Sub-Indicator: Groundwater Quality

Note: The groundwater quality sub-indicator *attempts* to evaluate the general status of the quality of shallow groundwater in the Great Lakes Basin, which is interactive with other components of the water cycle and has potential to impact the quality of the Great Lakes waters. *Data that are readily available for* select chemical constituents that are representative of a variety of potential sources of groundwater contamination are used to assess this threat to ecosystem health and water quality of the Great Lakes and their source tributaries.

There is, however, no monitoring performed specifically to assess the quality of groundwater contributing to the Great Lakes and their tributary waters. This sub-indicator, *Groundwater Quality*, as the sole support for General Objective 8 of the 2012 Great Lakes Water Quality Agreement (GLWQA): Groundwater, is based on available water quality data (chloride and nitrate) from predominantly provincial and state monitoring well networks in the Great Lakes Basin. These monitoring networks were primarily designed to inform about the management of water supplies, and, as a result, these data provide an imperfect assessment of groundwater quality impacts on Great Lakes waters. Several limitations of this data are described below in the Discussion section "Data Limitations".

Overall Assessment

Status: Good

Trends:

10-Year Trend: Undetermined

Long-term Trend: Undetermined

Rationale: The overall status of groundwater quality in the Great Lakes Basin is assessed as "Good" (Figure 1). For the assessed fraction of the basin (51% of the total area), the groundwater quality is "Good" in 57% of the area, "Fair" in 36% of the area, and "Poor" in 7% of the area, resulting in an overall assessment of "Good". Given the paucity of monitoring well data available, the previous (2022) report assessed the combined data from 2000-2020, using only the most recent data for those wells with data from multiple years (Environment and Climate Change Canada and the U.S. Environmental Protection Agency, 2022). Still, the bulk of the 6,554 data points were from the period 2005-2009. In this 2025 report, the status assessment for this sub-indicator is based on groundwater samples collected within the last 10 years (2014 to 2023 inclusive), combining new data with approximately 25% of the data from the previous report for a new total of 5,756 wells. As was the case in previous reports, there is insufficient spatial coverage of monitoring wells with available long-term time series of the required data to complete the trend analyses. However, a trend analysis on a select sub-set of the data for the past 20 years was performed and is included in the Discussion section Trends of Chloride and Nitrate Concentrations in Groundwater in the Great Lakes Basin. Note: The overall Great Lakes Basin assessment is a separate analysis compared to the individual lake basin assessment determinations. As such, the lake basin assessments do not collectively reflect the overall assessment for the Great Lakes Basin for groundwater quality.

Lake-by-Lake Assessment

Lake Superior

Status: Undetermined

10-Year Trend: Undetermined

Long-term Trend: Undetermined

Rationale: As illustrated in Figure 2, of the 364 wells that were assessed, the groundwater quality is assessed as "Good" in 301 (83%), "Fair" in 48 (13%), and "Poor" in 15 (4%). However, only 26% of the Lake Superior Basin area could be assessed due to limited data coverage, thus resulting in its status as "Undetermined". For the assessed fraction of the lake basin area, groundwater quality in 71% of the area is assessed as "Good", 29% as "Fair" and zero as "Poor."

Lake Michigan

Status: Undetermined

10-Year Trend: Undetermined

Long-term Trend: Undetermined

Rationale: As illustrated in Figure 3, of the 4,240 wells that were assessed, the groundwater quality is assessed as "Good" in 2,291 (54%), "Fair" in 955 (22.5%), and "Poor" in 994 (23.4%). Of the assessed area of the lake basin (48.4% assessed), groundwater quality is assessed as "Good" in 73%, as "Fair" in 14.5%, and as "Poor" in 12.5%. Despite the larger number of wells providing data in this report compared to the 2022 report, the clustering of the data into the western area of the basin meant much of the other parts of the basin had insufficient data coverage.

Lake Huron

Status: Good

10-Year Trend: Undetermined

Long-term Trend: Undetermined

Rationale: As illustrated in Figure 4, of the 456 wells that were assessed, the groundwater quality is assessed as "Good" in 253 (55.5%), "Fair" in 105 (23%), and "Poor" in 98 (21.5%). For the assessed fraction of the lake basin area (60.9%), groundwater quality in 64.6% of the area is assessed as "Good", 30.9% as "Fair" and 4.5% as "Poor."

Lake Erie

Status: Fair

10-Year Trend: Undetermined

Long-term Trend: Undetermined

Rationale: As illustrated in Figure 5, of the 228 wells that were assessed, the groundwater quality is assessed as "Good" in 107 (46.9%), "Fair" in 65 (28.5%), and "Poor" in 56 (24.6%). For the assessed fraction of the lake basin area (69.8%), groundwater quality in 41.5% of the area is assessed as "Good", 52.7% as "Fair" and 5.7% as "Poor."

Lake Ontario

Status: Fair

10-Year Trend: Undetermined

Long-term Trend: Undetermined

Rationale: As illustrated in Figure 6, of the 468 wells that were assessed (half the number assessed in the 2022 report), the groundwater quality is assessed as “Good” in 139 (29.7%), “Fair” in 151 (32.3%), and “Poor” in 178 (38%). For the entire lake basin area (73.7% assessed), groundwater quality in 28.7% of the area is assessed as “Good”, 60.5% as “Fair” and 6.7% as “Poor."

Status Assessment Definitions

Various standards and guidelines for the protection of both human health and aquatic life have been established by jurisdictions that have regulatory responsibilities in the Great Lakes Basin (GLB) (Table 1). In choosing the criteria for chloride and nitrate to be applied for this sub-indicator report (and all previous reports), the most stringent of these values were chosen to provide the most conservative (protective) assessment. Therefore, the Canadian Council of Ministers of the Environment (CCME, 2012) water quality guideline criteria for the protection of aquatic life (i.e., 120 mg/L for chloride and 3 mg N/L for nitrate) were selected. For the Status Assessment, these criteria were initially applied to each monitoring well, with those evaluations then extrapolated to each Great Lake drainage basin (watershed), following the three steps outlined below. The results from each of the three steps are presented in Tables 2 and 3 and Figure 8, including a comparison between basins.

Step 1 - Wells

For each monitoring well (i.e., data location), the groundwater quality was assessed based on the most recent data available for chloride (Cl^-) and nitrate-N (NO_3^-) concentrations, as being:

Good: less than or equal to (≤) 0.8 mg N/L NO_3^- AND ≤ 30 mg/L (Cl-)

Fair: greater than (>) 0.8 BUT less than (<) 3 mg N/L NO_3^- AND/OR >30 BUT < 120 mg/L (Cl-)

Poor: greater than or equal to (≥) 3 mg N/L NO_3^- AND/OR ≥120 mg/L (Cl^-)

These assessment criteria are shown graphically in Figure 7. In this approach, the distinction between “Fair” and “Poor” is based on the CCME 2012 water quality guideline criteria. The distinction between “Good” and “Fair” is based on concentrations equivalent to one quarter (25%) of the same guideline concentrations (i.e., 30 mg/L for chloride; 0.75, rounded up to 0.8 mg N/L for nitrate). Consistent with previous assessments, these “25% of guideline” criteria provide an interim, protective approach for this sub-indicator assessment, based predominantly on judgement rather than directly on established criteria. However, a recent study did note impairment of an important aquatic organism, *Daphnia,* living in low nutrient, soft water lake conditions (Precambrian Shield) at chloride concentrations < 40 mg/L (Arnott et al., 2020). These assessment criteria may be modified in the future if sufficient support becomes available for alternative values.

Step 2 - Tertiary Watersheds

Ideally, the areal (geographic) unit of observation for this sub-indicator would be the drainage basin (watershed) of each Great Lake, and also the entire Great Lakes Basin. However, due to spatial gaps and clustering in available groundwater data, there were insufficient data to assess certain portions of most lake basins in a spatially representative way. Therefore, the indicator status for each tertiary watershed (TW) was evaluated prior to completing the assessment for their respective Great Lake drainage basin based on the following criteria:

Good: If more than 50% of wells in a TW are assessed as “Good”, THEN the TW is assessed as “Good".

Poor: If more than 50% of wells in a TW are assessed as “Poor”, THEN the TW is assessed as “Poor".

Fair: If more than 50% of wells in a TW are assessed as “Fair”, or none of the “Good”, “Fair”, or “Poor” is dominant (i.e., >50%), THEN the TW is assessed as “Fair".

Undetermined: TWs with fewer than two data points were not assessed and are shown as “Undetermined".

It should be noted that the TW assessment is based on the well assessment percentages, which could generate potential bias where the wells are clustered. Future assessments could explore and implement methods for a spatially unbiased assessment (e.g., Belitz et al, 2010).

Step 3 - Drainage Basins

If more than 50% of the total lake basin area is assessed, then an indicator status for the basin is determined. The overall groundwater quality for each of the Great Lake Basins is assessed as follows:

Good: If more than 50% of the assessed basin area is assessed as “Good”, THEN the basin is assessed as “Good".

Poor: If more than 50% of the assessed basin area is assessed as “Poor”, THEN the basin is assessed as “Poor".

Fair: If more than 50% of the assessed basin area is assessed as “Fair”, or none of the “Good”, “Fair”, or “Poor” is dominant (i.e., >50%), THEN the basin is assessed as “Fair”.

Undetermined: If greater than 50% of the total basin area is unassessed due to insufficient data, THEN the basin is shown as “Undetermined”.

The overall groundwater quality for the entire Great Lakes Basin is calculated on an area basis using the same criteria described above for the individual lake basins.

Trend Assessment Definitions

As noted above, there was insufficient coverage of wells with available criteria data (i.e., chloride and nitrate concentrations measured repeatedly over a period of 10 or more years and with ample data points for statistical trend analysis) to allow the determination of trends at the basin or sub-basin level. This has been the case in the previous reports, and it is uncertain whether this will change in the near future. However, a trend analysis was performed on a select subset of data for informative purposes and is presented in the Discussion.

Improving: Concentrations of both nitrate and chloride are decreasing, or the decreasing trend is dominant between the two parameters (i.e., one parameter is decreasing and the other one is unchanging or increasing in a weaker pattern).

Unchanging: Concentrations of nitrate and chloride are not changing.

Deteriorating: Concentrations of both nitrate and chloride are increasing, or the increasing trend is dominant between the two parameters (i.e., one parameter is increasing and the other one is unchanging or decreasing in a weaker pattern).

Undetermined: Data are not available to determine trends.

No Trend: Data are available for a 10-year or longer period but the trend is not statistically improving or deteriorating due to high variability in the data.

Endpoints and/or Targets

The main criterion for assessing the groundwater quality is the lowest concentration that is specified as a standard, guideline, or maximum level in one or more of the standards or guidelines shown in Table 1 for the protection of aquatic life. Under the GLWQA, the sub-indicator and indicators are used to report on water quality and aquatic ecosystem health and therefore guidelines for the protection of aquatic life will be used for assessment purposes. That being the case, the criterion for nitrate (NO_3^-) is 3 milligrams nitrogen per litre (mg N/L), and the criterion for chloride (Cl^-) is 120 mg/L.

Sub-Indicator Purpose

The purpose of this sub-indicator is to assess the general status of the quality of shallow groundwater in the Great Lakes Basin, which is interactive with other components of the water cycle and has potential to impact the quality of the Great Lakes waters. Select chemical constituents that are representative of a variety of potential sources of groundwater contamination are used to assess this threat to ecosystem health and water quality of the Great Lakes and their source tributaries.

Ecosystem Objective

This sub-indicator supports work towards General Objective #8 of the 2012 GLWQA, which states that the waters of the Great Lakes should be “free from the harmful impact of contaminated groundwater.”

