MARKHAM'S NATURAL ASSETS AND CLIMATE CHANGE GUIDE

Prepared for

MARKHAM

Prepared by

Planet A Consulting ...Because there's no Planet B

GROUNDED SOLUTIONS

advisory services

CBCL

CLIMATE RISK INSTITUTE

Natural Assets Initiative MAKING NATURE COUNT

green ANALYTICS

May 2024

Contents

Acknowledgements and Disclaimers

The City recognizes the importance of Indigenous engagement and the value of Indigenous knowledge – particularly as it relates to natural heritage. The City also recognizes that Indigenous community(ies) would be valuable partners in advancing natural asset management in Markham and is committed to exploring opportunities for engagement on this topic, and on other related environmental topics, in the future.

This Guide was developed for the City of Markham by a multi-disciplinary team of professionals led by Green Analytics as one of the deliverables for the City's first natural assets inventory and evaluation.

The consulting team has tried to tailor this Guide to the local context and to this end has included local data and locally relevant examples and/or case studies where available. However, some examples, case studies and references not directly relevant to Markham have also been included to provide applied examples of how other jurisdictions have leveraged natural assets for the services they provide and to build community resilience in the face of climate change.

This Guide is the product of a collaborative effort by the various members of the consulting team and the City Project Team.

The bulk of the research and analysis that informed this Guide was provided by the Climate Risk Institute (CRI). CRI was able to draw on recent work completed for the Ontario Provincial Climate Change Impact Assessment (2023) [(1)] and incorporate case studies from their work elsewhere in Ontario and Canada. This Guide has also been informed by technical input and advisory support provided by other members of the consulting team: CBCL Engineering & Environmental Design Services, SLBC Advisory Services, Planet A Consulting and the Natural Assets Initiative. This Guide has been edited and formatted by Green Analytics and Grounded Solutions.

Special thanks are extended to the City of Markham's Project Team (Patrick Wong, Mark Head, Denny Boskovski, Robert Muir, Nory Takata, Josh van Kemp, Becca Spence and Tony Iacobelli formerly with the City) and other City staff in the broader Technical Advisory Committee who have contributed to this project. Their input and guidance were instrumental to informing this guide.

Special thanks are also extended to the external parties who provided high level insights and comments that informed this guide, including representatives from the:

- Toronto and Region Conservation Authority (TRCA)
- Regional Municipality of York
- Ontario Ministry of Natural Resources and Forestry (MNRF)
- Ontario Nature (ON)
- Parks Canada - Rouge National Urban Park (RNUP), and
- York Federation of Agriculture (YFA).

The consulting team has made every effort to ensure the accuracy of the information in this guide and to support statements with technical, scientific and/or other sources where appropriate, but nonetheless assumes responsibility for any errors or omissions.

Cover image: Photo of Milne Dam Conservation Park in Markham (Credit: City of Markham)

Glossary of Key Terms

asset management planning	"A formalized and integrated approach to planning and budgeting for municipal infrastructure needs, which considers a wide variety of data from across an organization with the long-term vision of the community in mind" [2].
engineered asset	A type of green infrastructure asset that is a built or manufactured structure intended to help mimic natural functions, particularly hydrologic functions, at the site-specific scale. Generally does not have a "green" or vegetated component.
enhanced green asset	"[L]and, water and vegetation features alongside human-made elements to sustain ecosystem functions and services… the enhancement of conventional grey infrastructure (e.g., piped, ditch and culvert, dam and reservoir systems) with nature-based elements, [often] in order to achieve the active and everyday management of the full rainfall-runoff spectrum" [3].
green infrastructure	"[R]efers to the natural vegetative systems, engineered and built features, and green technologies that collectively provide society with a multitude of economic, environmental and social outcomes" [3].
grey infrastructure	"[E]ngineered assets made exclusively of materials such as concrete and steel… including bridges, dams, water treatment plants, culverts, ditches and storm drains" [3].
levels of service	"[T]he parameters, or combination of parameters, that reflect the social, political, environmental, and economic outcomes that the organization delivers. The parameters can include safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost, and availability" [2, 4].
natural asset	"[T]he use of preserved, restored or enhanced elements or combinations of vegetation and associated biology, land, water and naturally occurring ecological processes to meet targeted infrastructure outcomes. It can be differentiated from the related category of green infrastructure based on its composition exclusively of natural ecosystem features and materials (e.g., water, native species of vegetation, sand and stone, etc.), and from grey infrastructure because it provides a range of co-benefits to the environment, the economy, community health and well-being that grey infrastructure usually cannot" [3].
nature-based solutions	"[M]easures that protect, restore and sustainably manage natural or modified ecosystems, with the aim of maintaining or enhancing the services provided to human communities and benefits to biodiversity" [3].
resilience	"[T]he capacity to recover quickly from difficulties … A resilient community has the capacity to survive and adapt to chronic stresses and acute shocks, like population growth or decline, aging populations, influxes of new immigrants, economic swings, or climate change impacts like severe storms, flooding or melting permafrost" [4].
urban forest	All trees across the given jurisdiction, including the soils that support them. This includes trees within and outside of natural areas and trees on all lands irrespective of ownership.

1 Introduction

What are "natural assets"? Natural assets are basically natural areas that provide recognized and valued environmental services, and that are maintained and managed to be able to continue to provide those services [3]. In Markham, these assets include woodlands, wetlands, meadows and water bodies (such as lakes and ponds).

Natural assets can occur on lands that are publicly or privately-owned. The focus of the City of Markham's natural asset assessment and management planning has been on the assets on its own lands. However, publicly-owned natural assets do not function in isolation from the natural areas on nearby lands owned by others, which also provide a range of services. Therefore, all natural areas in the city have been considered as part of Markham's natural asset condition assessment, risk assessment and valuation.

