

Land Use, Land Cover, and Climate Change in Southern Ontario: Implications for Nutrient Delivery to the Lower Great Lakes



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Abstract Southern Ontario is home to over a third of the Canadian population and is also one of the most productive agricultural areas in the country. This mosaic of a large and growing urban population and prime agricultural land creates particular challenges for soil and water resource management. While urban areas continue to expand in southern Ontario, changes in agricultural cover and practices within the headwaters are also important to consider. There have been dramatic increases in tile-drained cash crop production (principally grain, corn, and soybean) in southern Ontario over the past few decades, largely at the expense of pasture and forage land. Urban populations will continue to expand into the future, but there is considerable scope for further agricultural change in the headwaters as well. Expansions in urban land cover and intensification of agriculture affect the hydrologic response to extreme events as well as water quality and nitrate leaching in particular. It is important to consider the effects of shifts in both types of land cover on stream

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flow and water quality in the variable landscape and climatic conditions of the lower Great Lakes.

Keywords Agriculture, Land use change, Nutrients, Water quality

1 Population of Southern Ontario

Ontario is Canada's second largest and most populous province (13.4 million), accounting for 38% of the nation's population in 2016 [1]. Over 90% of the Ontario population lives within the approximately 84,000 km² area known as southern Ontario, shown in Fig. 1, concentrated within several larger urban centers that are located primarily along the northern shoreline of Lake Ontario. The Toronto census metropolitan area (CMA) alone accounts for almost half of the Ontario population (5.9 million) and 1 in 5 of all Canadians resides within the Toronto CMA (Fig. 1). Southern Ontario is also one of the fastest expanding areas in the country, with an overall population increase of 6.2% between 2011 and 2016 compared with a national growth rate of 5% [1]. The majority of future population growth in Ontario is expected to occur within southern Ontario, and if current rates of growth continue, the population is expected to grow by 30%, or almost 5 million, to approximately 18.5 million in 2040 [2].

2 Urban Land Cover in Southern Ontario

Urban land is classified through the Southern Ontario Land Resource Information System (SOLRIS; [3]) as "pervious," "impervious," and "transportation," and together these three categories of urban land cover 8.4% of southern Ontario (Table 1). Recent population increases in Ontario have been accompanied by expansions in urban land cover, although the rate of urban expansion has outpaced that of population growth due to what is commonly referred to as "urban sprawl." Construction of relatively low-density residential subdivisions became the conventional pattern of development in Canada in the 1950s and 1960s, and these often independent, single-family homes were built on agricultural and/or pristine forest or open space lands [5, 6]. Concerns over urban sprawl have generated substantial discussion and a variety of planning regulations and policies purported to direct growth and better protect natural environments and agricultural land from conversion and degradation. For example, Ontario's Places to Grow Plan was finalized in 2006 to address urban sprawl and establish a permanent greenbelt that would protect greenspace, farmland, wetlands, and natural areas in the Golden Horseshoe area, which includes Toronto [6]. Nevertheless, expansion at the boundaries of urban