Methods

This sub-indicator utilizes available measurements of the dissolved concentrations of two relevant water-quality constituents in groundwater in the GLB: nitrate and chloride. The data are derived from groundwater samples analyzed primarily as part of ongoing monitoring and surveillance programs, at the subcatchment to regional-scale (i.e., not site specific), performed by the following GLB agencies: the U.S. Geological Survey (USGS), various environmental state agencies, the Ontario Ministry of the Environment, Conservation and Parks (MECP) in coordination with various Conservation Authorities and municipalities, as well as Ontario Geological Survey (OGS). In this 2025 status assessment, existing data from USGS and some state agencies, MECP, OGS and municipal monitoring and surveillance programs for the period 2014-2023 were included. Well types include dedicated monitoring wells, private water supply wells, and public water supply wells in the GLB. For wells that have multiple samples during this period, the most recent sample concentrations were used.

Water-quality data for the U.S. states were primarily derived from a dataset compiled from three sources: the USGS National Water Information System (NWIS) (USGS, 2016), the U.S. Environmental Protection Agency

(USEPA) Safe Drinking Water Information System (SDWIS; for data from 2014 to 2019) (USEPA, 2013), and numerous agencies and organizations at the state, regional, and local level. More details related to the dataset compilation methods are provided in USGS ScienceBase data releases (Erickson and Wilson, 2021). Water-quality data and well construction information are also available in the data releases (Erickson and Wilson, 2021).

The primary data source covering southern Ontario is the MECP's Provincial Groundwater Monitoring Network (PGMN), which includes approximately 400 active long-term groundwater quality monitoring wells. The program, launched in 2000, is delivered in partnership with Ontario's Conservation Authorities and participating municipalities. Annual groundwater samples have been collected in fall, primarily, since the establishment of this network. Additional data comes from i) the OGS's Ambient Groundwater Geochemistry program (only those sampled in its final year - 2014) for southern Ontario (Hamilton, 2015) and several subsequent OGS regional sampling campaigns (Dell et al., 2016, 2017), ii) the Oak Ridges Moraine Groundwater Program (ORMGP) for the Greater Toronto Area (ORMGP, 2025), and iii) data compiled by Waters Environmental Geosciences Ltd. (2017) for the northern portion of the Lake Huron Basin and from the Lake Superior Basin "background" wells for landfill monitoring and data from municipal water supply monitoring programs.

Monitoring data collected from known groundwater contamination investigations (for example, studies related to plume investigations) are excluded because such data are not representative of the broader-scale groundwater quality and these data (such as background groundwater wells on site) are not conveniently recorded in digital databases.

Only "shallow" groundwater samples (collected from wells screened at depths less than 40 m below ground surface) are included in this assessment, given that shallow groundwater is the most interactive with the rest of the hydrologic system, including surface waters in the Great Lakes Basin (Conant et al. 2016). Most of the shallow groundwater in the basin flows towards, and will eventually discharge into, surface waters of the Great Lakes Basin, including the lakes themselves. This connection has many implications for water quality. Shallow groundwater tends to be "younger," or in other words, more recently recharged, and therefore it better reflects the groundwater quality impacts of recent activities in the recharge area (e.g., land use practices). That said, it can sometimes take years or decades for changes in land management practices to measurably impact the shallow groundwater (Zebarth et al. 2015).

The selection of 40 m as the boundary for "shallow groundwater" is arbitrary. Even within this limited depth range, the previous report (2022) showed that chloride and nitrate concentrations tended to be greater for wells of shallower depths (i.e., 0-10 m > 10-20 m > 20-30 m > 30-40 m) (Environment and Climate Change Canada and the U.S. Environmental Protection Agency, 2022). This is not surprising considering that most of the sources of chloride and nitrate contamination of groundwater occur at or close to ground surface (e.g., fertilizer application, road salt application, septic systems and leaky sewers). It is questionable whether this full range of depths best represents the groundwater that is discharging to GLB surface waters or if some weighting with respect to well depth should be applied. This is discussed in further detail in the Discussion section below. However, there isn't sufficient understanding on this topic from which to base a change of this well selection criterion. Also, restricting wells to even more shallow depths would further limit the available data and spatial coverage for this sub-indicator.

The area assessed in this sub-indicator report consists of the basin boundaries for each Great Lake. This will be expanded in the SOGL 2028 report to also include the Ogoki and Long Lac diversions in the Canadian portion of the Lake Superior Basin, as well as the St. Lawrence River Basin, up to the international boundary.

Discussion

Background

Groundwater can become contaminated with various substances including nutrients, salts, metals, pesticides, pharmaceuticals and various industrial organic compounds. Groundwater plays an important role as a reservoir of water that, if contaminated, can become a continuous source of contamination to the Great Lakes. Chemical parameters, such as nitrate and chloride, can be used to assess groundwater quality and provide information about ecosystem health and potential risk to Great Lakes water quality.

Nitrate and chloride were chosen as the water quality indicators for the Groundwater Quality sub-indicator assessment because they: i) are routinely assessed constituents in groundwater monitoring programs; ii) have known ecological impacts on aquatic ecosystems; and iii) are considered to be key indicator contaminants in groundwater (as explained further below).

Nitrogen is an essential nutrient for plants and animals. It promotes rapid growth, increases seed and fruit production, and improves the quality of leaf and forage crops. Nitrogen exists in the environment in many forms as a part of the nitrogen cycle, with nitrate (NO_3^-) and ammonium (NH_4^+) being important inorganic species in aquatic systems. Nitrate concentrations in groundwater in urban and agricultural areas are often elevated above typical background concentrations (Dubrovsky et al. 2010; IJC, 2010), typically in association with natural and synthetic fertilizers. Elevated concentrations of nitrate in water have been shown to have detrimental effects on aquatic organisms and aquatic ecosystems (e.g., direct toxicity, or increased risk of algal blooms and eutrophication; CCME, 2012), and human health (Health Canada, 2013).

Elevated chloride in groundwater within the GLB has largely been attributed to the application of de-icing salts to roads, parking lots and other impervious areas. However, it can also be sourced from wastewater (e.g., leaky sewers, septic systems), agricultural fertilizers, landfills and other sources. In addition, chloride is naturally sourced from some geologic materials, so groundwater can have naturally high concentrations in certain formations and where it is influenced by upwelling from deep bedrock brines (Curtis et al. 2018, 2019). Such brines may also be spilled at ground surface or travel up wells in association with oil and gas drilling activities (Curtis et al. 2019). Elevated concentrations of chloride in water have been shown to have detrimental effects on aquatic organisms and aquatic ecosystems (e.g., toxicity; CCME, 2012) and may promote proliferation of invasive species and release of phosphorus from pond/lake sediments (Radosavljevic et al., 2022).

Nitrate and chloride are considered to be key indicator contaminants in groundwater for the following reasons:

- They are two of the most prevalent and widespread contaminants in groundwater that have been measured and reported in the GLB (and elsewhere);
- They both are derived from multiple contaminant sources in both rural (agricultural) and urban areas. Even though some geologic sources of these compounds exist in the environment, nitrate and chloride are considered as general indicators of anthropogenic impact to aquatic systems;
- As anions, they are both extremely mobile (soluble) in water, so they easily infiltrate through the soil profile and subsequently enter the groundwater system; and
- They are stable contaminants that do not have much physical or chemical interaction with the material they flow through (although nitrate could be reduced or eliminated by denitrification in some subsurface environments), therefore they may have a long-term adverse effect on the ecosystem.

Status Assessment

This sub-indicator regional-scale assessment was based on measurements (2014-2023) of the dissolved concentrations of nitrate and chloride in groundwater in the GLB, as part of ongoing monitoring of groundwater quality by various GLB agencies (USGS, various environmental state agencies, MECP in coordination with various Conservation Authorities and municipalities, and OGS). As illustrated in Figure 7, the definition of “Fair” is more inclusive than “Poor” or “Good”, because “Fair” includes all cases where there is no majority of individual wells assessed as “Poor”, “Fair”, or “Good” (i.e., the central portion of this diagram, coloured in yellow, where each of these three classifications is < 50%).

The spatial distribution of data used in this assessment is uneven (Figures 2-6), even more so than the previous report, notably in the northern portion of the Lake Superior Basin, the eastern portion of the Lake Michigan Basin, the western portions of the Lake Huron Basin, and the southwestern portion of the Lake Erie Basin.

There was a stronger tendency for groundwater quality to range from “Poor” to “Fair” in those portions of the basin that had more intense development, including urbanization (e.g., areas within the Michigan, Erie, and Ontario Basins, Figures 3, 5, 6), and a tendency for groundwater quality to range from “Fair” to “Good” in the less developed areas (e.g., Superior and Huron Basins, Figures 2, 4). For the few tertiary watersheds of the Superior Basin that have been assessed, the overall groundwater quality is “Good". The unassessed tertiary watersheds (74% of the area) tend to be north of the lake in areas of low populations and limited development pressures. Some of these tertiary watersheds that are missing sufficient data were assessed as “Good” in the previous report, which made use of data from a longer time period (and older than the period assessed here). Therefore, it is likely that the groundwater quality in at least some of these relatively pristine tertiary watersheds is also “Good".

Note also that the previous report determined that there were statistically significant differences in nitrate and chloride concentration when wells were grouped by land cover and depth. For example, both median chloride concentration and median nitrate concentration were highest in the shallowest wells. Median chloride concentrations were highest in developed areas, and median nitrate concentrations were highest in agricultural areas. The differences between median concentrations in differing land covers and well depth ranges may reflect differences in the settings of the well sites that were outside the scope of this analysis (e.g., differences in nitrate loadings from surface, and differences in subsurface conditions such as permeability of geologic units and in intensity of microbial activity). These statistics were not determined again for the data in this report, given the overlap in data and reduced coverage, but the trends are expected to remain.

Trends of Chloride and Nitrate Concentrations in Groundwater in the Great Lakes Basin

There was insufficient long-term monitoring data for chloride and nitrate concentrations in wells (< 40 m depth) available to complete a trend analysis across the entire Great Lakes Basin, or even a substantial portion of any individual lake basin. The only readily available grouping of long-term data for performing a trend analysis was Ontario’s PGMN network, which is largely distributed throughout southern Ontario. To provide some insight into the potential changes in the groundwater sub-indicator for the Great Lakes Basin, a Mann-Kendall trend analysis was performed with this data set. Applicable monitoring wells were selected based on having at least 10 data points over the past twenty years (2004-2023 inclusive) and having a screened depth of 40 m or less. This selection criteria identified 137 wells for the chloride trend analysis and 115 for nitrate + nitrite nitrogen (hereafter referred to as nitrate). Samples with concentrations less than the method detection limit (mdl) were assigned a value of ½of the mdl for the purposes of the Mann-Kendall test. Additional QA/QC of the data resulted in the removal of some outlier values prior to performing the trend analysis.

The confidence factor (CF) for trend detection was set at 90%. Trends were detected if the calculated confidence level was ≥CF and the Mann-Kendall "S" value was positive (increasing trend) or negative (decreasing trend). If the calculated confidence level was <CF and the coefficient of variation (CoV) was <1, the data was deemed to have "no trend". Lastly, if the confidence level was <CF and the CoV was >1, the trend analysis result was defined as "undetermined" since the method could not conclusively identify a trend or the lack of one.

Tables 4 and 5 summarize the results of the Mann-Kendall trend analysis for chloride and nitrate, respectively. In addition to summaries for all wells meeting the selection criteria, the results are also summarized for only those wells that were at or above the "Fair" concentration criterion during their latest sampling. This latter summary is particularly relevant for the nitrate trend assessment results because many wells had nitrate concentrations at or close to method detection limits. As such, changes in methods and their detection limits over time can be responsible for the detection of a trend in wells with very low nitrate levels. In contrast, very few wells had chloride concentrations at or near detection limits.