Services provided by natural assets are typically called "ecosystem services". These include environmental such as water filtration and stormwater management, access to nature-based recreational opportunities, air quality regulation, carbon storage (i.e., sequestration), extreme heat regulation and pollination (contributing to crop productivity). They also include other services such as contributing to higher residential sale prices and to the value of having open and/or greenspaces in a community.

These ecosystem services can be valued (as in Figure 1) and have the added benefit of coming with co-benefits that are often harder to value but still very valuable (e.g., benefits to human physical and mental health of having access to natural areas). An overview of the estimated value of each of these services provided by natural assets in Markham is provided in Figure 1. Figure 1 also shows that together these services are valued at between $114 and $120 million per year (in 2024 Canadian dollars), with about half of this value coming from natural assets on City-owned lands [5].

Figure 1: Estimated annual value of selected services provided by natural assets in the City of Markham
(Credit: Green Analytics *et al.* [5])

Residents and businesses in Markham generally rely on the local municipal and regional governments to provide environmental services such as public facilities and spaces for recreation, potable water, wastewater and stormwater management. These services have traditionally been largely provided by investing in "grey infrastructure" without much regard for the natural infrastructure that helps provide these services.

A considerable amount of the public grey infrastructure across Canada is in poor condition and requires significant attention in the coming decades [6]. Replacing or upgrading this infrastructure will require considerable investments. Natural assets cannot by themselves address the challenges of replacing and upgrading the extensive networks of ageing grey municipal infrastructure in a context of advancing climate change. However, **natural assets can be cost-effective complements to grey infrastructure that provide core services (such as helping to reduce flood risks and improve water quality)** [7, 8]**, while also providing other services (such as helping communities adapt to climate change by moderating urban heat and air pollution)** [9, 10, 11, 12, 13].

This Guide includes an overview of:

- key concepts related to this Guide (Section 2)
- the approach to climate change risk assessment (Section 3)
- overview of existing natural assets in Markham (Section 4)
- key services provided by the different natural asset types in Markham (Section 5)
- vulnerabilities of Markham's natural assets (Section 6)
- strategies for maintaining and enhancing the services provided by Markham's natural assets (Section 7)
- policies and plans in Markham that help advance natural asset management (Section 8), and
- concluding remarks (Section 9).

This guide has been developed for decision-makers, residents and other interested parties in Markham to: (a) explain what natural assets are and how they provide important environmental services (including services that support climate change mitigation and adaptation) that are not currently accounted for, and (b) strategies for sustaining and enhancing these environmental services as climate change advances.

Protecting and investing in natural assets is a cost-effective strategy for municipalities to continue to provide a range of important environmental services while also building local climate resilience.

2 Key Concepts for this Guide

The key concepts central to this Guide are:

- green infrastructure, including natural assets
- climate change mitigation and adaptation, and
- resilience.

Definitions for key terms are also provided in the glossary at the beginning of this Guide.

2.1 Green Infrastructure includes Natural Assets

Green infrastructure is the umbrella term used to capture the full range of "green" systems and technologies that deliver a wide range of ecosystem services and provide many co-benefits to the environment, the economy, community health and well-being. Green infrastructure often complements or supports the services provided by grey infrastructure and can be implemented directly or indirectly through supporting policies, by-laws, plans and guidelines (as outlined for Markham in Section 9).

As shown in Figure 1, green infrastructure includes (a) natural assets, (2) enhanced assets, and (3) engineered assets. The focus of this Guide is on Markham's natural assets, but it is worth noting that the City also has enhanced and engineered assets (e.g., naturalized stormwater ponds, passive open spaces with manicured lawns) and plans to continue to incorporate low impact development approaches as growth in the city proceeds.