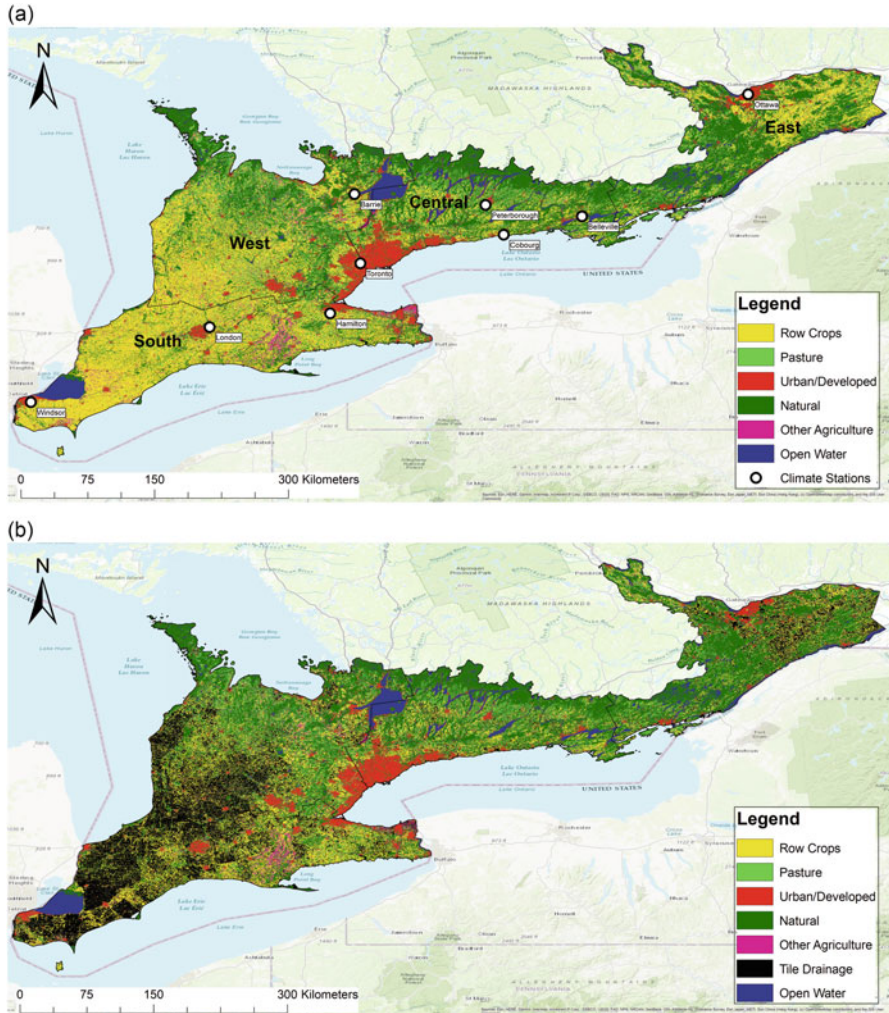


Fig. 1 (a) Land cover in southern Ontario. Data are from SOLRIS (version 2.0) and Agriculture and Agri-Food Canada (AAFC)’s Annual Crop Inventory (2018 data). Also shown are locations of climate stations. (b) Locations of recorded tile drainage in southern Ontario. Data are from OMAFRA (record updated through 2018)

areas continues, and reported population increases in the Greater Toronto CMA between 2011 and 2016, for example, were entirely due to growth in its “peripheral” census subdivisions including Mississauga, Brampton, and Markham, as numbers within the “central” census subdivision of the city of Toronto itself actually declined over the same time period [1].

Table 1 Land cover in southern Ontario

	Total area (km ²) (83,905 km ²)	% of southern Ontario
Forest (includes coniferous, deciduous, and mixed)	11,300	13
Wetland (includes swamp, bog, and marsh)	11,171	13
Built-up impervious	3,345	4.0
Transportation	2,838	3.3
Built-up pervious	915	1.1
Pasture and forages	14,720	18
Corn, soybean, and cereals	24,830	30
Total agriculture (includes the two categories above plus nursery, sod, vegetables, vineyards, and specialty crops)	44,450	53

Urban and natural land cover areas were assessed using SOLRIS (version 2.0; dated 2009–2011), which is based on the Ontario Ministry of Natural Resources and Forestry (MNR)’s ecological land classification system [4]. Agricultural land cover is only crudely classified in SOLRIS as “tilled,” and so Agriculture and Agri-Food Canada (AAFC)’s Annual Crop Inventory (2018 data) was used to quantify areas and types of agricultural land