Of the 137 wells analyzed for chloride trends, 78 (56.9%) exhibited a statistically significant trend of increasing concentrations over the two-decade period examined. Furthermore, almost half of these increasing wells are already at Fair or Poor status with respect to chloride concentrations. Only 19 wells (13.9%) showed decreasing chloride concentrations over time and 37 wells (27%) had no discernible trend. For nitrate, 20% of the wells exhibited increasing concentrations over time, with half of these wells already at Fair or Poor status with respect to nitrate levels. A larger fraction of the wells had decreasing nitrate concentrations (33.9%) or had no detectable trend (38.3%). For wells with nitrate ≥ 0.8 mg N/L, a similar percentage were increasing, decreasing, or had no trend.

Supporting information about trends of chloride and nitrate in groundwater in the Great Lakes Basin is available from various studies and status reports published over the past several decades. These studies are summarized below. Most of these studies lack either widespread coverage and/or do not specifically target shallow groundwater, which is likely influencing Great Lakes waters to a greater degree than deeper groundwater. Also, the "USGS Online Mapper" (https://www.usgs.gov/news/usgs-online-mapper-provides-decadal-look-groundwater-quality,) is an online interactive mapping tool that provides "summaries of decadal-scale changes in groundwater quality" across the United States, including areas in the Great Lakes Basin (Lindsey et al. 2016, 2018).

Chloride

Many studies throughout the United States side of the Great Lakes Basin found that chloride levels in groundwater had increased on a decadal level (Bubeck et al.,1971; Kelly and Wilson, 2008; DeSimone et al., 2014). The USGS National Water-Quality Assessment (NAWQA) has evaluated various well networks across the United States for trends in chemical constituents. Well networks in the Lake Michigan, Huron and Erie Basins all show an increasing trend in chloride (Lindsey et al. 2016, 2018).

Findings on the Canadian side of the basin are similar. A decadal increase of chloride concentration in a watershed in Metropolitan Toronto was documented by Howard and Haynes (1993) and Perera et al. (2013). Their studies as well as Eyles and Meriano (2010) all indicated a connection between road salt impacted shallow groundwater and its discharge as springs and baseflow. A recent study by Ontario MECP (Sorichetti et al. 2022) assessed trends using the complete provincial monitoring well network (i.e., no wellscreen depth restriction) across 2002-2020. They reported that groundwater chloride concentrations were highest in more populated areas and tended to be increasing (30%) more so than decreasing (8%) in overburden wells (likewise 23% increasing and 7% decreasing for bedrock wells) with sufficient long-term data (others stable or variable). The Ontario Ministry of the Environment (1998) reported that a high percentage of stream water quality monitoring stations along Lake Erie

had increasing chloride concentrations “indicative of the significant amount of urbanization and development that has occurred in watersheds in southern Ontario since the early 1980s.”

Nitrate

There are limited studies regarding trends of groundwater nitrate concentration, especially on a regional or basin scale. The USGS NAWQA program found no trend or increasing trends in nitrate in the Lake Erie and Lake Michigan Basins (Lindsey et al. 2016, 2018). Gardner et al (2020) observed no distinctive trends of groundwater nitrate concentration at three sites with different hydrogeologic and land-use settings in the northeastern Lake Erie Basin. The study indicated that the combination of climatic conditions, land-use pressure, and hydrogeologic setting played an important role in the characteristics of groundwater nitrate time-series trends. Similar to chloride, increasing nitrate concentrations have been reported in some municipal supply wells in southern Ontario (Credit Valley Conservation Authority, 2015; Conservation Ontario, 2025).

Linkages

Linkages to other Great Lakes sub-indicators include:

- Treated Drinking Water – Many municipalities rely on groundwater as a source of drinking water. The groundwater quality sub-indicator only incorporates information about chloride and nitrate in ambient groundwater (i.e., untreated), whereas assessment of the quality of drinking water takes into consideration a much broader range of parameters in both surface water and groundwater.
- Water Quality in Tributaries – Groundwater discharge contributes a substantial amount of the flow in many Great Lakes tributaries. The Water Quality in Tributaries sub-indicator is based on the Water Quality Index (WQI), which is calculated using a total of eight parameters to assess the status, including both chloride and nitrate concentrations in surface water. The trend assessment is based on three parameters: chloride, nitrate and total phosphorus.
- Coastal Wetlands: Extent and Composition – Groundwater seeps into coastal wetlands, and some coastal wetlands are groundwater-dependent; the health of these ecosystems is influenced by the quality of groundwater discharging to them.
- Nutrients in Lakes (open water) – Groundwater is a known source of nutrient loading (especially nitrogen) to the lakes or to streams flowing into the lakes. This contribution may contribute to elevated nutrient concentrations and associated water quality/algal blooms issues, especially in nearshore areas.
- Land Cover – to some extent, the pattern of groundwater quality status appears to be associated with land-use and development patterns. Poorer groundwater quality tends to be in shallow wells in areas of urban and agricultural land cover. Additional statistical analysis is warranted to confirm linkages in future reports.
- Human Population – Similarly, poorer groundwater quality tends to be in areas that are more densely populated. Additional statistical analysis is warranted to confirm linkages in future reports.
- Baseflow due to Groundwater – Groundwater discharge is a main component of baseflow, and the quality of this groundwater affects the quality of streams.
- Water Levels – Changes in lake water levels could be linked to changes in groundwater quality, particularly in nearshore areas, and to changes in baseflow.

- Precipitation Amounts – Changes in precipitation amounts could be linked to changes in baseflow and groundwater quality, in part by changing the depth of the water table and by affecting shallow groundwater flow systems and groundwater – surface water interaction.

Future consideration of the above linkages may be useful in terms of demonstrating how regional groundwater quality patterns are related to surface water quality, habitats, and various stressors.

Assessing Data Quality

Data Characteristics	Agree	Neutral or Unknown	Disagree	Not Applicable
Data are documented, validated, or quality-assured by a recognized agency or organization	X			
Data are from a known, reliable and respected generator of data and are traceable to original sources	X			
Geographic coverage and scale of data are appropriate to the Great Lakes Basin			X	
Data obtained from sources within the U.S. are comparable to those from Canada			X	
Uncertainty and variability in the data are documented and within acceptable limits for this sub-indicator report*		X		
Data used in assessment are openly available and accessible	Yes	MECP PGMN groundwater quality data: https://data.ontario.ca/dataset/provincial-groundwater-monitoring-network USGS groundwater quality data: https://waterdata.usgs.gov/		

Data Limitations

The groundwater quality sub-indicator is based on select data that are readily available from existing monitoring programs. While no set of supporting sub-indicator data is perfect, those used here have several notable shortcomings. These include:

- Poor spatial coverage. First, there aren't enough monitoring wells across these regions to provide high confidence that the data are properly capturing a representative range in concentrations of the groundwater criteria across the Great Lakes Basin. Monitoring wells are typically 10s to even 100s of kms

apart. Local studies of groundwater quality would commonly have a much higher density of monitoring wells. Also, organizations provided data voluntarily, so data density varies across the study area. Therefore, the degree of assessment of individual constituents is not equal across the study area.

- Probable spatial bias related to contaminant sources. Monitoring wells are typically located to avoid influences from major point sources of contamination, and often in rural areas or on the outskirts of urban areas. As a result, urban groundwater, which would also be influenced by diffuse urban contamination, is likely under-represented in this data set. However, monitoring wells also need to be easily accessed, and so may be nearer to roads, with greater potential for road salt impacts, rather than in the middle of undeveloped land (e.g., forests). Indeed, there are much fewer monitoring wells in the less-developed northern portion of the basin.
- Missing the very shallow groundwater. Most groundwater contaminant sources are at the ground surface and therefore groundwater contamination is often focused at the water table and shallow depths below it. This is especially relevant in agricultural areas that have tile drains (in the range of 20% of permanent cropland for Canada-U.S.; Radcliffe et al., 2015), which create a preferential (rapid) pathway for the very shallowest groundwater to get to adjacent surface water systems. This shallow groundwater and related tile drain effluents are known to have elevated nutrient concentrations (including nitrate) (e.g. Macrae et al., 2023), possibly not represented in the data available for this sub-indicator report. Rapid shallow groundwater pathways may also be more dominant in areas with shallow bedrock. Even in targeting shallow groundwater (as noted above) by restricting monitoring well data to sample collection at < 40 m depth, the very shallowest depths are likely not represented well in this data set.
- Monitoring well data may not be representative of the groundwater discharging to Great Lakes waters. The depths of sampling and areas covered by monitoring wells likely miss many of the shallow, near-to-stream groundwater flow paths that supply much of the water to headwater streams (especially), rivers and shorelines. Also, riparian and near-shore areas are often zones of increased chemical and biological reactions (e.g., Vought et al., 1994; Hill, 1996), which can alter contaminant concentrations in the groundwater that discharges to the surface water. However, there is no regular monitoring of groundwater discharge. In addition, surface water quality may be influenced by contaminant mass flux with groundwater, which may not be properly represented in an assessment based on contaminant concentration, and which was not captured here. Finally, how the contaminated groundwater impacts and interacts with the water of the Great Lakes, particularly in the nearshore zone, following its discharge, requires a better understanding.

  To further address this issue, an example is provided using samples of groundwater discharging to several urban streams and shorelines in Ontario's portion of the GLB, collected from an Environment and Climate Change Canada (ECCC) research program (2008-2014; general protocol outlined in Roy and Bickerton, 2010). These data are shown and compared to those for urban-associated monitoring wells in Ontario used in the SOGL 2022 report (2000-2020), in Figure 9. The discharging groundwater data illustrates the substantial variation in concentrations that can occur within a site (100-1000 m distances; sample points 10-50 m apart) and between sites for both chloride (Fig. 9a) and nitrate (Fig. 10a). When grouped together, the discharging groundwater set had higher chloride concentrations than the monitoring well set (median about 2 x higher; Fig. 9b). The higher concentrations for the former are likely due to greater capture of very shallow groundwater affected by road salt application nearby (Roy, 2019). In contrast, the nitrate concentrations were generally lower for discharging groundwater than for the monitoring wells (Fig. 10b), which might be attributable to denitrification losses within the commonly anaerobic conditions of the urban riparian and shoreline sediments (Roy and Bickerton, 2012). Without denitrification, nitrate

patterns in agricultural areas may have been more like that shown here for chloride in urban areas.

- Limited contaminants considered. There are many different types and sources of groundwater contaminants that pose a threat to Great Lakes water quality and ecosystem health, including geologic source constituents (e.g., arsenic and manganese), human source constituents (e.g., petroleum compounds or organic pesticides), or other substances, such as pathogenic microorganisms. Some of these will be associated with elevated nitrate or chloride concentrations, but many will not. A prime example is the emerging contaminant class of PFAS (per- and polyfluoroalkylated substances), of which Perfluorooctane Sulfonate (PFOS), Perfluorooctanoic Acid (PFOA), and Long-Chain Perfluorocarboxylic Acids (LC-PFCAs) are current Chemicals of Mutual Concern under Annex 3 of the GLWQA (highly relevant for the Toxic Chemicals in Water sub-indicator). Generally, PFAS are highly persistent and pose a toxicity risk to human health and aquatic ecosystems (Sunderland et al., 2019), including Great Lakes fisheries. These chemicals come from a range of sources, including fire-fighter training facilities and airports, various industries, landfills, and wastewater, in addition to atmospheric deposition. It is known that groundwater can supply PFAS to nearby streams, wetlands, and lakes (Briggs et al., 2020; Petre et al., 2021). However, PFAS are not routinely monitored in any of the monitoring network programs supplying data for the Groundwater Quality sub-indicator.