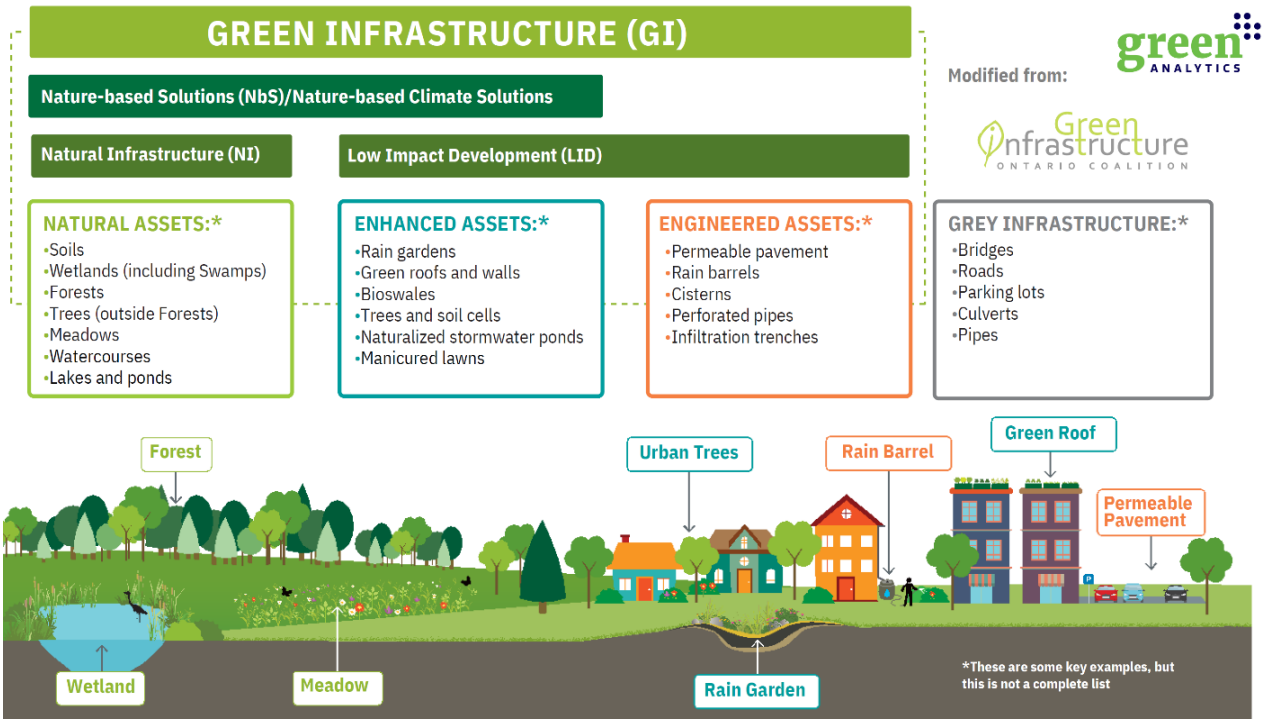


Figure 2: Illustration of different types of green and grey infrastructure with examples.
(Credit: Green Infrastructure Ontario and Green Analytics)

Natural assets (sometimes referred to as natural infrastructure) are natural features and areas that are, or could be, relied on for the sustainable provision of one or more local environmental services (e.g., management of water quantity and/or quality, air temperature cooling, etc.) [3, 14]. Typical natural asset types include woodlands, wetlands, meadows, lakes, ponds and watercourses, which all occur in Markham.

Both natural assets and enhanced assets are considered nature-based solutions because they include at least some "green" elements (i.e., plants, soil or substate). However, natural assets are distinct from enhanced assets in that they are generally more complex habitat types or ecosystems with references in nature that support a diversity of (largely native) plants and wildlife. Natural assets are also different from engineered assets and grey infrastructure in their ability to provide a range of co-benefits (e.g., physical and mental health benefits associated with access to nature and greenspaces [10, 15, 16]).

2.2 Climate Change

Climate change refers to measurable and significant shifts in the state of climate and weather patterns. These shifts can be identified by changes in variability and/or trends of key climate parameters such as temperature and precipitation that persist for an extended period of time (typically decades or longer) [17].

Climate change may be attributed to natural processes as well as human activities (such as greenhouse gas emissions from vehicles and industries), however it is primarily human activities that have both triggered and exacerbated climate change at rates that are unprecedented over the past few centuries [18].

Viewed as one of the most significant challenges of our time, climate change has begun to manifest itself in southern Ontario with generally increasing temperatures, more variable precipitation and more frequent extreme weather events (such as heat waves, droughts, high intensity storms and flash floods) [1, 19]. These trends are expected to persist, and (in most climate scenarios) intensify in the coming decades [20].

Climate Change Mitigation

Climate change mitigation refers to human intervention to (a) reduce the sources and/or (b) enhance the sinks of greenhouse gases, thereby limiting the human causes of climate change.

Sequestration is one way to maintain and enhance the sinks of greenhouse gases. It aims to capture and store greenhouse gases, primarily carbon dioxide (i.e., CO_2), to reduce their presence in the atmosphere. Natural sinks for storing CO_2 include individual trees, woodlands and other wooded natural areas, as well as meadows and bodies of water.

The storage of CO_2 in vegetation and soils occurs as plants absorb CO_2 from the air and bind it into their above and below-ground biomass (i.e., stems, trunks, roots). For trees and wooded natural areas, CO_2 storage capacity increases over time as the trees grow and mature. Carbon can also be stored directly in soils as it binds to certain minerals that are present in different soil types [21].

Conservation and management of natural assets therefore has the potential to capture and store large amounts of carbon, especially when the soils are factored in [22].

Planting trees and creating woodlands to sequester more carbon, while also contributing to community health by providing air quality and cooling benefits associated with maturing trees, is a good example of climate change mitigation and related ecosystem services linked to natural assets [23].

