedwood Plains, Ontario Shield, and Hudson Bay Lowlands, respectively.

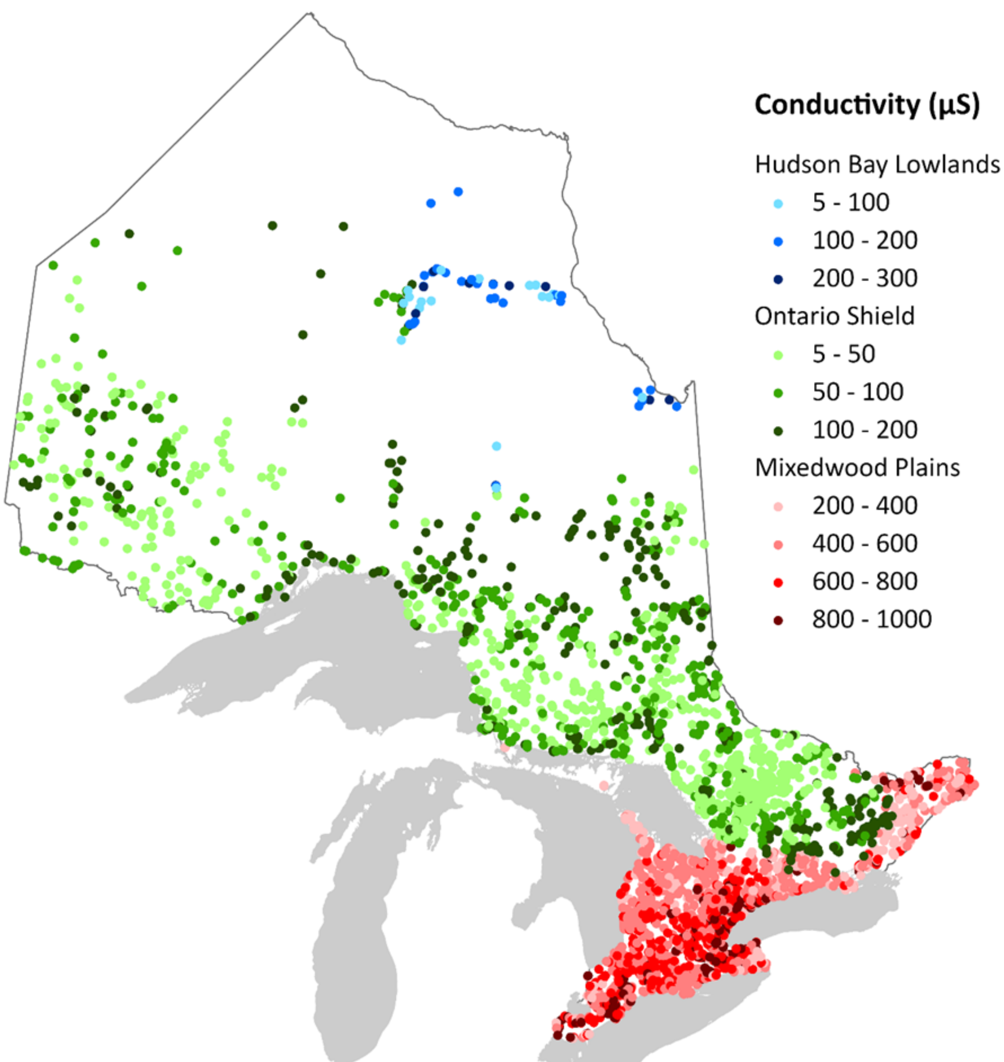


Figure 22. Map of conductivity points used to calculate average ecozone values. Average water conductivity values for the ecozones are 571, 69, and 138 µS for Mixedwood Plains, Ontario Shield, and Hudson Bay Lowlands, respectively.

Growing degree days of air temperature was used to approximate regional differences in the potential growth and development of ectotherms during the growing season (Shuter et al. 1980, Neuheimer and Taggart 2007). Generally, the higher the GDD and conductivity the higher the productivity potential of the stream. Riparian shading related to stream size and turbidity, however, may alter expectations because high levels of turbidity and shade can reduce photosynthesis, potentially affecting productivity.