Other potential limitations of the data set used here or considerations for its interpretation include:

- The networks of monitoring wells that were used for this assessment differ (ages of the wells, their construction methods) on the United States and Canadian sides of the border, and even between states/provinces and regions within.
- Although the methods of chemical analyses used for the United States and Canadian data also differed, this was assumed to not have a substantial effect on the outcome of the assessment.
- Reasonable quality assurance was performed during data compilation to ensure that wells were less than 40 m deep and that samples were of raw (untreated and unblended) source water. Exhaustive quality assurance across the myriad data sources was, however, outside of the scope of the indicator report.

A potential avenue to explore as a second sub-indicator for General Objective 8 of the 2012 GLWQA: Groundwater, would be the water quality (chloride, nitrate) of Great Lakes Basin streams and rivers at times of low flow. In low flow periods (often base flows), groundwater often contributes a large proportion of the water to streams, especially headwater streams, and some rivers. Streams or rivers sourced by reservoirs or receiving substantial direct water discharges from a wastewater treatment plant or other anthropogenic sources would have to be excluded. The benefit of this measure would be that the streams would better represent the actual groundwater inputs to the stream, providing an accurate integration of the various flow paths / systems contributing. Losses of nitrate within the river, due to plant uptake for instance, could lead to underestimates; while chloride is still highly conservative in stream systems. Also, many of the jurisdictions within the Great Lakes have stream monitoring programs that would include such water quality data. Analysis of water quality in Great Lakes tributaries is currently addressed through the Water Quality in Tributaries sub-indicator report, which assesses status and trends of stream water quality. However, this sub-indicator incorporates stream data across a range of flows, and so does not represent base flows. It also only includes data from Ontario. Methods for properly targeting data from low flow periods and its spatial application across the basin (limiting spatial bias) would have to be determined.

Report Authors

Authors

James Roy, Environment and Climate Change Canada, jim.roy@ec.gc.ca; Helen Zhang, Ontario Ministry of the Environment, Conservation and Parks, helen.zhang@ontario.ca; George Zhang, Ontario Ministry of the Environment, Conservation and Parks, george.zhang@ontario.ca; John Spoelstra, Environment and Climate Change Canada, john.spoelstra@ec.gc.ca; Hayden Lockmiller, U.S. Geological Survey, klockmiller@usgs.gov.

Others who contributed as authors to previous versions of this assessment include Melinda Erickson, U.S. Geological Survey; Dale Van Stempvoort, Environment and Climate Change Canada; Chris Hoard, U.S. Geological Survey; Norman Grannemann, U.S. Geological Survey; Scott MacRitchie, Ontario Ministry of the Environment, Conservation and Parks.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Arnott, S.E., Celis-Salgado, M.P., Valleau, R.E., DeSellas, A.M., Paterson, A.M., Yan, N.D., Smol, J.P., Rusak, J.A. 2020. Road Salt Impacts Freshwater Zooplankton at Concentrations below Current Water Quality Guidelines. Environ Sci Technol. 54 (15), 9,398 – 9,407. https://doi.org/10.1021/acs.est.0c02396.

Belitz, K., Jurgens, B., Landon, M.K., Fram, M.S., Johnson, T. 2010. Estimation of aquifer scale proportion using equal area grids: assessment of regional scale groundwater quality. Water Resour. Res. 46, 1–14. https://doi.org/10.1029/2010WR009321.

Briggs, M.A., Tokranov, A.K., Hull, R.B., LeBlanc, D.R., Haynes, A.B. and Lane, J.W., 2020. Hillslope groundwater discharges provide localized stream ecosystem buffers from regional per-and polyfluoroalkyl substances contamination. Hydrological Processes, 34(10), pp.2281-2291.

Bubeck, R.C., Diment, W.H., Deck, B.L., Baldwin, A.L., and Lipton, S.D. 1971. Runoff of deicing salt: Effect on Irondequoit Bay, Rochester, New York. Science, 172(3988):1128–1132.

Canadian Council of Ministers of the Environment (CCME). 2012. Canadian Environmental Quality Guidelines.

Conant, B., Danielescu, S., Reeves, H., and Coulibaly P. 2016. Groundwater/surface water interaction. Chap. 2 in Grannemann, G. and Van Stempvoort, D. (Eds.), Groundwater science relevant to the Great Lakes Water Quality Agreement: A status report. Prepared by the Annex 8 Subcommittee for the Great Lakes Executive Committee, Final version, May, 2016. Published (online) by Environment and Climate Change Canada and U.S. Environmental Protection Agency.

Conservation Ontario. 2025. Conservation Ontario Open Data Hub. Available at https://co-opendata-camaps.hub.arcgis.com/ (accessed November 17, 2025).

Credit Valley Conservation Authority. 2015. Approved updated assessment report: Credit Valley Source Protection Area, volume 1 of 2: Report, July 27 2015.

Curtis, Z.K., Li, S.-G., Liao, H.-S., Lusch, D. 2018. Data-Driven Approach for Analyzing Hydrogeology and

Groundwater Quality Across Multiple Scales. Groundwater 56(3), 377-398.

Curtis, Z.K., Liao, H.-S., Li, S.-G., Sampath, P.V., Lusch, D.P. 2019. A Multiscale Assessment of Shallow Groundwater Salinization in Michigan. Groundwater 57(5), 784-806.

Dell, K.M., Francis, M.A., and Hamilton, S.M. 2017. The Ambient Groundwater Geochemistry Program: Manitoulin Island and North Shore Areas. Chapter 26, Project NE-17-004 in: Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p. 26-1 to 26-10.

Dell, K.M., Fudge, S.P., and Hamilton, S.M. 2016. The Ambient Groundwater Geochemistry Program: Sudbury Area. Chapter 32, Project NE-16-001 in: Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p. 32-1 to 32-11.

DeSimone, L.A., McMahon, P.B., and Rosen, M.R. 2014. The quality of our Nation's waters—Water quality in Principal Aquifers of the United States, 1991–2010: U.S. Geological Survey Circular 1360, 151 p., http://dx.doi.org/10.3133/cir1360.

Dubrovsky, N., Burrow, K., Clark, G., Gronberg, J., Hamilton, P., Hitt, K., et al. 2010. The quality of our Nation's waters—Nutrients in the Nation's streams and groundwater, 1992–2004. Reston (VA): US Geological Survey Circular 1350, 174 p., http://pubs.usgs.gov/circ/1350/.

Environment and Climate Change Canada and the U.S. Environmental Protection Agency. 2022. State of the Great Lakes 2022 Technical Report. Cat No. En161-3/1E-PDF.EPA905-R-22-004. Available at https://binational.net/.

Erickson, M.L., and Wilson, J.T., 2021, Nitrate and chloride groundwater quality data, selected well construction characteristics, and aquifer assignments for wells in the Great Lakes Watershed, United States: U.S. Geological Survey data release, https://doi.org/10.5066/P9JT8PXS.

Eyles, N., and Meriano, M. 2010. Road-impacted sediment and water in a Lake Ontario watershed and lagoon, City of Pickering, Ontario, Canada: An example of urban basin analysis. Sedimentary Geology 224(1–4):15–28.

Gardner S.G, Levison J., Parker B., and Martin R.C. 2020. Groundwater nitrate in three distinct hydrogeologic and land-use settings in southwestern Ontario, Canada. Hydrogeology Journal (2020) 28:1891-1908.

Hamilton, S.M. 2015. Ambient groundwater geochemistry data for southern Ontario, 2007–2014; Ontario Geological Survey, Miscellaneous Release—Data 283–Revised.

Health Canada. 2013. Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Nitrate and Nitrite.

Hill, A.R. 1996. Nitrate removal in stream riparian zones. *Journal of Environmental Quality* 25(4): 743-755. https://doi.org/10.2134/jeq1996.00472425002500040014x.

Howard, K.W.F., and Haynes, J. 1993. Urban geology 3. Groundwater contamination due to road de-icing chemicals - Salt balance implications. Geoscience Canada 20(1):1–8.

International Joint Commission (IJC). 2010. Groundwater in the Great Lakes Basin: a report of the Great Lakes Science Advisory Board to the International Joint Commission. Windsor (ON), 162 p.

Kelly, W.R., and Wilson, S.D. 2008. An evaluation of temporal changes in shallow groundwater quality in northeastern Illinois using historical data. Illinois State Water Survey, Center for Groundwater Science, Champaign, Illinois, February 2008.

Lindsey, B.D., Johnson, T.D., and Belitz, K. 2016. Decadal Changes in groundwater quality: U.S. Geological Survey Web Page, http://nawqatrends.wim.usgs.gov/Decadal/.

Lindsey, B.D., Johnson, T.D., Privette, L.M., and Estes, N.J. 2018, Decadal changes in groundwater quality: U.S. Geological Survey Web page, https://nawqatrends.wim.usgs.gov/Decadal/.

Macrae, M.L., Plach, J.M., Carlow, R., Little, C., Jarvie, H.P., McKague, K., Pluer, W.T. and Joosse, P. 2023. Trade-offs in nutrient and sediment losses in tile drainage from no-till versus conventional conservation-till cropping systems *Journal of Environmental Quality* 52(5): 1011-1023. https://doi.org/10.1002/jeq2.20502.

Oak Ridges Moraine Groundwater Program, 2025. Public Mapping Portal. Accessible at: https://maps.oakridgeswater.ca/Html5Viewer/index.html?viewer=ORMGPP (accessed November 17, 2025).

Ontario Ministry of the Environment. 1998. Surface Water Monitoring and Assessment, 1998 Lake Erie Report. Environmental Monitoring and Reporting Branch.

Perera, N., Howard, K.W.F., and Gharabaghi, B. 2013. Groundwater chloride response in the Highland Creek watershed due to road salt application: a re-assessment after 20 years. Journal of Hydrology 479(4):159–168.

Pétré, M.A., Genereux, D.P., Koropeckyj-Cox, L., Knappe, D.R., Duboscq, S., Gilmore, T.E. and Hopkins, Z.R., 2021. Per-and polyfluoroalkyl substance (PFAS) transport from groundwater to streams near a PFAS manufacturing facility in North Carolina, USA. Environmental science & technology, 55(9), pp.5848-5856.

Radcliffe, D.E., Reid, D.K., Blombäck, K, Bolster, C.H., Collick, A.S., Easton, Z.M., Francesconi, W., Fuka, D.R., Johnsson, H., King, K., Larsbo, M., Youssef, M.A., Mulkey, A.S., Nelson, N.O., Persson, K., Ramirez-Avila, J.J., Schmieder, F., and Smith, D.R. 2015. Applicability of Models to Predict Phosphorous Losses in Drained Fields: A Review. Journal of Environmental Quality, 44 (2), 614-628.

Radosavljevic, J., Slowinski, S., Shafii, M., Akbarzadeh, Z., Rezanezhad, F., Parsons, C.T., Withers, W. and Van Cappellen, P., 2022. Salinization as a driver of eutrophication symptoms in an urban lake (Lake Wilcox, Ontario, Canada). Science of The Total Environment, 846, p.157,336.

Roy, J.W. 2019. Endobenthic organisms exposed to chronically high chloride from groundwater discharging along freshwater urban streams and lakeshores. Environmental Science and Technology 53(16): 9389-9397. DOI: 10.1021/acs.est.9b02288.

Roy, J.W., G. Bickerton. 2010. A proactive screening approach for detecting groundwater contaminants along urban streams at the reach-scale. Environmental Science & Technology 44(16), 6088–6094. DOI: 10.1021/es101492x.

Roy, J.W., G. Bickerton. 2012. Toxic groundwater contaminants: An overlooked contributor to urban stream syndrome? Environmental Science & Technology 46(2), 729–736 DOI: 10.1021/es2034137.

Sorichetti, R.J., Raby, M., Holeton, C., Benoit, N., Carson, L., DeSellas, A., Diep, N., Edwards, B.A., Howell, T., Kaltenecker, G. and McConnell, C., 2022. Chloride trends in Ontario's surface and groundwaters. Journal of Great Lakes Research, 48(2), pp.512-525.