2.1 Effects of Urban Land Use on Water Resources

Urban development has serious consequences for water resources in the Great Lakes basin. Development alters the local hydrologic cycle by removing vegetation that intercepts and transpires precipitation inputs as well as natural depressions that temporarily store water. Native soils are compacted or covered with impervious surfaces including roads, parking lots, sidewalks, and buildings. Impervious surfaces decrease the amount of water that infiltrates into the ground, increasing the volume and rate of stormwater runoff into recipient waterways. Eimers and McDonald [7] found that annual and seasonal runoff totals were similar between rural and urban tributaries draining into Lake Ontario and were relatively insensitive to urban cover. Instead, urban streams had significantly greater high flow frequency and flow variability and more quickflow and lower baseflow compared with rural streams. Furthermore, differences in high flow frequency between urban and rural stream groups were largest in the summer and fall and less extreme in the winter and spring, perhaps because of the homogenizing effect of winter snow cover, frozen ground, and spring melt on surface imperviousness. The enhancement of extreme flow regimes during the growing season in urban streams may have more severe consequences for aquatic ecosystems and stream habitat.

Habitat within urban-impacted streams is also affected by rapid conveyance of runoff and increases in peak flows, which accelerate erosion and destabilize stream banks [8]. Impervious surfaces augment the transfer of nutrients (e.g., phosphorus and nitrogen) and contaminants from urban areas to waterways including pesticides, road salts, and other chemicals associated with urban areas. Higher nutrient and contaminant exports in urban watersheds are attributed not only to anthropogenic changes to the land surface and subsurface drainage network that promote rapid

drainage but also to the relatively large inputs these watersheds receive from external sources, including atmospheric deposition, fertilizer, and pet wastes [9–11].

Since the 1990s, stormwater management has been required in southern Ontario, and Ontario is considered one of the more “environmentally progressive” provinces with respect to urban storm water management [12]. Stormwater ponds are the most common best management practice in urban areas and are a common feature in new residential developments where they are intended to slow runoff movement into streams and allow sediment (and associated nutrient/contaminant) retention. Because storm water ponds only became standard after the 1990s in southern Ontario, “new”/post-1990s urban areas may respond differently to hydrologic inputs and extreme events compared with older urban centers that were established before urban stormwater management became conventional. As such, the sensitivity of stream flow and nutrient and contaminant transfer may be different in newly urbanized areas, such as those that are currently expanding around the periphery of existing high-density urban areas.

2.2 Urban Contributions to Nutrient Losses

Land use is an important determinant of nutrient export from land to waterways, and urban runoff is recognized as an important source of nutrient inputs to the lower Great Lakes (e.g., [13]). Urban areas are consistently associated with higher total phosphorus (TP) exports compared with natural watersheds, but differences in TP export from urban vs. agricultural landscapes are more varied, with some studies reporting higher TP export at urban compared with agricultural dominated catchments and others reporting the opposite (e.g., [14]). Variability in export rates both among and within land covers is likely due to the very large range of agricultural types (e.g., cash cropping, livestock, horticulture) and practices (e.g., tillage, tile drainage, fertilizer application) as well as form (suburban, high density urban) and phase (construction, established) of urban development and associated use of best management practices. For example, Duan et al. [15] found that P exports were higher from catchments dominated by higher density urban land compared with lower density residential developments along an urban-to-rural gradient in Maryland, United States. Despite expansions in urban cover across southern Ontario since the 1970s, significant declines in TP concentration were observed at almost 70% of the streams studied by both Raney and Eimers ([16]; $n = 114$ streams) and Stammer et al. ([17]; $n = 56$ streams) over a 30-year period, and the highest TP concentrations and the largest TP declines occurred in mixed land use watersheds that encompassed both urban and agricultural land cover [17]. Declines in offshore TP concentrations in the lower Great Lakes over the same time period have been largely attributed to improved P removal from point sources including wastewater treatment plants (WWTPs) [18]. However, Raney and Eimers [16] reported that declines in stream TP occurred at sites both with and without upstream WWTPs and concluded that improved P removal from treated wastewater could not be the sole driver. While the

cause(s) of observed TP declines in southern Ontario streams remain unresolved, it is conceivable that land use change may play a role. For example, TP export from “new urban” developments may be lower than expected as a result of BMPs like stormwater management ponds and newer low-impact design (LID) strategies, and therefore increases in urban cover at the expense of agricultural land may be associated with lower P exports if the replacement urban land involves effective stormwater and erosion management. Studies conducted through the Stormwater Assessment Monitoring and Performance (SWAMP) Program in Ontario found that stormwater ponds and retention basins that slow runoff and allow sedimentation generally reduce P losses in runoff [19].