Five growing degree day (>5 °C) bands occur in Ontario (Band 1: <700, Band 2: 700–1,100, Band 3: 1,100–1,500, Band 4: 1,500–1,900, Band 5: ≥1,900) as do three ecozones of the terrestrial ecological land classification system (ELC; Crins et al. 2009): Hudson Bay Lowlands, Ontario Shield, and Mixedwood Plains. Growing degree day bands and a reach's predominant (>50%) upstream ecozone combine to create nine unique productivity regions across Ontario. Streams that originate within one ecozone (e.g., Ontario Shield) and drain into another ecozone (e.g., Hudson Bay Lowlands) carry their classification and bleed into the neighbouring ecozone. This carry over is because the water upstream does not instantly change character when it crosses an ecoregion border (Figure 23). These regions delineate large areas of potential differences in aquatic ecosystem productivity.

Stream size and wadeability

Stream size is used to further stratify streams over broader spatial scales, independent of stream class. Stream size determines many stream characteristics, with predictable changes as streams grow from headwater to large rivers. The River Continuum Concept (Vannote et al. 1980) describes downstream changes including depth, channel width, shade, velocity, discharge, and temperature. Overlain on these abiotic gradients are corresponding changes in biological characteristics in riparian influence, organic matter size, algae, benthic invertebrates, and fishes. The AEC provides upstream catchment area (UCA) and Strahler order (Strahler 1957) which uses integers to represent stream size: small streams (order 1–3), mid size streams (order 4–6), and lower reach large rivers (order >6). Because Strahler order changes with the scale and accuracy of the DEM, the AEC also provides stream size based on drainage area divided into three categories (Figure 24) that address constraints on field sampling methods: wadeable streams (UCA<200 km^2), non-wadeable streams (>2,000 km^2), and semi-wadeable streams (UCA≥200 to <2,000 km^2). For wadeable streams, more than 95% of the stream is wadeable and many sampling methods exist. For non-wadeable streams, 95% is boatable (UCA≥2,000 km^2) and methods designed for slow moving rivers and lakes may apply. The semi-wadeable streams are difficult to travel along, navigate within, and sample, and require a mixture of approaches. Notable exceptions to these rules include streams running through clay geology and organics because they tend to have U-shaped channels that can be non-wadeable, even in relatively small streams. Furthermore, backwater conditions in small to intermediate streams near the estuaries of the Great Lakes may be accessible by boat depending on lake levels.