Sunderland, E.M., Hu, X.C., Dassuncao, C., Tokranov, A.K., Wagner, C.C. and Allen, J.G., 2019. A review of the pathways of human exposure to poly-and perfluoroalkyl substances (PFASs) and present understanding of health effects. Journal of exposure science & environmental epidemiology, 29(2), pp.131-147.

U.S. Environmental Protection Agency. 2013. Safe Drinking Water Information System Federal Reporting Services. Accessible at: https://sdwis.epa.gov/ords/sfdw_pub/r/sfdw/sdwis_fed_reports_public/200 (accessed on November 17, 2025).

U.S. Geological Survey, 2016, National Water Information System data available on the World Wide Web (USGS Water Data for the Nation), last accessed January 24, 2024, at https://doi.org/10.5066/F7P55KJN.

Vought, L.B.M., Dahl, J., Pedersen, C.L. and Lacoursiere, J.O. 1994. Nutrient retention in riparian ecotones. *Ambio*: 342-348. https://www.jstor.org/stable/4314234.

Waters Environmental Geosciences Ltd. 2017. Great Lakes Groundwater Quality Database, Lake Superior and Lake Huron Basins. Report prepared under contract for Environment and Climate Change Canada.

Zebarth, B.J., Ryan, M.C., Graham, G., Forge, T.A., and Neilsen, D. 2015. Groundwater monitoring to support development of BMPs for groundwater protection: The Abbotsford-Sumas aquifer case study. Groundwater Monitoring & Remediation 35(1):82-96. doi:10.1111/gwmr.12092.

List of Tables

Table 1. Examples of standards and water quality objectives for some of the jurisdictions that are responsible for protecting human health and environmental water quality in the Great Lakes Basin.

Table 2. Summary of individual well data assessments for each Great Lake basin and all basins.
Source: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey and Oak Ridges Moraine Groundwater Program.

Table 3. Summary of areal data assessments by drainage basin for each Great Lake and all basins.

Table 4. Results of the Mann-Kendall chloride trend analysis for, 1) all wells that met the data requirements and, 2) for wells with chloride concentrations at or above the "Fair" criterion.
Source: Ontario Ministry of the Environment, Conservation and Parks

Table 5. Results of the Mann-Kendall nitrate-N trend analysis for, 1) all wells that met the data requirements and, 2) for wells with nitrate-N concentrations at or above the "Fair" criterion.
Source: Ontario Ministry of the Environment, Conservation and Parks

List of Figures

Figure 1. Groundwater quality status in the Great Lakes Basin is based on nitrate and chloride concentrations in shallow groundwater (based on measurements from 2014-2023 for wells ≤ 40 m below ground). A total of 5,756 wells in the basin were included in the analysis. The groundwater quality was assessed as "Good" in 3,091 wells, "Fair" in 1,324 wells, and "Poor" in 1,341 wells. The shaded areas shown (see legend) indicate the status in the individual lake basins: "Fair" in the Lakes Ontario and Erie Basins, "Good" in the Lake Huron Basin, and "Undetermined" for the remaining two basins. See Figures 2 through 6 for details.

Sources of data: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017).

Figure 2. Assessment results for the groundwater quality sub-indicator for the Lake Superior Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Sources of data: U.S. Geological Survey, Ontario Ministry of the Environment, Conservation and Parks and other Ontario sources (Waters Environmental Geosciences Ltd., 2017)

Figure 3. Assessment results for the groundwater quality sub-indicator for the Lake Michigan Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Source of data: U.S. Geological Survey

Figure 4. Assessment results for the groundwater quality sub-indicator for the Lake Huron Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Sources of data: U.S. Geological Survey, Ontario Ministry of the Environment, Conservation and Parks, Ontario Geological Survey, other Ontario sources (Waters Environmental Geosciences Ltd., 2017).

Figure 5. Assessment results for the groundwater quality sub-indicator for the Lake Erie Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Sources of data: Ontario Ministry of the Environment, Conservation and Parks, Ontario Geological Survey and U.S. Geological Survey

Figure 6. Assessment results for the groundwater quality sub-indicator for the Lake Ontario Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Source of data: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey and Oak Ridges Moraine Groundwater Program.

Figure 7. Criterion diagram for groundwater quality indicator status assessment.

Figure 8. Tertiary diagram summarizing the individual well assessments for each lake basin (see Table 2). Black symbols indicate lake basins that had insufficient data coverage for lake basin scale assessment.

Source of data: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017).

Figure 9. Concentrations of chloride in a) samples of groundwater discharging to twelve different urban streams (< 1 m depth below streambed typically) in the Ontario portion of the Great Lakes Basin (data subset from Roy, 2019), and b) the combined data from a) (GW-D) with sample data from the shallow (< 40 m depth) monitoring wells from the Ontario portion of the Great Lakes Basin data set used in this report (Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017)).

Figure 10. Concentrations of nitrate (NO_3-N) in a) samples of groundwater discharging to twelve different urban streams (< 1 m depth below streambed typically) in the Ontario portion of the Great Lakes Basin (data subset from Roy, 2019), and b) the combined data from a) (GW-D) with sample data from the shallow (< 40 m depth) monitoring wells from the Ontario portion of the Great Lakes Basin data set used in this report (Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017)).

Last Updated
State of the Great Lakes 2025 Report

Table 1. Examples of standards and water quality objectives for some of the jurisdictions that are responsible for protecting human health and environmental water quality in the Great Lakes Basin.
Source: U.S. Environmental Protection Agency, Canadian Council of Ministers of the Environment, Health Canada, Ontario Ministry of the Environment, Conservation and Parks.

Jurisdiction	Standard / guideline for chloride (milligrams per litre)	Standard / guideline for nitrate (milligrams nitrogen per litre)
U.S. Environmental Protection Agency	230 (chronic criterion for aquatic life = criterion continuous concentration)	10 (maximum contaminant level goal for drinking water)
Canadian Council of Ministers of the Environment	120 (water quality guideline for the protection of aquatic life, freshwater concentration, long term)	3 (water quality guideline for the protection of aquatic life, freshwater concentration, long term)
Health Canada	≤ 250 (aesthetic objective)	10 (health based maximum acceptable concentration)
Ontario Ministry of the Environment, Conservation and Parks	250 (aesthetic objective level)	10 (maximum acceptable concentration in drinking water)

Table 2. Summary of individual well data assessments for each Great Lake basin and for the entire Great Lakes Basin (all basins).
Source: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey and Oak Ridges Moraine Groundwater Program.

	Total Number of Wells	Assessed as "Good"		Assessed as "Fair"		Assessed as "Poor"	
		# Wells	%	# Wells	%	# Wells	%
Superior	364	301	82.7%	48	13.2%	15	4.1%
Michigan	4240	2291	54.0%	955	22.5%	994	23.4%
Huron	456	253	55.5%	105	23.0%	98	21.5%
Erie	228	107	46.9%	65	28.5%	56	24.6%
Ontario	468	139	29.7%	151	32.3%	178	38.0%
All Basins	**5756**	**3091**	**53.7%**	**1324**	**23.0%**	**1341**	**23.3%**

Table 3. Summary of areal data assessments by drainage basin for each Great Lake and all basins. Source: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey and Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017).

	Total Number of Tertiary Watersheds	Number of Tertiary Watersheds Assessed	Percentage of Basin Area		Percentage of Assessed Area			Basin-wide Assessment
			Assessed	Not Assessed	Assessed as "Good"	Assessed as "Fair"	Assessed as "Poor"	
Superior	26	8	26.4%	73.6%	70.7%	29.3%	0.0%	Undetermined
Michigan	33	16	48.4%	51.6%	73.0%	14.5%	12.5%	Undetermined
Huron	39	20	60.9%	39.1%	64.6%	30.9%	4.5%	Good
Erie	31	20	69.8%	30.2%	41.5%	52.7%	5.7%	Fair
Ontario	23	16	73.7%	26.3%	28.7%	60.5%	10.8%	Fair
All Basins	**152**	**80**	**53.1%**	**46.9%**	**56.9%**	**36.4%**	**6.7%**	**GOOD**

Table 4. Results of the Mann-Kendall chloride trend analysis for, 1) all wells that met the data requirements and, 2) for wells with chloride concentrations at or above the "Fair" criterion. Source: Ontario Ministry of the Environment, Conservation and Parks

Trend	All Wells		Wells, Cl ≥ 30 mg/L	
	n =	%	n =	%
Undetermined	3	2.2%	2	3.3%
No Trend	37	27.0%	15	25.0%
Decreasing	19	13.9%	7	11.7%
Increasing	78	56.9%	36	60.0%
Total	137	100.0%	60	100.0%

Table 5. Results of the Mann-Kendall nitrate-N trend analysis for, 1) all wells that met the data requirements and, 2) for wells with nitrate-N concentrations at or above the "Fair" criterion. Source: Ontario Ministry of the Environment, Conservation and Parks

Trend	All Wells		Wells, NO_3^--N ≥ 0.8 mg/L	
	n =	%	n =	%
Undetermined	9	7.8%	1	2.9%
No Trend	44	38.3%	11	31.4%
Decreasing	39	33.9%	12	34.3%
Increasing	23	20.0%	11	31.4%
Total	115	100.0%	35	100.0%