3 Agricultural Land Cover in Southern Ontario

Expansions in urban land have been associated with agricultural loss [20], and total agricultural land in Ontario declined from a peak around 1920 to its current coverage of just over half of total land area by 2011 ([21]; Table 1). Total agricultural land continues to decline, albeit at a slower pace, and currently 1/3 of all urban land in Canada is located in Ontario [22]. Expansions of urban area at the expense of agricultural soils are of particular concern in a country such as Canada, where agricultural land is a scarce resource and only 5% of total land area is considered free from severe constraints to crop production [20]. Indeed, Ontario is home to the best agricultural land in Canada, and over 50% of the nation’s entire endowment of “Class 1” agricultural land (defined as free from any soil or climatic constraints) is found in southern Ontario [20]. Ontario has more farms than any other province (~49,000 in 2016), ranks fourth in Canada for total area and accounts for 1/5 of national farm income [1].

3.1 *Changes in Southern Ontario Agriculture*

While agriculture remains the most common land cover in southern Ontario (53% of total land area), less well recognized is that while total farmland declined in Ontario, the total area under crop production held relatively constant, and so the proportional area of row crops (also commonly referred to as “cash crops”) actually increased between 1976 and 2011 [21]. Increases in row crop area were largely at the expense of land previously under pasture and forage (e.g., hay), which declined substantially over the same time period. Forest and wetland area also declined [21]. Decreases in pasture and forage area are attributed to a major reduction in cattle and dairy cow numbers in Ontario between 1976 and 2011 (45% and 52%, respectively) which may be partly attributed to an east-to-west shift in cattle production within Canada [21]. Pasture and forage together currently represent approximately 1/3 of total agricultural area in southern Ontario (Table 1).

Two cash crops in particular – grain corn and soybean – currently dominate agriculture in Ontario (Table 1), and Ontario accounts for 60% and 50% of national grain corn and soybean area, respectively [1]. Smith [21] describes increases in soybean production in Ontario (+552%) and grain corn (+29%) between 1976 and 2011 as “meteoric,” and similar increases in soybean and grain corn production have occurred in the United States portion of the Western Lake Erie Basin [23]. Dramatic increases in soybean and corn production in Ontario have been attributed to a variety of factors, including the emergence of cold-hardy, short-season soybean cultivars, increased demand from the Chinese market, as well as greater reliance on corn-derived ethanol (e.g., [24]). Much of the cropland in Ontario is concentrated in the extreme southern and western portions of southern Ontario, which drain into Lake Erie and Lake Huron, respectively, whereas agricultural land north of Lake Ontario (central and eastern regions; see Fig. 1) is more mixed, with both cropland and pasture/forage common. Nevertheless, shifts from mixed livestock farming toward increased cash cropping have occurred in the central and eastern portions of southern Ontario as well [25].