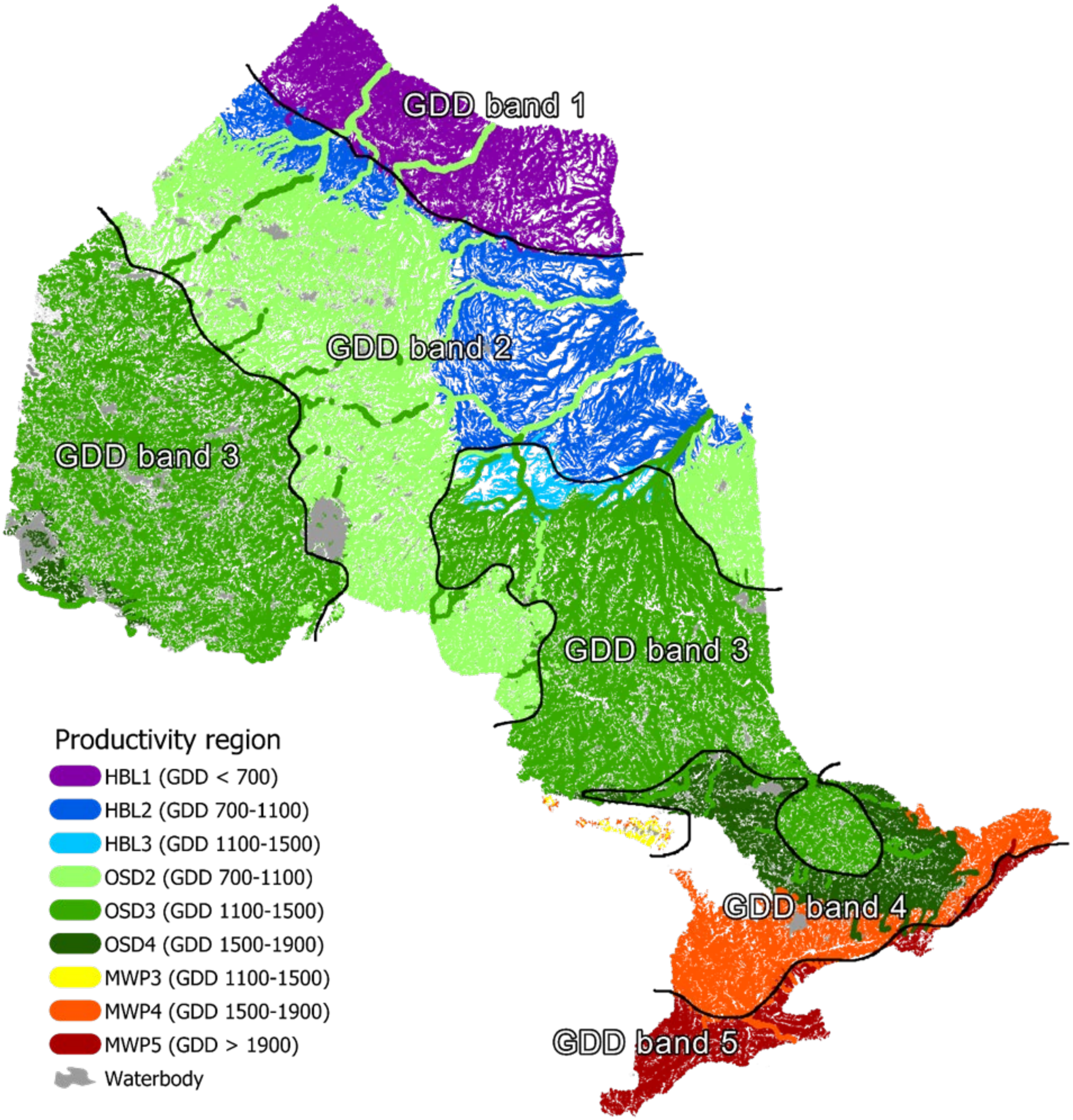


Figure 23. The combinations of bands of air growing degree days (GDD) above 5 ˚C and ecozones create nine unique productivity regions that delineate large areas of potential differences in productivity across Ontario (HBL = Hudson Bay Lowlands; OSD = Ontario Shield; MWP = Mixedwood Plains). Some bleeding across regions can occur at their edges because the upstream influence of a region carries downstream for a distance, especially on large mainstem rivers.

Figure 24. The three stream size categories in Ontario based on drainage area: wadable streams (<200 km², light blue), non-wadeable streams (>2,000 km², dark blue), and semi-wadeable streams (≥200 to <2,000 km², medium blue).

Reach attributes

Each stream reach's spatial data is supplemented by attributes such as unique identifiers, position within the stream network, and ecologically relevant landscape characteristics (Table 3). Where appropriate, field names are prefixed with the spatial scale (e.g., UCA; Figure 3) at which the information was summarized.

Table 3. An overview and brief description of the core aquatic ecosystem classification (AEC) reach attribute table. The table fields have been organized into groups, which are separated by thicker lines. The fields within each group share a common theme (from top to bottom): Network line function and identifiers, ecological classification codes, stream size metrics, ecological classification values, productivity metrics, and metadata.

Field name	Description
WorkUnitID	The numeric AEC work unit identifier for use when working with data composed of multiple merged work units.
Network line type	The role a reach plays within the stream network spatial structure.
ProvReachID	A provincially unique reach identifier and the primary/foreign database key for joining core AEC feature classes, tables, and supplementary data tables.
ProvNeighbourhoodID	A provincially unique identifier for groupings of reaches that have similar upstream catchment areas.
ProvSegmentID	A provincially unique segment identifier for groupings of reaches that are part of the same stream class within the same size neighbourhood.
Stream class	A combination of abbreviated codes of a reach's thermal class, turbidity, and flow velocity that defines a reach's abiotic habitat template (e.g., cold = CD; Clear = C; Fast = F).
Thermal class	A probabilistic-based membership to one of five thermal categories (cold, cold-cool, cool, cool-warm, warm) based on 30 years (1981–2010) of modelled water temperature.
Turbidity	Denotes whether a reach is perennially clear or turbid, based on proportion of clay geology underlying the upstream network channels (UCh).