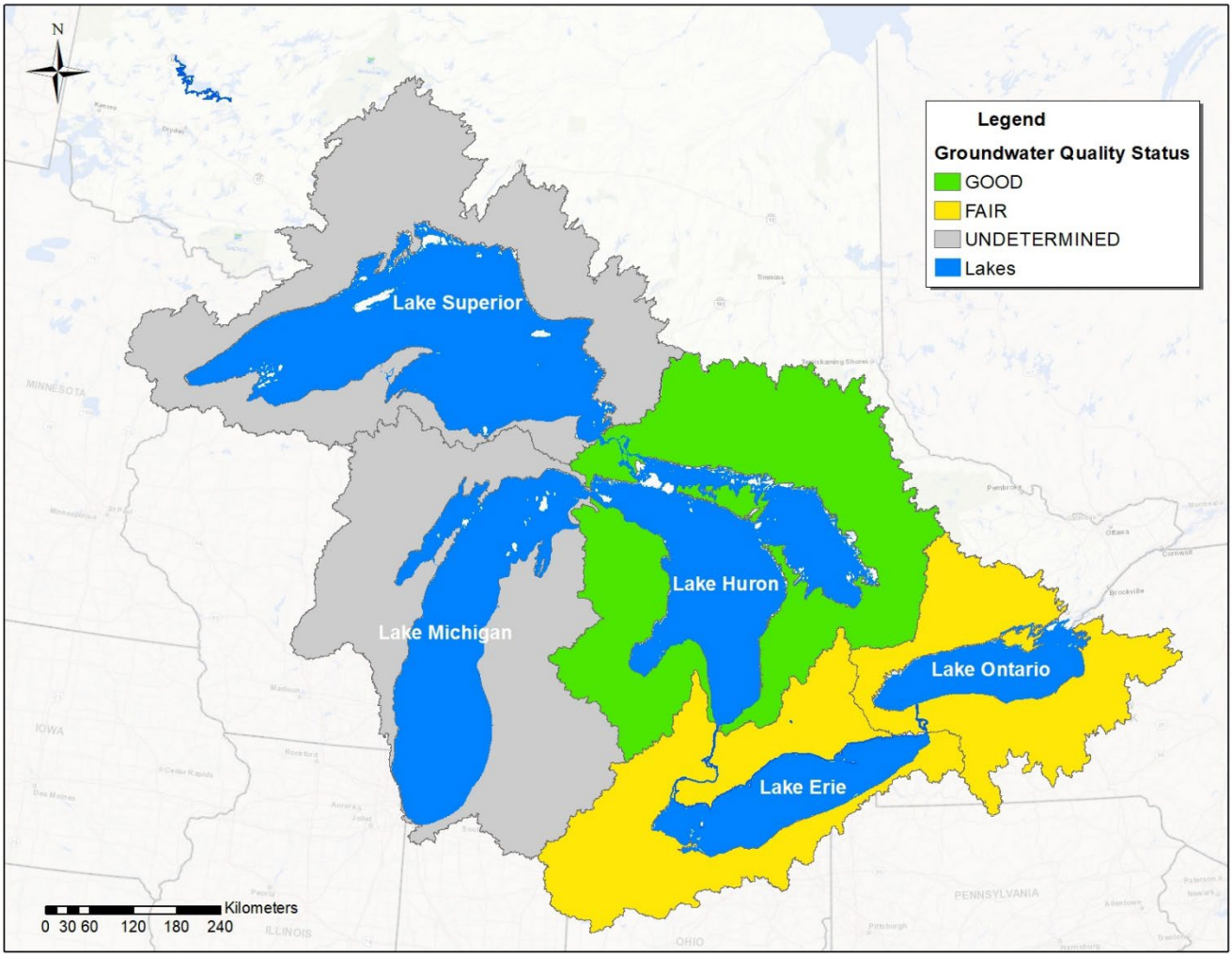

Figure 1. Groundwater quality status in the Great Lakes Basin is based on nitrate and chloride concentrations in shallow groundwater (based on measurements from 2014-2023 for wells ≤ 40 m below ground). A total of 5,756 wells in the basin were included in the analysis. The groundwater quality was assessed as "Good" in 3,091 wells, "Fair" in 1,324 wells, and "Poor" in 1,341 wells. The shaded areas shown (see legend) indicate the status in the individual lake basins: "Good" in the Lake Huron Basin, "Fair" in the Lakes Ontario and Erie Basins, and "Undetermined" for the remaining two basins. See Figures 2 through 6 for details.

Sources of data: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017).

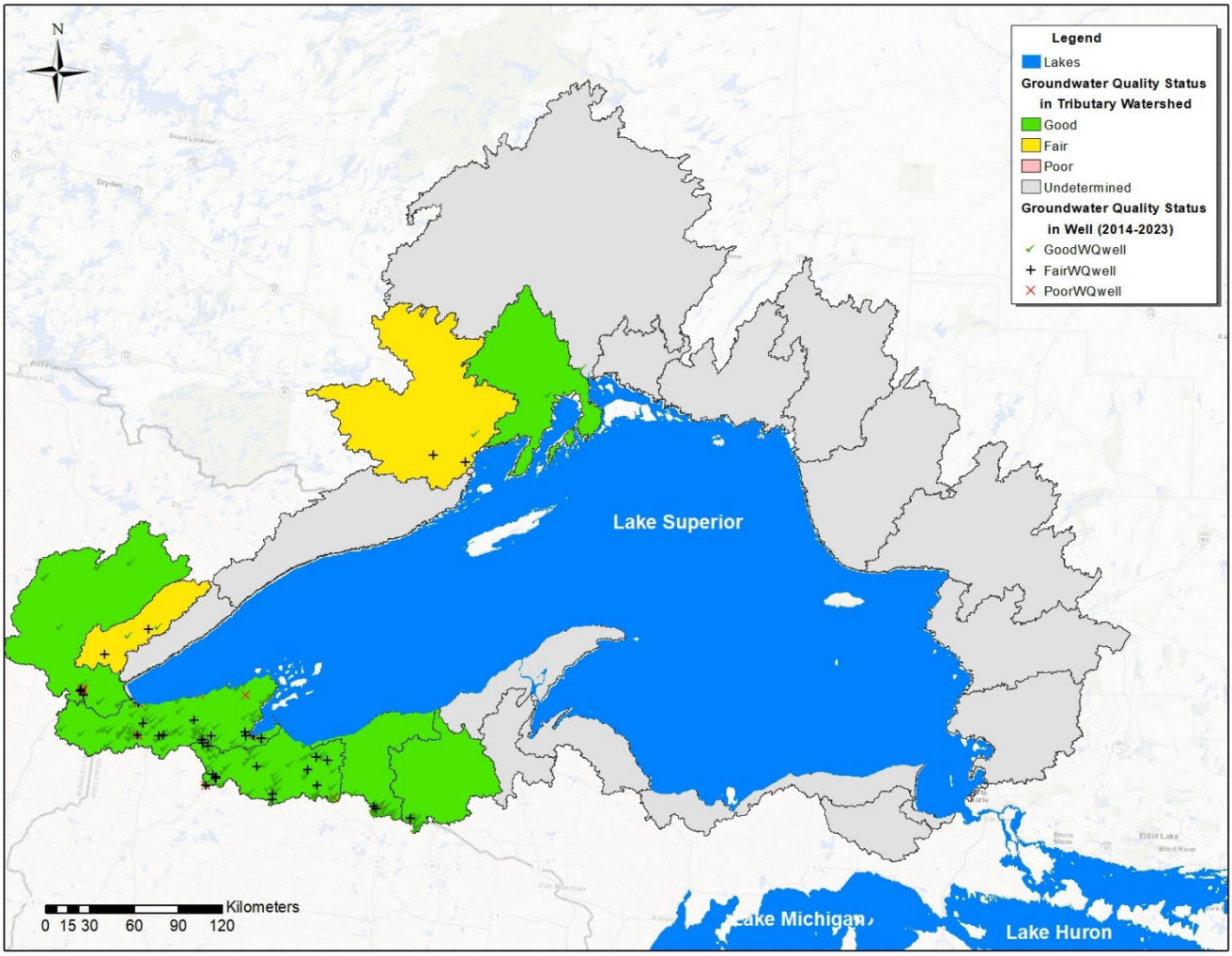

Figure 2. Assessment results for the groundwater quality sub-indicator for the Lake Superior Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Sources of data: U.S. Geological Survey, Ontario Ministry of the Environment, Conservation and Parks and other Ontario sources (Waters Environmental Geosciences Ltd., 2017)

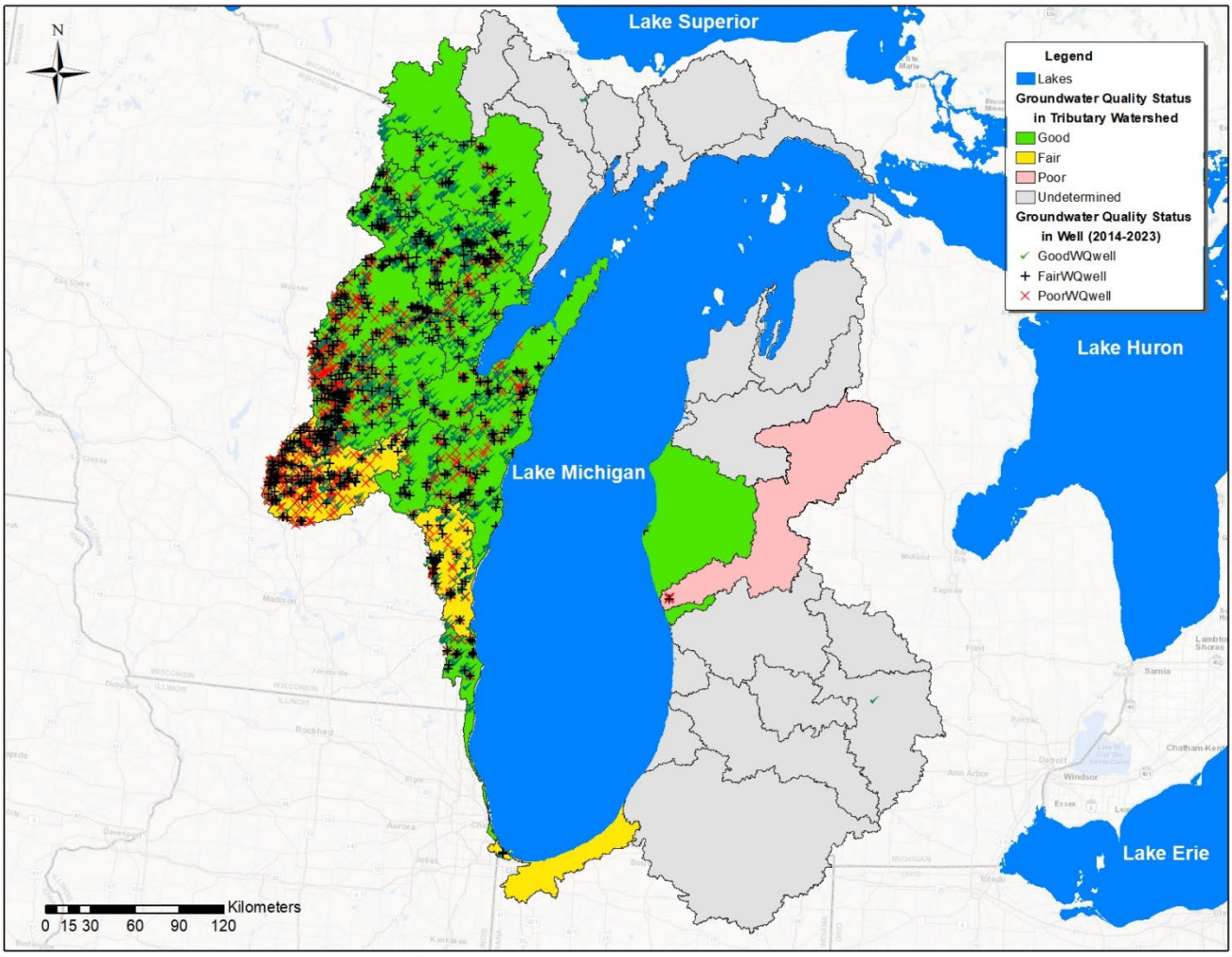

Figure 3. Assessment results for the groundwater quality sub-indicator for the Lake Michigan Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Source of data: U.S. Geological Survey