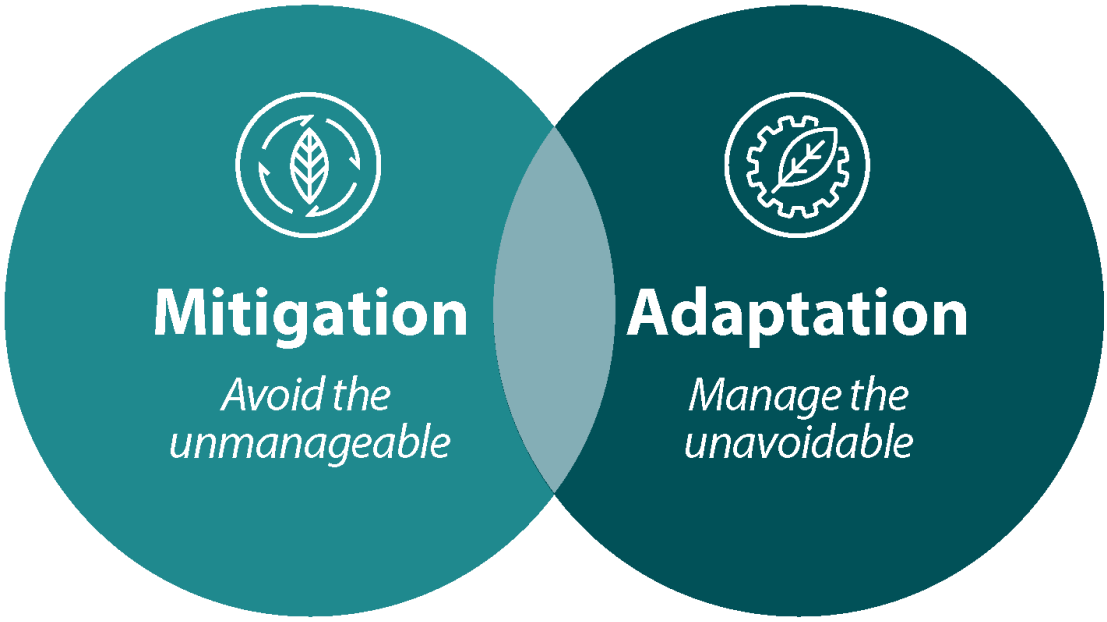


Figure 3: An illustration of climate change mitigation and adaptation
(Credit: Peel Region Urban Forest Best Practice Guide 5 [24])

Climate Change Adaptation

Climate change adaptation is the process of building resilience in our communities to be able to withstand the actual or expected shifts and extremes in climate conditions, including taking advantage of beneficial opportunities where they arise (e.g., milder winter temperatures).

Increasing species and genetic diversity within natural assets is generally a good strategy to make these assets able to rebound more quickly from short-term disturbance events, and potentially to help them adapt to longer term climate shifts. However, this work should be done by persons with a good understanding of an appropriate selection of species for the given natural asset type and site conditions. Notably, while introducing a limited number of non-invasive species from slightly warmer climates may be a good strategy to assist with climate change adaptation, increasing biodiversity with invasive and/or unsuitable species is likely to cause more harm than good to a natural asset.

What does natural asset resilience in a climate change context mean?
Resilience as it relates to natural assets refers to their ability to recover quickly from serious environmental stressors (such as an ice storm) or catastrophic events (such as a forest fire), and their ability to adapt to longer term trends in the changing climate. Natural systems generally have a certain amount of inherent ability to both recover from short-term impacts and adapt to longer term changes, in large part to their structural and species diversity as well as their genetic plasticity [24, 25, 26].

However, every species and every natural asset has limits (as outlined in Section 7). As these limits are not well understood it makes sense to consider and plan within the context of a “high-emissions” scenario (as described in Section 3) and to implement multiple strategies across multiple asset types (as outlined in Section 8) to help improve the odds of sustaining and enhancing the local natural asset network in a changing climate.

An example of a climate change adaptation project to improve ecosystem and community resilience related to natural assets is restoring a degraded watercourse (e.g., with natural meanders, wetland pools and naturalization using a diversity of native species) to better attenuate flood waters, while also improving local biodiversity and providing an amenity for the community. The City of Markham has implemented a number of these types of projects in collaboration with Toronto and Region Conservation Authority, York Region and other public sector, private sector and non-profit partners over the past three decades [25] (as illustrated in the Robinson Creek case study below) and continues to do so as opportunities and resources permit.

Case Study: Robinson Creek North Naturalization and Recreational Access, Markham, ON

A section of Robinson Creek south of Major Mackenzie Drive, west of McCowan Road and east of Stonebridge Drive was identified as one of seven priority restoration sites in the City in 2007. The opportunity to act arose in conjunction with the approval of a subdivision development in the eastern portion of the Robinson Creek watershed which required both enhanced valleyland protection and an open space amenity for the new community.

Between 2010 and 2012 the City of Markham worked with various partners to fund, design and implement this restoration project. As part of the approval of the subdivision, the City secured funding for a multi-use pathway from the developer which was combined with Federal funding from York Region to deliver an integrated trails and restoration project. Toronto and Region Conservation Authority provided the technical site analysis, developed the detailed designs and implemented the trail and restoration works, including securing required permits. The project has improved watercourse storage functions, fish habitat and local biodiversity while also providing public access to the valleyland.

Naturalized section of Robinson Creek north in Markham
Credit: City of Markham

3 Approach to Climate Change Risk Assessment

Climate change scientists have developed, and are continually refining, different climate change scenarios. These generally range from "low emissions" to "high emissions" scenarios, each with different projections about how our climate may change in the coming decades. The complex nature of the global climate system and being in uncharted territory make it very challenging predict how the climate will change, and how natural systems will respond. However, we do know for certain that the climate is already shifting, and that it will continue to shift, in significant and unprecedented ways that will impact every aspect of our society, including our municipal infrastructure – both grey and green.

Markham's natural heritage system provides many valuable services and benefits (as outlined in Section 1). However, the natural assets in this system have already been impacted by over a century of industrialization and urbanization (e.g., habitat fragmentation, drainage alterations, introduction of invasive plant species and pests). As a result, both planning and management are required to help sustain these assets and ensure they can continue to provide the services the community has come to rely on.

Over the next 30 years Markham's population is expected to nearly double (i.e., from 349,000 in 2021 to 618,000 in 2051). This will provide opportunities to invest in community amenities (including public natural areas) and to expand natural area stewardship efforts. However, it will also put more pressure on public open spaces and natural areas making proactive and adaptive management of Markham's natural assets more important than ever if these assets are to continue to provide core services to the community and help the community adapt to climate change.

Given this context it was agreed by the Project Team that climate change risks to Markham's natural should not be underestimated. Consequently, the scenario referred to as "RCP8.5" (known as the "high-emissions" scenario) was selected for assessing climate change risks to natural assets in Markham to the 2050s. While this scenario may not represent the most likely climate change pathway over the next century, it was selected because of its ability to help flag some of the greatest vulnerabilities of Markham's natural assets and inform how best to mitigate and manage these vulnerabilities. Use of RCP8.5 is also consistent with the approach being used by the City's regional partners (i.e., York Region and Toronto Region Conservation Authority) to inform their climate change action planning.