Field name	Description
Flow velocity	Denotes whether a reach is slow or fast flowing based on reach channel slope.
Wadeability	One of three categories describing the wadeability/navigation of the reach (wadeable, semi-wadeable, and non-wadeable).
Strahler order	An integer value that describes the position, and thus size, of a reach within the stream network (integers values range from 1 to 8, where headwaters at the outer branches of the network are assigned a value of 1, and the largest mainstem rivers in the AEC a value of 8; Strahler 1957).
Upstream catchment area	The area of landscape draining to the lower end of a reach in square kilometres.
July 30yr average temperature	The average July water temperature of a reach calculated using 30 individually modelled years (1981–2010) of data in degrees Celsius.
Thermal class probabilities	The probabilities (%) of a reach belonging to one of the three primary thermal classes of cold, cool, or warm based on modelled stream temperatures for the period from 1981 to 2010. The three colon-separated values always add up to 100.
Lake influenced (temperature)	Denotes whether a reach's water temperature is influenced by one or more lakes upstream (yes or no). Modelled stream temperature conditions are potentially superseded by the influence those lakes exert on water temperature downstream.
RCA baseflow index	An indicator for cold groundwater seepage potential along the stream bed at the local intra-reach scale. It is based on the groundwater contribution potential of the geology types found in the reach contributing area (RCA), where seepage potential increases with increasing index values.
UCh turbid geology	The percentage of all upstream network channels (UCh) underlaid by turbidity producing clay geology.
Channel slope	The reach channel slope expressed as a percentage (i.e., metres of elevation drop for every 100 m of stream length). It is calculated by dividing the drop in elevation between the

Field name	Description
	start and end point of a reach by the simplified length of the reach.
Extended class	A colon-separated combination of stream class, productivity region, Strahler order and lake influence, providing further context for the stream class by including additional components with potential to influence the abiotic habitat template.
Productivity region	Denotes reach membership within one of nine provincial productivity regions, which are defined by the predominant upstream ecozone and growing degree band.
UCA predominant ecozone	The predominant (≥50%) terrestrial ecozone in the upstream catchment area (UCA).
Growing degree days band	Denotes reach membership in one of five bands (i.e., value ranges) of average upstream catchment area growing degree days for air temperatures above 5°C.
UCA average GDD_{air}	Average upstream catchment area (UCA) growing degree days (GDD) for air temperatures above 5°C.
Manual modification flags	A set of integer codes that flag whether the thermal class, turbidity, or flow velocity (codes or values) have been assigned outside of the standard assignment rules.
Simplified reach length	The length of a reach based on the simplified line geometry (i.e., reduced vertices compared to the mapped blue lines) rounded to the nearest metre.
Shape_Length	A mandatory ArcGIS field added to each line feature class table and measured in metres (m).

Reaches with upstream areas partially out-of-province

Some streams have upstream connected reaches that flow into Ontario from either Quebec or Manitoba. These out-of-province reaches do not have the required base data needed to perform the modelling/analyses with the same certainty as reaches whose entire upstream catchment area are fully attributed. We chose to still classify these rivers because the missing data only represents a minor fraction of the upstream, except near their headwaters. Three large rivers are affected: the Abitibi River, the last 8 km of the Moose River below the Abitibi confluence, and the Severn River and its tributary the Beaver Stone River (Figure 25).