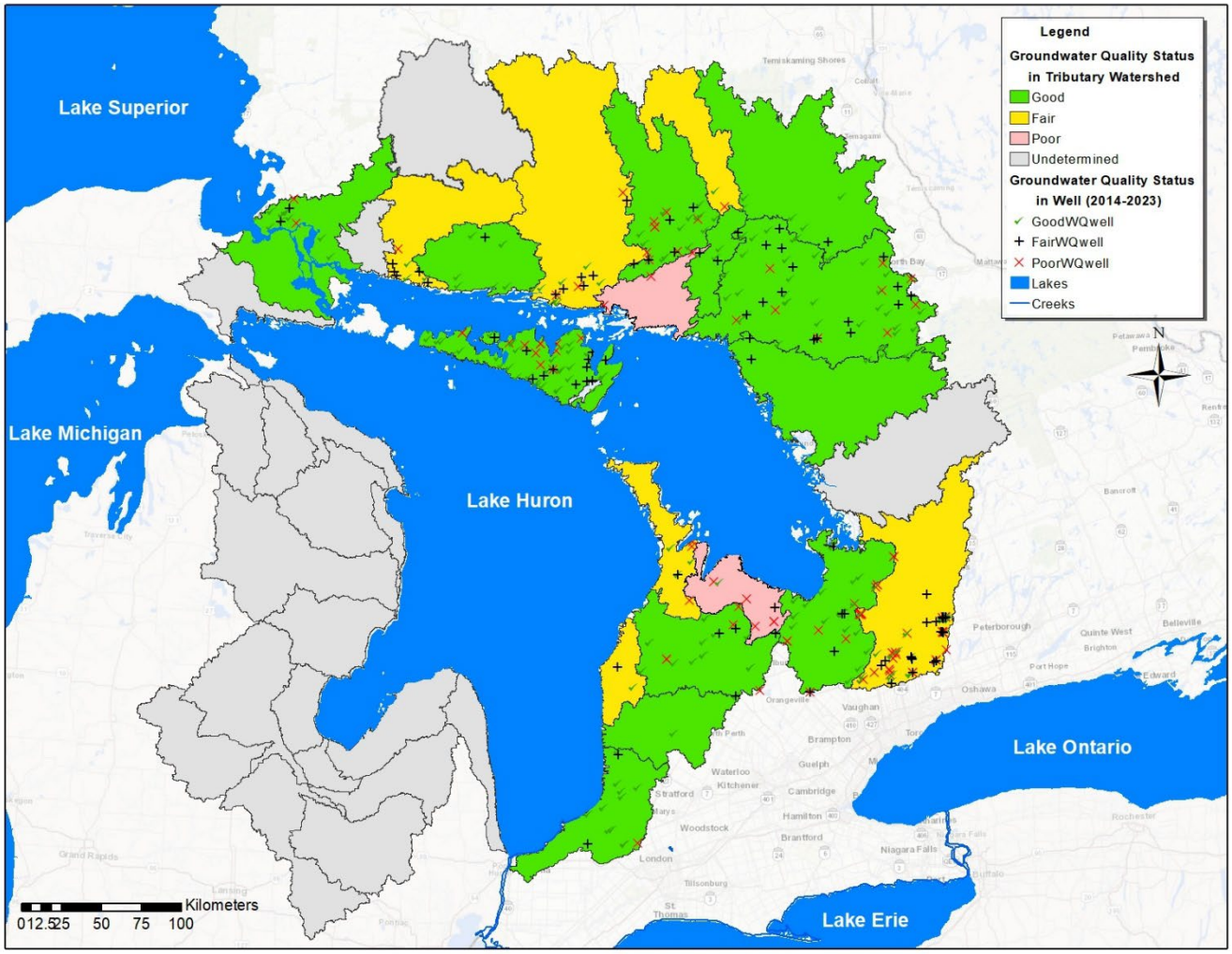

Figure 4. Assessment results for the groundwater quality sub-indicator for the Lake Huron Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Sources of data: U.S. Geological Survey, Ontario Ministry of the Environment, Conservation and Parks, Ontario Geological Survey, other Ontario sources (Waters Environmental Geosciences Ltd., 2017).

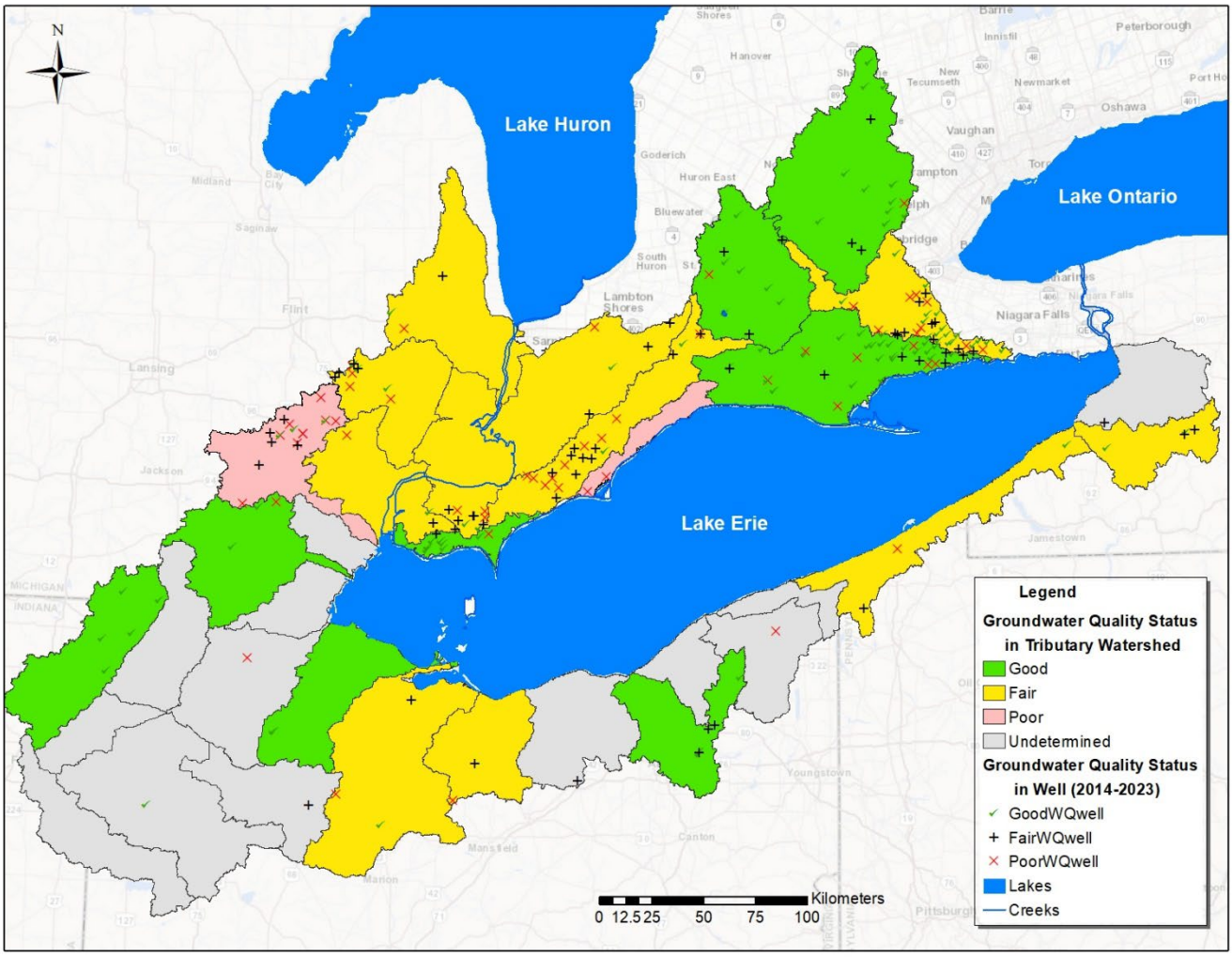

Figure 5. Assessment results for the groundwater quality sub-indicator for the Lake Erie Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Sources of data: Ontario Ministry of the Environment, Conservation and Parks, Ontario Geological Survey and U.S. Geological Survey

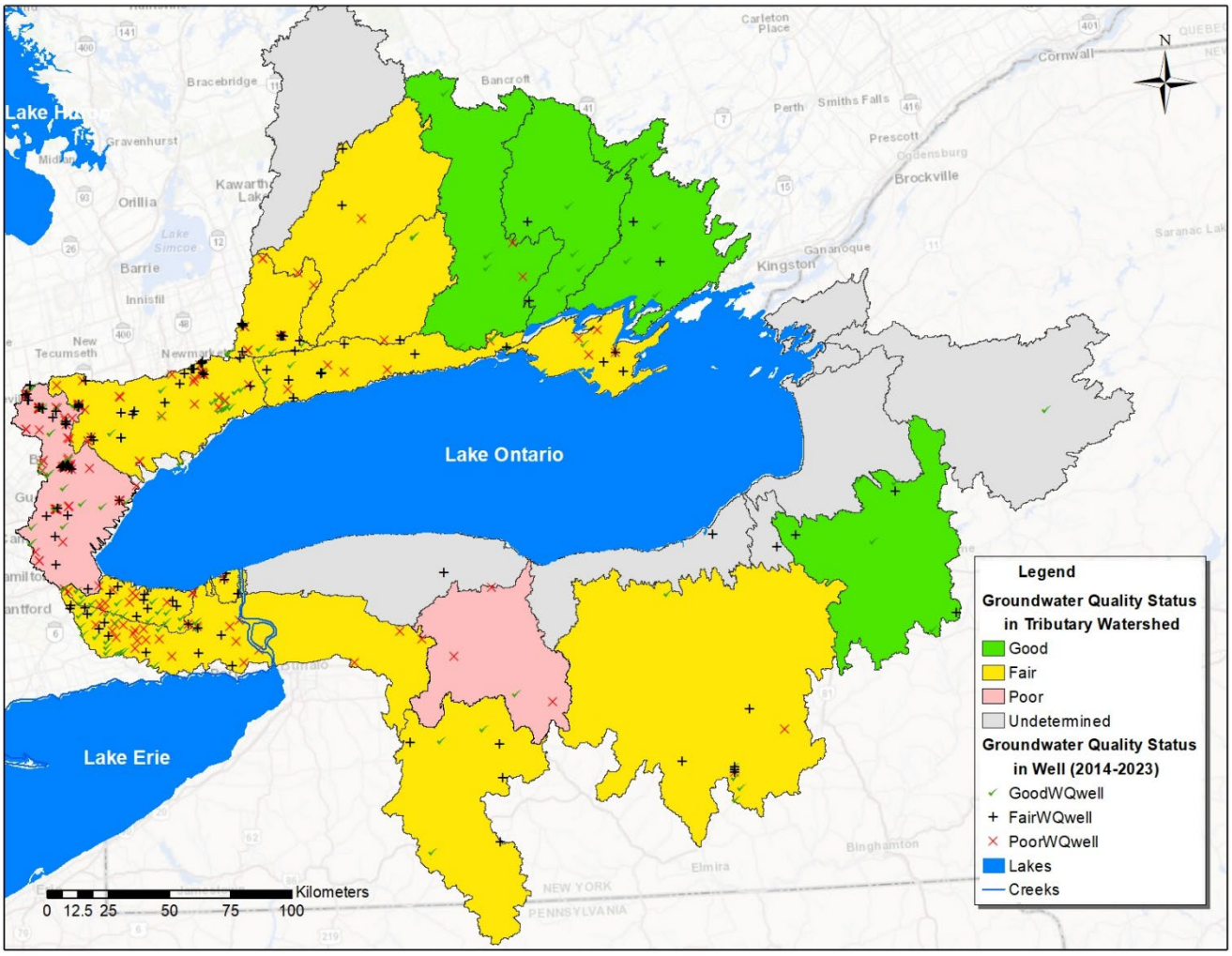

Figure 6. Assessment results for the groundwater quality sub-indicator for the Lake Ontario Basin (based on measurements from 2014-2023 for wells ≤ 40 m below ground). Symbols indicate the results for individual monitoring wells.

Source of data: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey and Oak Ridges Moraine Groundwater Program.

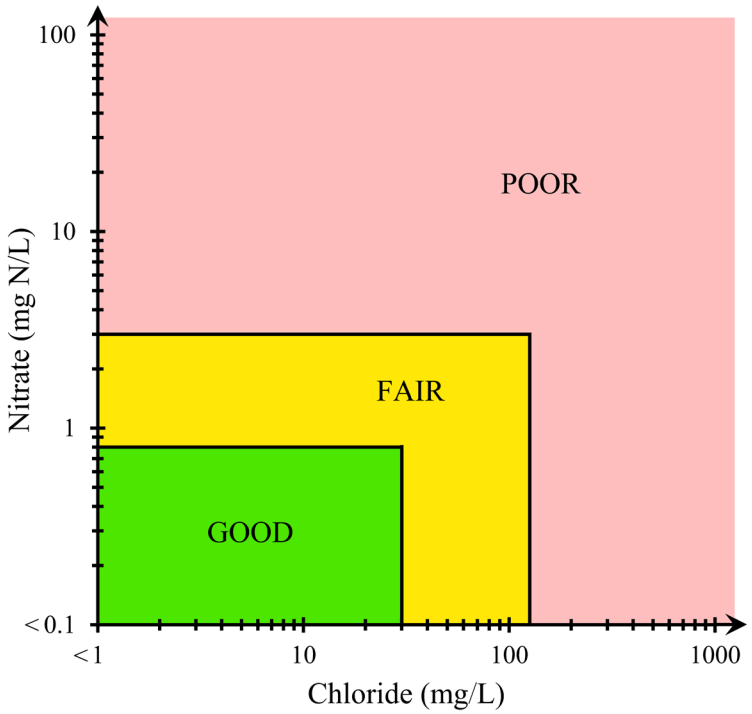

Figure 7. Criterion diagram for groundwater quality indicator status assessment.