3.2 Changes in Agricultural Practices: Impacts on Water Quantity and Quality

In addition to major shifts in the type of agriculture practiced in southern Ontario, there have been substantial changes to agricultural procedures in the region, including tillage methods, type of fertilizer application, and the extent of tile drainage. These shifts may have consequences for both soil and runoff water quality in southern Ontario and the downstream Great Lakes. Soil conservation concerns in the 1980s led to the widespread promotion of reduced tillage as a means of increasing soil organic matter storage and limiting erosion. Current reported levels of no-till or reduced till in Ontario (63% of cropland in 2011) suggest this practice is far more common than conventional tillage, where most of the crop residue is incorporated into the soil (37% in 2011) [21]. While employing methods of reduced tillage encourages organic matter storage in soil, which is generally associated with improved soil structure and lower erosional losses, it also has been speculated to be associated with recent increases in soluble reactive phosphorus (SRP) in Lake Erie and its major tributaries in New York (e.g., [26]). The relationship between tillage practices and runoff water quality is not straightforward and may depend on soil texture and other management methods including whether fertilizer is applied to the soil surface or injected. For example, surface broadcast P fertilizer in combination with no-till practices in a fine textured soil that is prone to cracking and macropore drainage could lead to higher P losses compared with a soil that is coarse textured or where P additions are homogenized through the soil rooting zone via conventional tillage [27]. More frequent extreme rainfall events may exacerbate nutrient losses

Table 2 Tile drainage area and date of installation in the four subregions of southern Ontario

Area (km ²)	South	West	Central	East	Total
Total recorded tiled area	8,279	5,975	452	2,082	16,789
Recorded tiled area with date	1,224	1,322	142	664	3,352
Total urban area	1,965	2,163	1,861	1,110	7,098

Tile drainage areas are from OMAFRA (2018); urban areas (sum of pervious, impervious, and transportation) are from SOLRIS version 2.0. Subregions of southern Ontario are the same as shown in Fig. 1a

through enhanced erosion and associated export of particulate-associated P, especially in areas dominated by fine-textured soils like southwestern Ontario [27].

Tile drainage is another management practice that may alter both water quality and quantity in the Great Lakes basin. Tile drainage is generally encouraged by the provincial ministry of agriculture (Ontario Ministry of Agriculture, Food and Rural Affairs; OMAFRA) due to its proven agronomic benefits including improved crop production and longer and more reliable access to fields. Drainage is considered almost essential in no-till or reduced-till agriculture, since soil drying is one of the benefits of conventional tillage. Tile drainage installations in Ontario do not require prior consideration of impact on groundwater or offsite water quality or quantity, and the Tile Loan Program, authorized by the *Tile Drainage Act*, provides loans to agricultural property owners to help them finance these tile drainage projects [28, 29]. The sheer magnitude of tile drainage in Ontario and its pace of expansion suggest that this form of agricultural water management may have cumulative impacts on downstream environments. Tile drainage currently underlies over 16,700 km² of southern Ontario (see Fig. 1b; Table 2), although this area is widely acknowledged to be an underestimation given the very advanced age of many installations that pre-date modern record keeping, as well as private installations that do not require site plan submission. For example, of the 16,789 km² of recorded tile drainage, only 20% is associated with a date of installation (Table 2).

Nevertheless, even this incomplete record indicates that a substantial proportion of agriculture in southern Ontario is currently underlain by tile drainage. Furthermore, the recent rate of tile drainage expansion in southern Ontario appears to outpace that of urban expansion over the past two decades, particularly in the southwestern extreme of the province (Fig. 2).

While tile drainage is an important agronomic tool that boosts agricultural production, it also affects water quality and quantity. Subsurface drainage facilitates export of both P (e.g., [30]) and nitrate (NO₃-N) to waterways by improving drainage beneath the rooting zone and expediting transfer to downstream surface waters [31, 32]. Increases in corn and soybean production in Ontario are of particular concern with respect to NO₃-N, which tends to be higher in surface water and groundwater within agricultural watersheds compared with watersheds dominated by suburban or urban land cover [33]. Corn is known to have a high N-demand but low N-use efficiency, and thus NO₃-N leaching rates from corn fields tend to be much higher than for other common row crops [34]. Studies in Iowa, which is part of