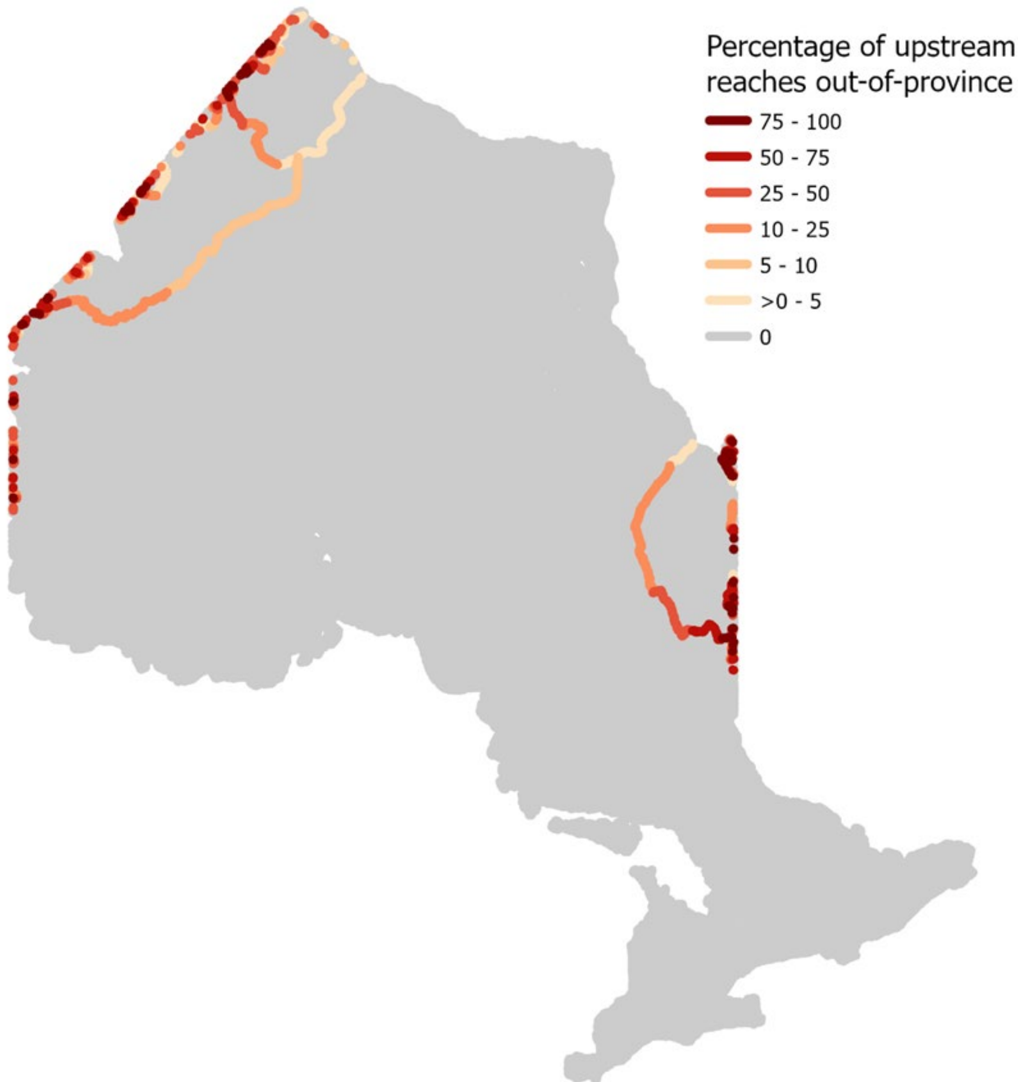


Figure 25. The stream reaches with some percentage of upstream connected reaches outside Ontario's provincial border. Three large rivers are affected: the Abitibi River, the final kilometre of the Moose River below the Abitibi confluence near the Quebec border, and the Severn River and its tributary the Beaver Stone River near the Manitoba border.