Source: Canadian Council of Ministers of the Environment.

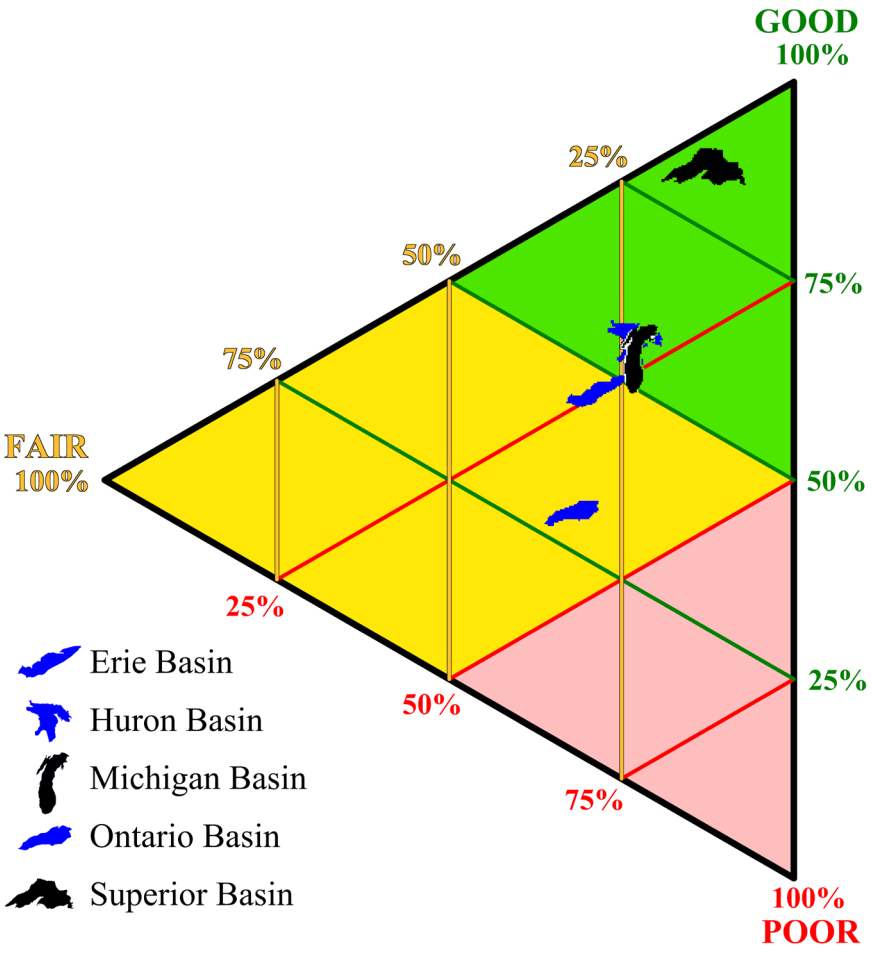

Figure 8. Tertiary diagram summarizing the individual well assessments for each lake basin (see Table 2). Black symbols indicate lake basins that had insufficient data coverage for lake basin scale assessment.
Source of data: Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017).

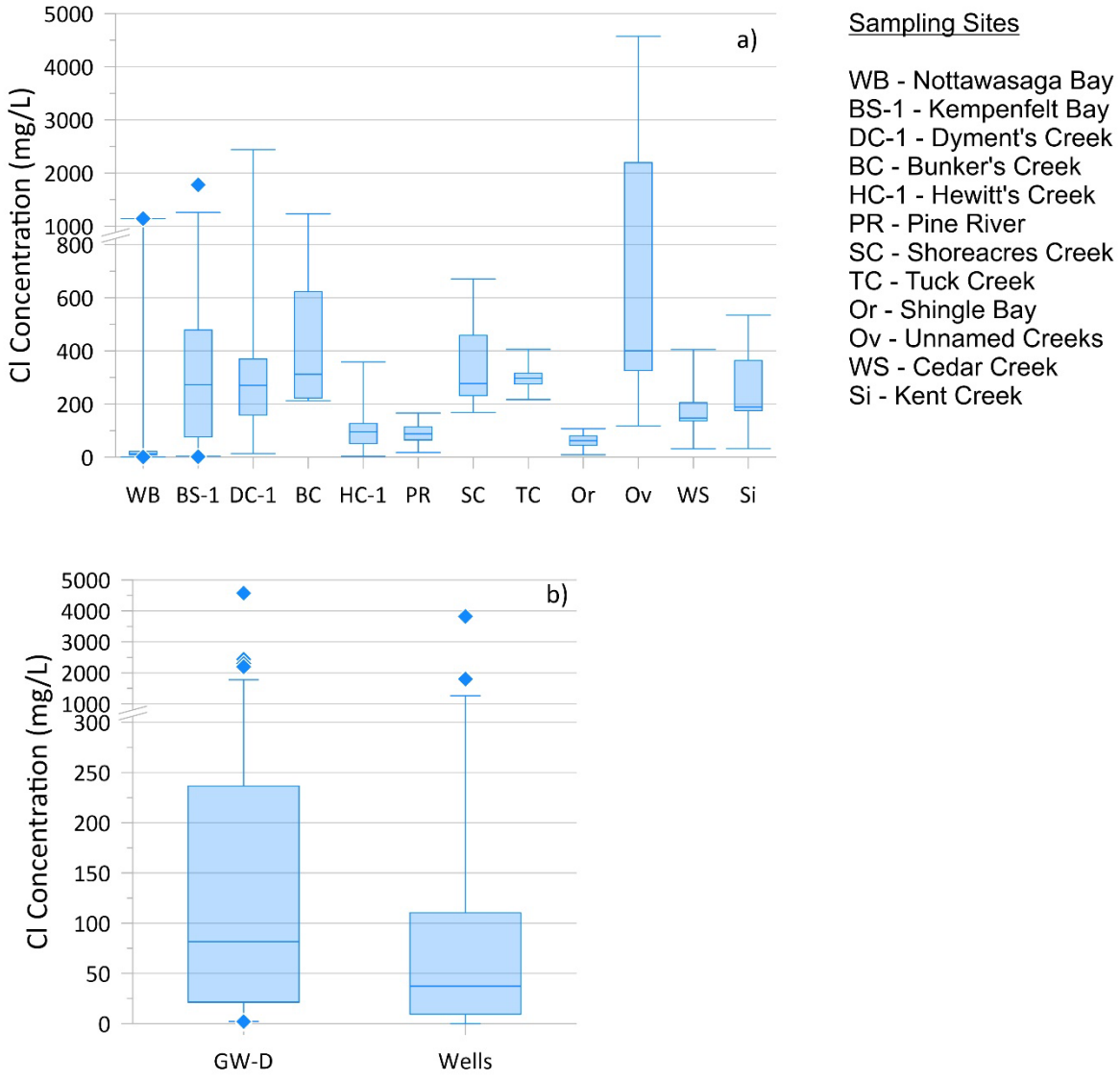

Figure 9. Concentrations of chloride in a) samples of groundwater discharging to twelve different urban streams (< 1 m depth below streambed typically) in the Ontario portion of the Great Lakes Basin (data subset from Roy, 2019), and b) the combined data from a) (GW-D) with sample data from the shallow (< 40 m depth) monitoring wells from the Ontario portion of the Great Lakes Basin data set used in this report (Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017)).

.

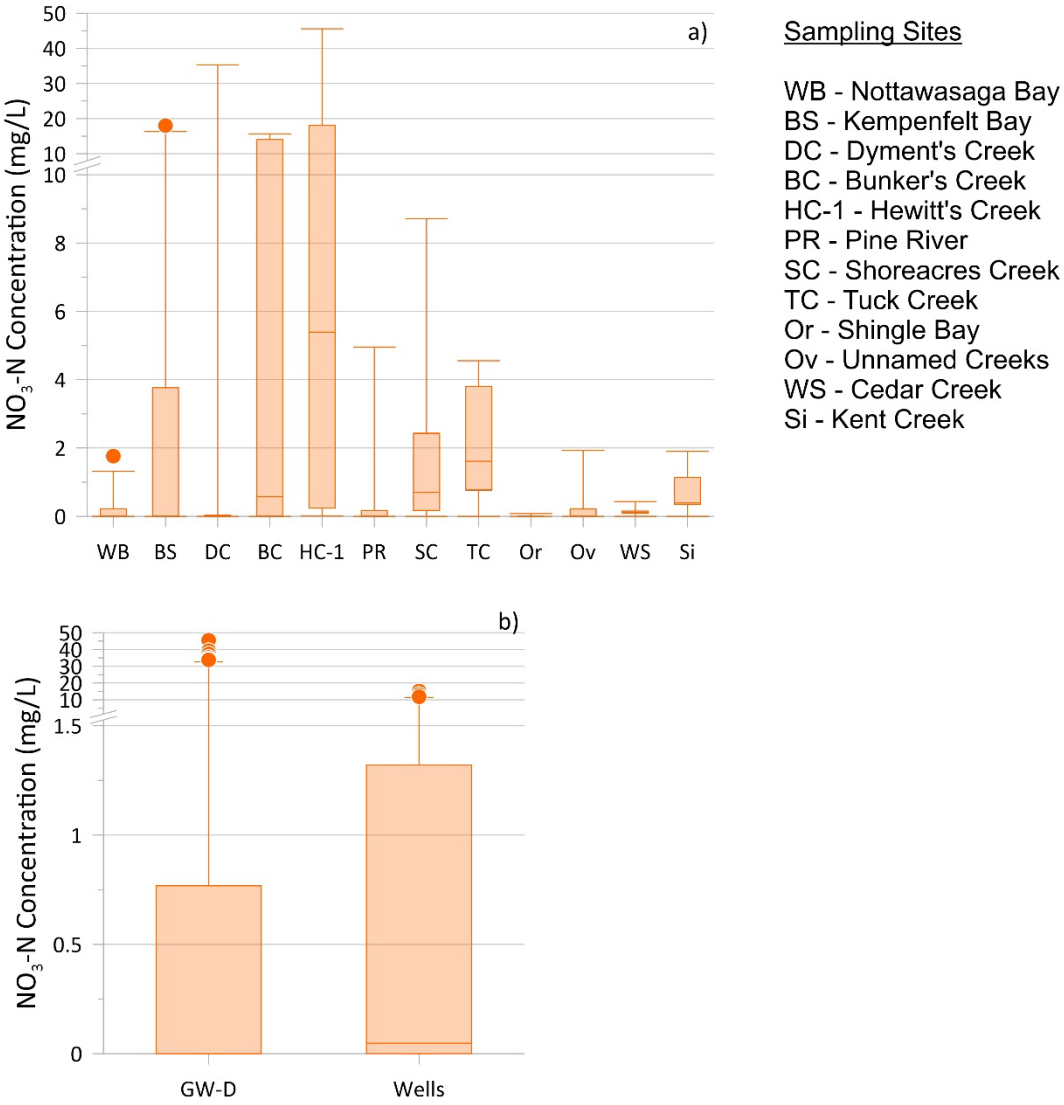

Figure 10. Concentrations of nitrate (NO_3-N) in a) samples of groundwater discharging to twelve different urban streams (< 1 m depth below streambed typically) in the Ontario portion of the Great Lakes Basin (data subset from Roy, 2019), and b) the combined data from a) (GW-D) with sample data from the shallow (< 40 m depth) monitoring wells from the Ontario portion of the Great Lakes Basin data set used in this report (Ontario Ministry of the Environment, Conservation and Parks, U.S. Geological Survey, Ontario Geological Survey, Oak Ridges Moraine Groundwater Program, and other Ontario sources (Waters Environmental Geosciences Ltd., 2017)).