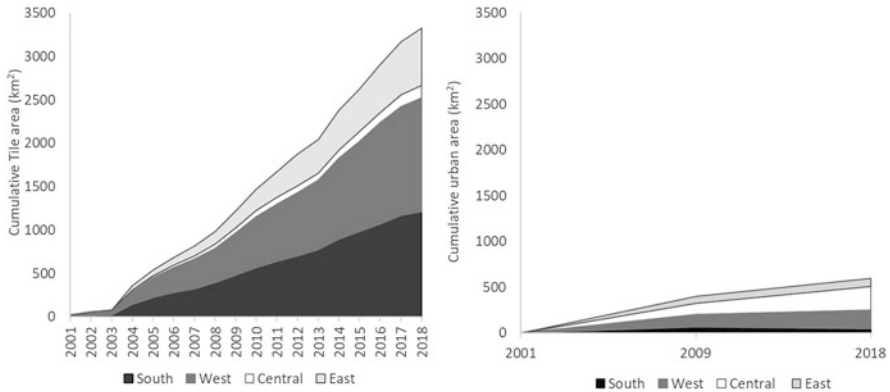


Fig. 2 Cumulative expansions in tile drainage area (left panel) and urban area (right panel) in the four subregions of southern Ontario between 2001 and 2018; analysis is limited to 2001 onward as the area of tile installed prior to this period is unknown

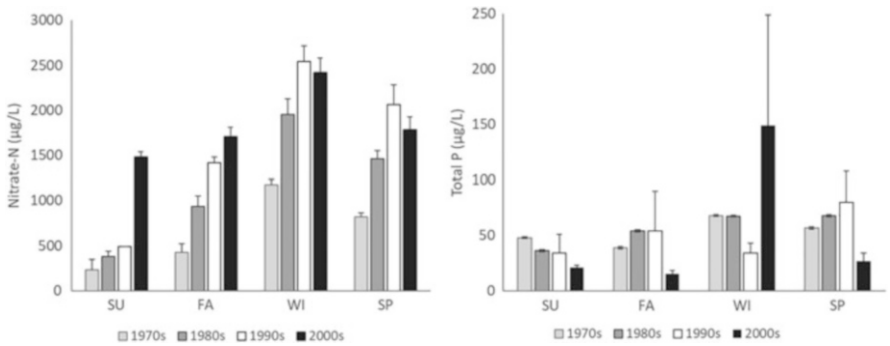


Fig. 3 Decadal averages of seasonal (*SU* Summer, *FA* Fall, *WI* Winter, *SP* Spring) concentrations of stream nitrate-N (left panel) and total P (right panel) at Gages Creek, a 46.6 km² agricultural watershed in the central subregion that drains directly to Lake Ontario [25, 37]

the Corn Belt in the Midwestern United States have shown a positive relationship between land under row crop (particularly corn) and surface water NO₃-N concentrations [35, 36]. Soybeans, in contrast, are legumes that fix atmospheric N and are known to augment the soil N pool and may facilitate greater NO₃-N losses from the following corn crop if residual soil-N is not adequately accounted for in fertilizer applications.

Significant increases in stream NO₃-N concentrations occurred at agriculturally dominated watersheds that drain into Lake Ontario between 1971 and 2010 (see Fig. 1b), with the largest and most significant increases occurring in watersheds where row crop cover also increased [25, 37]. Nitrate concentrations increased significantly over time in every season at Gages Creek, for example (Fig. 3), whereas TP trends were more variable. Total urban area increased in Gages Creek between 1971 and 2011 from 2% to 9%, while total agricultural area declined from 91% to

71%. However, the proportion of agricultural land under row crops (primarily corn and soybean) increased over the same period from 42% to 61%, and this may have particular relevance for nitrate export via tributaries [25]. Increases in corn and soybean area at the expense of pasture and forage have undoubtedly altered the N budget of agricultural watersheds in southern Ontario and may even contribute to observed increases in $\text{NO}_3\text{-N}$ in the lower Great Lakes [18, 21].