Manual attribute modifications

Manual corrections are occasionally applied to the AEC data in response to user feedback and based on expert opinion. Modifications are flagged in the [Manual Modification Flags] field of the reach attribute table (e.g., TEMP:1 TURB:0 SLOPE:0). Manual temperature class corrections were applied to improve consistency and continuity of the modelled temperature predictions. The turbidity class was manually adjusted according to field observations in several small areas where the presence of upstream clay geology did not appear to produce perennial turbidity. The velocity class of some tributaries near the Niagara River were manually adjusted from fast to slow because digital elevation model conditioning (i.e., "burn-in") produced artificially steep slopes. Each class (thermal, turbidity, and velocity) has two field types associated with it: 1) the value fields that contains numerical values (e.g., [July 30yr average temperature (Celsius)] = 19.4 °C; [Thermal class probabilities (% Cold:Cool:Warm)] = 16:82:1) and 2) the code field (e.g., [Thermal class] = “Cool”). Table 3 shows the four possible flag values and hypothetical examples of how each type of modification might appear in the attribute table.

Table 1. The modification flags with descriptions and examples.

Flag	Description	Example
0	No modifications	No values or codes were modified.
1	Both the values and the code has been modified	The [Thermal class] code field was modified from ‘CL’ to ‘CW’ and its associated value fields [July 30yr average temperature (Celsius)] and [Thermal class probabilities (% Cold:Cool:Warm)] were set to <null>.
2	Only the class code has been modified	The [Thermal class] code field was modified from “CL” to “CW” but its associated value fields [July 30yr average temperature (Celsius)] and [Thermal class probabilities (% Cold:Cool:Warm)] were not modified (all associated value fields are always modified together).
3	Only the value(s) has been modified	The value fields [July 30yr average temperature (Celsius)] and [Thermal class probabilities (% Cold:Cool:Warm)] were modified (all associated value fields are always modified together) but it’s associated code field [Thermal class] was not unmodified.

Differences between versions

Version 1 and 2

Between 2013 and 2017, we conducted more than 30 meetings to provide organizations an understanding of the initial version of the classification (AECv1), including the then Ministry of Natural Resources and Forestry (MNRF), conservation authorities (CA), Department of Fisheries and Oceans Canada (DFO), universities, and non-government organizations. Given the positive reception of the AECv1 and the demonstrated need for this product in the ministry and other agencies, we recommended the development of an updated second version (Jones and Schmidt 2019b). Participants at our stakeholder meetings reported that AECv1 correctly classified most streams in southern Ontario. Incorrectly classified streams need to be vetted by those familiar with them, as some are rare (e.g., karst streams), have base data issues (e.g., missing waterbodies), or are unique within Ontario (e.g., deeply incised valleys with connections to the deep aquifers).

One issue in AECv1 was the interpretation of baseflow index (BFI; Neff et al. 2005) as a measure of groundwater inputs. The BFI was assumed to represent potential cold groundwater contributions to stream flow and used as a surrogate for stream temperature. This assumption worked well in southern Ontario because most streams are relatively small (<100 km^2) and strongly influenced by local catchment BFI rather than air temperature. In contrast, this approach did not work well in Northern Ontario – particularly for larger rivers (catchment areas >700 km^2). This result is not surprising given that the influence of BFI on thermal character declines as stream size increases. This effect can be attributed to the increasing influence of air temperature and solar heating as the river surface area open for convective heating increases combined with increases in stream width that reduce the effectiveness of riparian shading, allowing more of a river's surface to be exposed to solar radiation (Caissie 2006). In Northern Ontario, streams often have high BFI (i.e., large amounts of groundwater inflow) in headwater areas. This high BFI is carried downstream, leading to relatively high BFI in large rivers. These large rivers appeared as cold on the AEC map when they are, in fact, much warmer. To address this issue, AECv2 replaced BFI with modelled July water temperatures for all streams in the Mixedwood Plains Ecozone and large rivers (>700 km^2) of the Ontario Shield and Hudson Bay Lowlands ecozones. Small streams (<700 km^2) in the northern ecozones (Ontario Shield and Hudson Bay Lowlands) will be modelled once an ongoing temperature collection campaign allows for more accurate modelling.

Other refinements in AECv2 included the following (with rationale and more details provided in Jones and Schmidt 2019b):

- Updating the geology-based turbidity classification scheme because many streams were incorrectly classified as being turbid. Some clay-containing quaternary geology types (4, 6, 8, 15, and 21) were removed because they did not produce low flow turbidity. Only types 24, 26, and 29 remain (as defined in Barnett 1992).