All the projections in Figure 4 are based the RCP-8.5 scenario except for the growing season projection which includes results from different scenarios including RCP-8.5. Figure 4 shows, for York Region and Ontario:

- Climate trends already observed from 1961 to 2020 (on the left) [27], and
- Projected climate trends to the 2050s relative to 1961 (on the right) [28].

As shown in Figure 4, both documented trends for York Region and projected trends for Ontario show that climate change already has caused, and is expected to continue to cause:

- Overall higher temperatures, with more extreme heat events, fewer frost days and expansion of the growing season
- Increasing variability in rainfall events
- More variable but overall increases in the amount of precipitation, with more extreme precipitation events (e.g., increased number and intensity of flood events), and
- More extreme wind events (e.g., tornadoes).

Notably, recent stormwater analyses found that so far there has been a slight decrease in the number of extreme rainfall events (i.e., 100-year events) in Markham, and across southern Ontario, since the 1940s rather than the predicted increase [29, 30]. This is an example of how regional climactic responses can vary from broader trends.

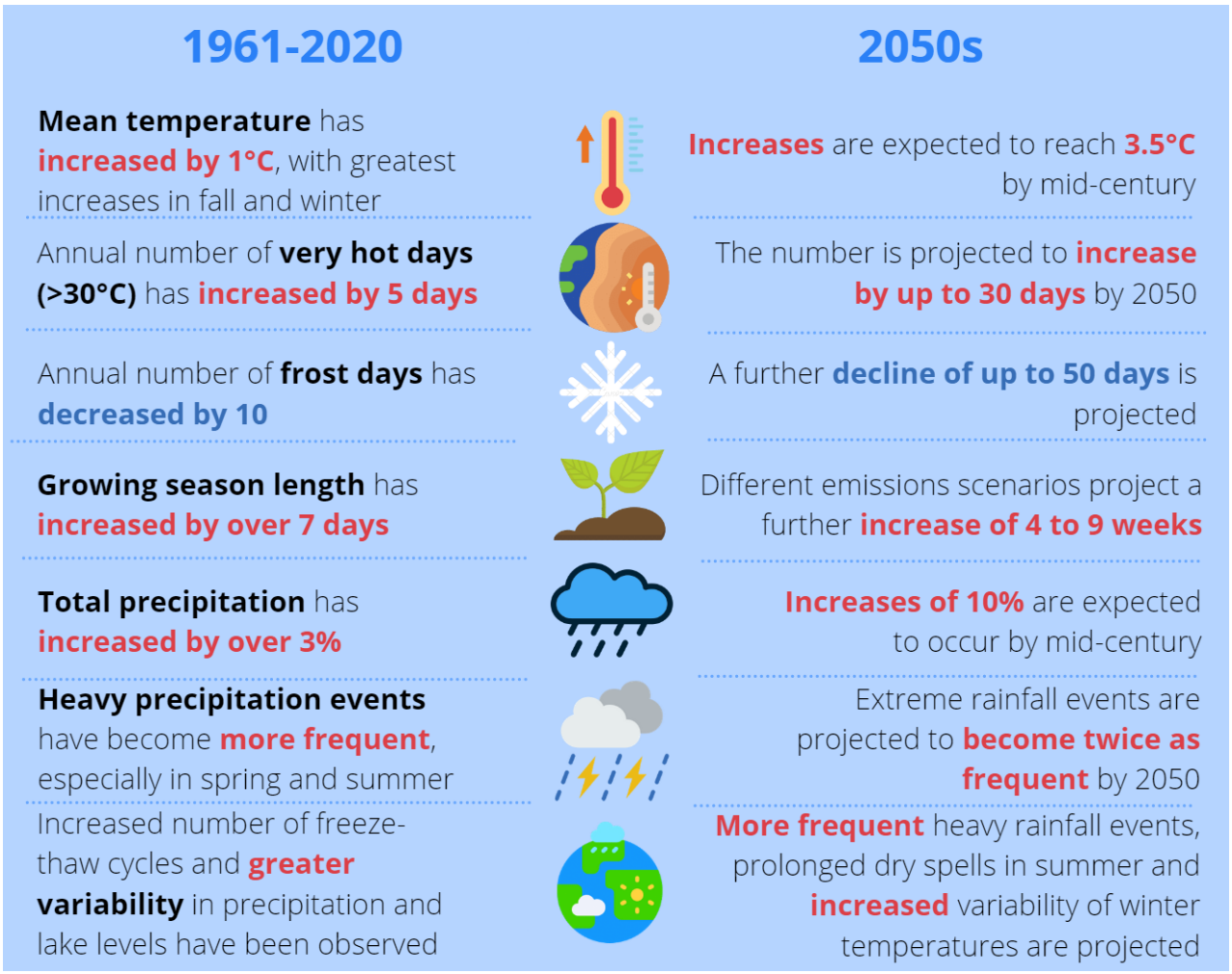


Figure 4: Documented climate trends for York Region [27] and projected climate trends for Ontario [28]
(Credit: Climate Risk Institute)

Damage from the December 2013 ice storm in Markham
(Credit: Toronto Star)

4 Overview of Markham's Natural Assets

Markham is a largely urbanized city and is expected to urbanize further in the coming decades. It currently has about 4100 hectares of natural assets [5] within its boundaries covering about 20% of the city.