The effects of tile drainage on total runoff quantity are more complex and may be influenced by site-specific conditions, but a recent review by Gramlich et al. [27] suggests that stormflow is augmented by tile drainage in areas with a naturally low water table, whereas stormflow may decline following drainage in areas with a typically high water table. The overall water budget may be also affected by increases in tile-drained row crops through replacement of perennial vegetation (i.e., hay, pasture) with annual plants (corn and soybean) that typically have smaller transpiration losses and less evaporation from standing water/saturated surface soils due to improved drainage. Drainage may also cause more rapid conveyance of water from fields to recipient streams, and ditching and straightening of channels that often accompany agricultural production may further contribute to rapid transit times [27]. The few Ontario studies that have examined the effects of drainage on watershed-scale hydrology have been generally inconclusive (e.g., [38]) although the authors acknowledged that the history of drainage preceded the instrumental record of streamflow in much of southern Ontario, which precludes a before-and-after comparison. While this is certainly the case in the south and west subregions of Ontario, where installations date back to 1906 [39] and there is little remaining untilled cropland (see Fig. 1b), the central region of southern Ontario may be a ripe area for research, since it has the lowest amount of currently recorded tile drainage (Table 1) and therefore the greatest potential for expansion. The effects of drainage and vegetation shifts in agricultural headwaters should be considered when evaluating flood potential in downstream urban areas. Indeed, Wiskow and Van der Ploeg [40] argue that agricultural drainage has contributed to increased flood incidence in Germany. The potential for tile drainage to contribute to downstream flood incidence in southern Ontario urban areas has not been evaluated but should be considered particularly in the context of a changing climate.

3.3 The Interaction Between Water Resources, Land Use, and Climate Change

Water resources are closely connected to the climate elements of air and water temperature, precipitation, evaporation, and snow and ice cover, and so changes in these parameters may have considerable impacts on water resource management. Climate model projections for Ontario over the next century indicate higher air and water temperatures, more precipitation (with high regional and seasonal variability), shorter winters, less ice and snow coverage, a longer growing season, higher rates of

evaporation and transpiration, and increased potential for extreme weather events [41]. While differences in annual average (1981–2010) temperature and precipitation across the region of southern Ontario shown in Fig. 1 are relatively small (see Table 3), ranges in extreme conditions are more considerable. For example, Windsor, in the extreme southwest of the province, routinely experiences the greatest number of extreme hot days ($T_{\max} > 30^{\circ}\text{C}$) with an average of 24 days per year exceeding this threshold between 1980 and 2010, compared with Cobourg, where extreme hot days numbered less than 5 per year over the same time period (Table 3). Extremes in precipitation are of greater direct relevance to water resources but are less variable across sites, with much of southern Ontario receiving an average of 8–9 rainfall events per year that exceed the 90th percentile (Table 3). The majority of these large rainfall events occur in the summer and fall, when differences in runoff extremes between urban and rural streams are greatest [7]. Notably, all sites receive at least 1–2 large rainfall events per year during the winter and spring months. Extreme rainfall events during the non-growing season have a high potential to generate flooding due to generally frozen or snow-covered ground that limits infiltration as well as minimal evapotranspiration losses during the period of senescence. A recent national analysis of floods and flood regimes found that 38% of reference rivers in southeastern Canada showed significant ($p < 0.05$) increases in the frequency of extreme runoff events (>90th percentile) between 1961 and 2010 and no sites showed declining trends [42]. Furthermore, 14% of these watersheds showed an advancement in the timing of extreme runoff events, which is consistent with a reduction in snowmelt events and an increased importance of pluvial contributions to flooding [42]. Warmer winter temperatures and/or more regular temperature excursions above 0°C could produce more frequent winter thaw events that result in extreme runoff. While there is limited capacity for older urban areas to adjust to augmented winter flow, newer urban developments that incorporate stormwater ponds have some storage capacity to absorb extreme runoff events, even during the winter. Seasonal comparisons of pond efficiency in southern Ontario, for example, have shown that flow extremes are similarly muted in summer and winter-spring; however, nutrient removal rates are often less in the dormant season likely due to lower biological activity (e.g., [43]). In contrast, tile drains consistently respond to both rainfall and melt inputs during the nongrowing season and very rarely generate discharge during the summer [44]. As a result, winter rainfall and temperature extremes may produce a larger runoff response in tile-drained agricultural systems. As tile-drained agriculture ubiquitously surrounds urban centers in southern Ontario, there is the potential for tile-drained agriculture to amplify the hydrologic response of downstream urban watersheds to extremes in winter rainfall and temperature-driven melt events.