- Applying a dynamic turbidity assignment process based on a set of variable, upstream catchment area dependent, turbidity producing geology percentages instead of a single static threshold.

- Correcting channel slope class codes for the Haldimand Clay Plain of Niagara Peninsula and the St. Clair Clay Plains west of London as their extremely low topographic relief and digital elevation model (DEM) conditioning methods result in DEM base data issues.

- Improving lake influence estimates using more sophisticated analysis methods (in progress PhD thesis, M. Allerton).

- Using a more intuitive method for creating stream classes and segments (Jones and Schmidt 2019b).

Version 2 and 3

The current version of the AEC (AECv3) includes data enhancements and changes to the way streams are classified. Detailed descriptions of the changes listed below can be found throughout this document.

- Temperature models were updated using a larger and more refined data set and newly developed inverse distance weighted landscape predictor variables (Sutton et al. 2024).
- Temperature models were developed and applied to all real (i.e., non-virtual) reaches across Ontario, providing coverage for small streams (<700 km^2) in the north (Ontario Shield and Hudson Bay Lowlands) that were unclassified in AECv2.
- A spatial layer was added to show modelled lake surface temperatures at lake outlets.
- The algorithm used to assign thermal class was modified to produce less biased results.
- Temperature classes were manually corrected to improve consistency and continuity of the modelled data (e.g., at small/large river model interfaces).
- The channel slope threshold used to differentiate between slow and fast streams was increased from 0.1% to 0.15%.
- The velocity class of some tributaries to the Niagara River were manually adjusted from “fast” to “slow” because digital elevation model conditioning (i.e., “burn-in”) produced artificially steep slopes.
- Turbidity classes were manually adjusted according to field observations in several areas where the upstream clay geology does not produce turbid streams.
- Lake effect influence on water temperature (LEI_T) calculations were updated using improved methods and lake effect influence on flow attenuation (LEI_F) was added for the first time.
- Values for percent upstream ecozone, GDD band, and productivity region were added to inland lake virtual connector reaches for continuity and clarity.
- Some fields in the attribute table were renamed for clarity.

Summary

The aquatic ecosystem classification is a science-based tool that groups and classifies Ontario’s rivers and streams. The AEC stream classes are composed of three attributes: thermal habitat, perennial turbidity, and stream flow velocity. These continuous variables are discretized into categories (i.e., binned) and combined to form 20 stream classes. The main goals of the AEC project include providing a universal and consistent spatial framework for Ontario’s flowing waters, capturing the ecological nature of streams and rivers, validating the classification by working with stakeholders during development and testing, and simplifying the enormous complexity of streams across Ontario for understanding and to support management. The AEC is an ongoing project that will continue to be supplemented with additional variables and information that can be used to better understand and manage Ontario’s aquatic resources. Version 3 of the classification addresses issues discovered during the application of version one and two. The current version of the AEC uses OHN and OIH data from 2014. Major updates to the AEC spatial data will be considered when substantial revisions to hydrography and digital elevation data are available consistently for the entire province. Light detection and ranging (LiDAR) technologies may improve our understanding of stream network geometry, including our ability to classify small (<1 km^2) temporary streams. In the meantime, users of the AEC can provide valuable information about where the classification works well and where it does not by submitting the classification error reporting form provided in Appendix 1. Geodatabase files associated with this project are available via Ontario GeoHub.

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Appendix 1: User feedback form

Users of the AEC can provide valuable information about where the classification works well and where evidence suggests it can be improved. We would like to hear from you so we can adjust class designations if warranted. Please use the table below to submit possible errors for evaluation and consideration. Additional rows can be added if required.

Please email the completed form to aec@ontario.ca.

Name	
Position	
Organization	
Primary use of the AEC	

AEC reach ID [ProvReachID]	Current class	Suggested class	Reason for change
R7.1234	CLCF	CDCF	Measured average July water temperature was below 16 ˚C between 2015 and 2020
Mariposa Brook: R5.11983 to R5.11941	CWTS	CWCS	Main creek channel is not turbid during summer
Nowhere Creek: all reaches upstream of R33.1234	CDCF	CDTF	Entire upstream watershed is turbid all year

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