Markham's natural assets are largely contained and protected within the City's Greenway System, shown in Figure 5. This Greenway System captures many of the creek and river corridors that run through the city including the Berczy, Bruce and Robinson Creeks and the Rouge River. These assets are more concentrated outside of the urbanized portions of the city and on the eastern side where they are largely interspersed with agricultural lands and largely protected within the provincial Greenbelt and the Rouge National Urban Park.

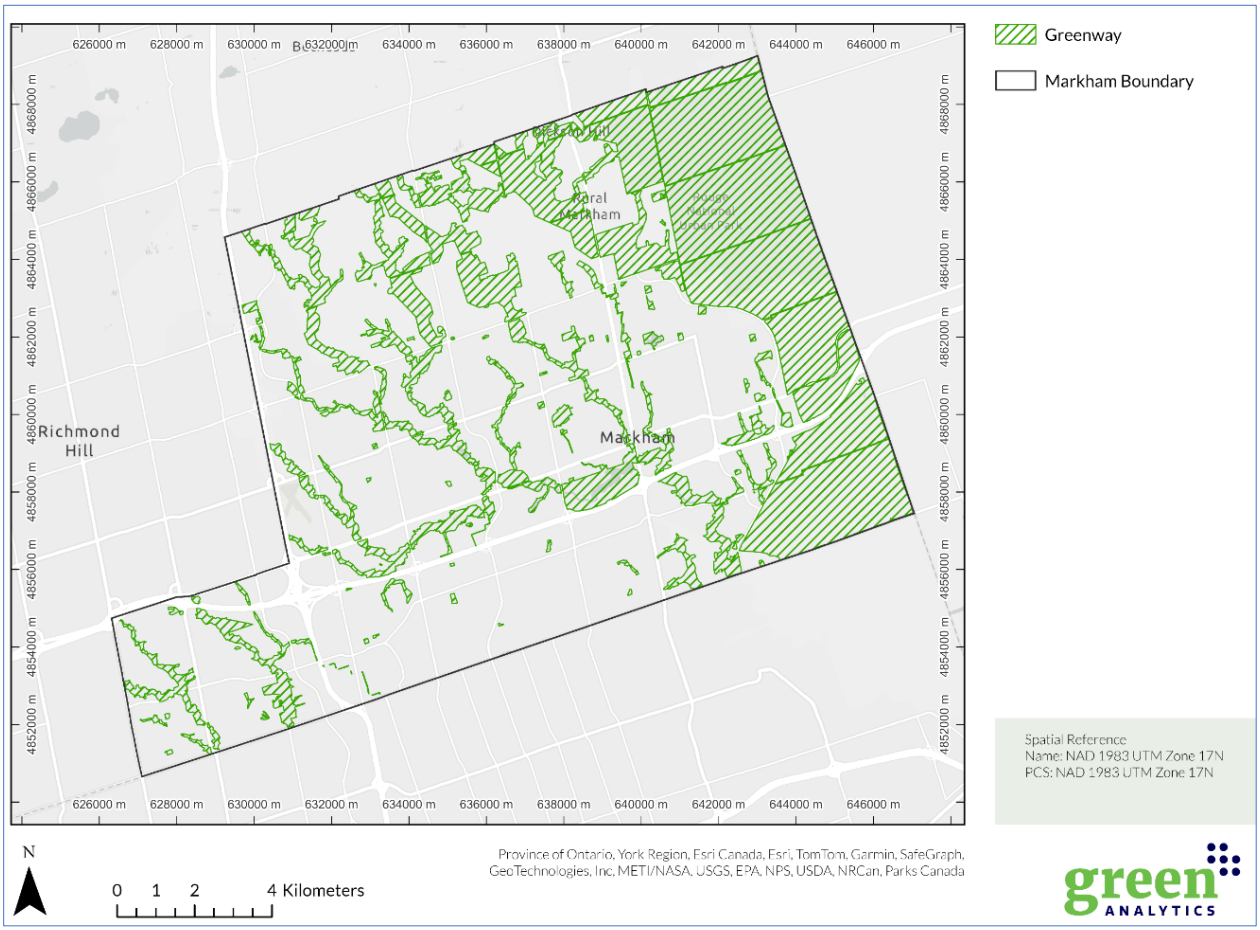


Figure 5: Map of the Greenway System in the City of Markham [5] (Credit: Green Analytics)

About a quarter of these natural assets (i.e., 1,000 hectares) are City-owned. Although applied natural asset management in Markham (e.g., woodland restoration, wetland creation, invasive species control) focus on the City-owned assets, it is recognized that natural areas cross ownership boundaries, that species do not distinguish between landowners, and that nearby natural areas tend to have an influence on each other. Therefore, the City has considered all natural assets in its inventory, condition and risk assessments, irrespective of ownership. For example, the creeks and rivers running through the city are not owned by the City but are closely associated with most of the natural areas in the City's Greenway System and effectively form the backbone to this system. Assessment of flooding and erosion risks to different natural assets in the City can only be done with consideration for the watercourses running through them.

Markham contains a diversity of natural assets including woodlands, wetlands, meadows (including grasslands and old fields), hedgerows, water bodies (such as lakes, ponds and watercourses) and a few natural bluffs and beach bars (associated with the Rouge River corridor) (see Figure 6). The ecosystem services provided by each of these natural asset types is discussed in Section 5.