Table 3 Long-term average temperature and precipitation within the southern Ontario study region

	Ottawa	Belleville	Peterborough	Cobourg	Toronto	Barrie	London	Hamilton	Windsor
1981–2010 averages									
Annual avg (°C)	6.6	8.1	6.2	7.5	8.2	6.9	7.9	7.9	9.9
Jan avg (°C)	-10.2	-6.7	-8.5	-5.6	-5.5	-7.7	-5.6	-5.5	-3.8
Jul avg (°C)	21.2	21.8	19.6	19.9	21.5	20.8	20.8	20.9	23
# days with max $T \leq 0^\circ\text{C}$	74	54	62	50	53	67	57	56	44
# days with max $T > 30^\circ\text{C}$	12	8	9	1	16	10	10	11	24
Degree days $> 5^\circ\text{C}$	2,182	2,330	1,916	2,015	2,290	2,107	2,211	2,212	2,688
Annual precipitation (mm)	920	912	855	890	786	933	1,012	930	935
%Snow	18	15	17	11	13	24	16	15	12
Annual rainfall; R (mm)	756	772	712	794	682	710	846	792	822
% Summer (JJA)	35	28	32	27	33	35	30	33	30
% Fall (SON)	32	34	32	33	30	33	31	29	29
% Winter (DJF)	10	14	11	15	12	8	13	13	14
% Spring (MAM)	24	25	24	25	25	24	25	24	26
90th percentile of daily R (mm)	19.3	19	19	19	18.4	17	19.6	19.7	21.2
# days daily $R > 90\text{th}$									
Annual	8.9	8.7	8.7	8.8	8.1	8.8	7.9	8.8	8.6
Summer	3.8	2.7	3.4	2.7	3	4	2.5	3.6	2.8
Fall	2.5	3	3	2.9	2.4	2.8	2.7	2.9	2.9
Winter	0.7	1.1	0.8	1.2	0.6	0.4	1.1	0.8	1
Spring	1.8	2	1.6	2	2	1.6	1.7	1.5	1.8

Seasons include summer (Jun, Jul, Aug); fall (Sep, Oct, Nov); winter (Dec, Jan, Feb); and spring (Mar, Apr, May)

4 Where Do We Go From Here?

Southern Ontario is a mosaic of urban and agricultural lands with natural cover mainly located in the northern parts of the region (Fig. 1). The intersection between prime agricultural land and a growing urban population poses particular challenges for soil and water resource management in the region. Nitrate levels in the lower Great Lakes have been increasing over the past few decades, whereas total P concentrations have declined [18]. Similar trends in nutrient concentrations in agricultural tributaries draining to Lake Ontario suggest that shifts in watershed land use may be a contributing factor [25, 37]. The area of southern Ontario described in this chapter drains to Lake Ontario, Lake Erie, and Lake Huron, which together supply drinking water for millions of Canadians and Americans in the Great Lakes basin. While there is currently strong interest in sustainable urban development and low impact design strategies are becoming more common in new urban areas, agricultural practices are becoming more intensive. There is significant scope for further increases in tile-drained row crop area within southern Ontario, particularly in the central and eastern regions, if demand for cash crops like corn and soybean remains strong. Understanding the cumulative effects of both agricultural and urban land cover change, as well as possible mitigation strategies, is important for the protection of water quality and flood prevention in the lower Great Lakes basin, particularly under a changing climate.

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