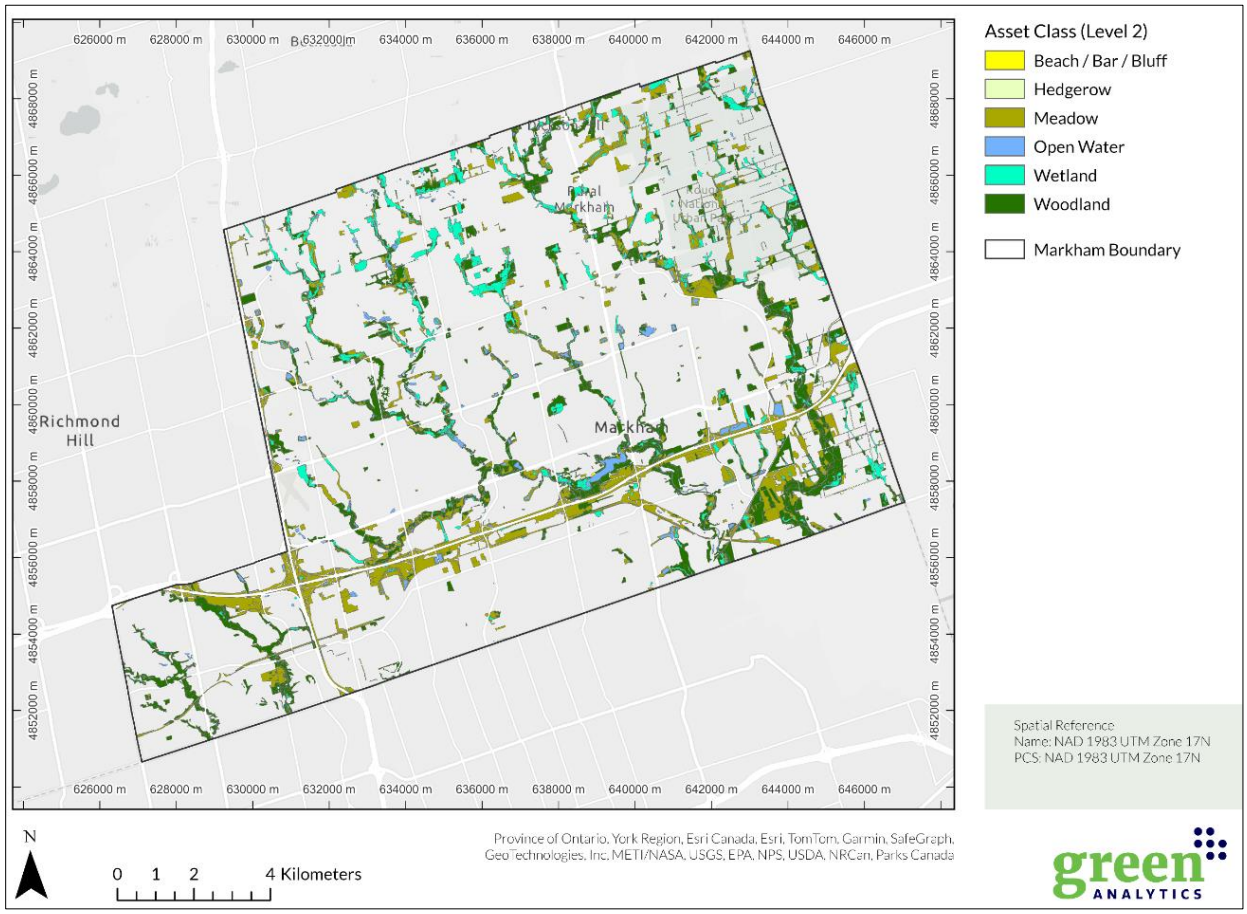


Figure 6: Map of the natural assets in the City of Markham at Level 2 [5] (Credit: Green Analytics)

Recent natural heritage work completed for the City [31, 32] found that:

- There has been a slight increase in natural asset cover since 1991, mainly due to reforestation, and overall levels of plant and wildlife species biodiversity have not changed much, although there are more areas impacted by invasive species and dominated by Black Walnut
- Natural assets in Markham are largely centred around watercourses
- There are some high-quality natural assets that are persisting, with the Little Rouge River and the Rouge River corridors are the most significant from an ecological perspective and a few other areas with concentrations of ecologically significant features and/or species, and
- There are also many natural areas that have already been and/or are being degraded (e.g., by encroachments and invasive species).

Recent and preliminary desktop condition assessments rated about 20% of City-owned assets in "very good" condition, about 55% in "good" condition, and the remaining 25% in "fair" or "poor" condition. This assessment can help the City prioritize its management efforts.

Milne Dam Conservation Area
(Credit: City of Markham)

4.1 Beyond Natural Assets

Although not the focus of this Guide, it is worth noting that Markham contains fairly extensive areas of enhanced green assets and agricultural lands which both also provide some ecosystem services that are generally complementary to those provided by natural assets.

Markham contains a range of enhanced green assets (such as naturalized storm water management facilities and passive open spaces with manicured lawns) which provide open greenspaces and support attenuation and infiltration of precipitation. This includes over 400 hectares of City-owned golf course lands and naturalized stormwater management ponds throughout the city, as well as some bioswales and infiltration trenches.

The City of Markham is somewhat unique for a largely urban area in that it also has over 5,400 hectares of land in agricultural production, with over two thirds of these lands within the Rouge National Urban Park, Greenbelt and/or Greenway System and currently protected from urban development. While these lands are not considered natural *per se*, they are generally considered complementary to natural assets insofar as they are vegetated for most of the growing season and allow for infiltration, soil retention and movement of wildlife through the landscape. Agricultural lands also sequester carbon, an ecosystem service that can be enhanced where appropriate if the lands are managed using sustainable practices such as planting cover crops and reducing or eliminating tillage [(33)].

5 Ecosystem Services Provided by Markham's Natural Assets

Natural assets are basically natural areas that provide recognized and valued ecosystem services, and that are maintained and managed to be able to continue to provide these services. Markham's natural assets are conservatively estimated to provide between $114 and $120 million of ecosystem services each year (see Figure 1), including services needed to sustain human life and community well-being.

Figure 7 illustrates the relationship between a natural asset, an ecosystem function and and an ecosystem service provided by that asset. An overview of the ecosystem functions and related municipal services provided by the natural assets that occur in Markham is presented in Table 1.

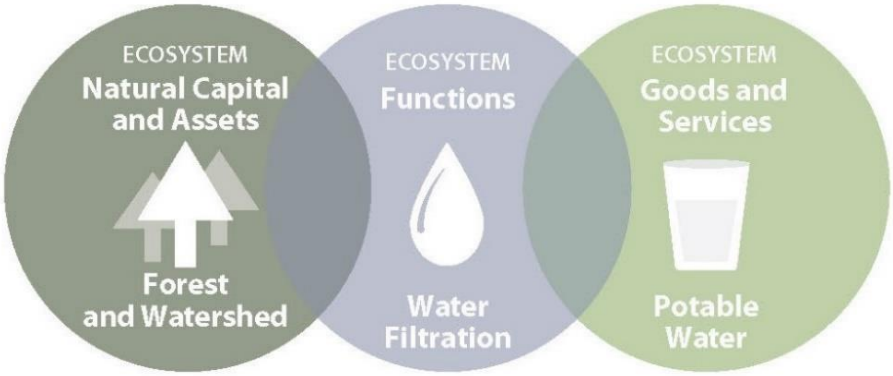


Figure 7: The relationship between natural assets and ecosystem services
(Credit: Natural Assets Initiative [34])

Table 1: Overview of ecosystem functions and related municipal services provided by Markham's natural assets**

Ecosystem Function	Related Municipal Services
Water quantity (including storm water) management	• flood protection and risk reduction to property and human life • protection of drinking water (through groundwater recharge)
Maintenance of soil quality and erosion management	• protection of drinking water • risk reduction to property and human life • protection of recreational fisheries • provision of safe recreational areas, including bank erosion control
Water quality management	• protection of drinking water • improving recreational value of waters (e.g., for swimming, fishing)
Air quality management (e.g., attenuation of airborne particulates)	• reducing energy loads for summer cooling • contribution to public health (e.g., reduction in asthma, providing carbon sinks which contributes to mitigation of greenhouse gases)
Climate regulation (e.g., cooling)	• contribution to public health (e.g., reduction in heat stress) • adaptation and mitigation of climate change
Support of natural vegetation and wildlife	• contribution to local food systems (e.g., pollination for food crops) • contribution to public health (e.g., stress reduction) • contribution to recreation and tourism (e.g., bird watching) • property value appreciation

** Adapted from "Life Cycle Costing of Restoration and Environmental Management Actions: Costing Natural Assets in Peel Region" [35]

Natural assets, by virtue of providing the ecosystem services listed in Table 1 can, for example:

- Reduce the burden on related grey infrastructure (e.g., air conditioning in public buildings, sizing of new stormwater management facilities) and thereby extend their useful life
- Contribute to community climate change adaptation and mitigation support by providing carbon sinks while also helping to regulate air quality and providing opportunities to recreate in nature
- Support the production of certain crops by sustaining pollinators, and
- Help sustain Markham's community health and overall quality of life by providing opportunities to view, enjoy and recreate in nature.

The following sub-sections provide examples of some of the documented services and benefits provided by the different natural asset types that occur in Markham along with selected case studies illustrating how these natural asset services and benefits have been leveraged in Markham and in other jurisdictions.

Forest in the City of Markham
(Credit: City of Markham Official Plan)

5.1 Woodlands and the Urban Forest

Markham's **urban forest** includes all trees across the city and the soils that support them. This includes trees within and outside of wooded natural areas, and trees on all lands irrespective of ownership.

Although wooded natural areas are the focus of this Guide, it is important to recognize that Markham also contains many trees outside of its natural areas (e.g., in manicured parks and lawns, along streets) on both public and private lands that comprise what is called the urban forest.

Woodlands and trees in urban areas can play a critical role in water and carbon cycles and contribute to climate change mitigation and adaptation while also providing important economic, cultural, and health benefits [36]. In woodlands, complex interactions between a diversity of plants, wildlife and other organisms such as insects and fungi allow woodlands to adapt to a continuously changing environment, recover from disturbances, maintain ecosystem functions and habitats, and provide ecosystem services and an array of co-benefits [37, 38].

A healthy woodland can:

- Benefit human health by filtering air, moderating extreme heat (with shade and the cooling effects of transpiration), and providing opportunities to recreate in nature which, together, can reduce cardiovascular disease, respiratory issues and diabetes while also improving mental health [10, 11, 36]
- Mitigate climate change through carbon sequestration and long-term carbon storage in soil, roots, branches and trunks [38]
- Stabilize river/stream banks and help manage slope erosion [38], and
- Act as living filters preventing excess nutrient and chemical runoff from roads, parking lots, lawns, golf courses and farmed fields reaching streams, rivers and lakes [39].

While not as ecologically complex or diverse as woodlands, hedgerows can also provide ecosystem service contributions in rural and urbanizing jurisdictions. Hedgerows are strips of densely planted trees or shrubs, or sometimes remnants of woodlands cleared for agriculture left to provide wind breaks. In the City of Markham, there are many hedgerows associated with the remaining agricultural lands that account for 71 hectares of land. In Ontario's Greenbelt, hedgerows provide pollination services valued at $1,108 per hectare [40] which if extrapolated to Markham would be valued at about $80,000 for that service alone.

Toronto and Region Conservation Authority recently completed an assessment of Markham's urban forest [41]. This study found that Markham's urban forest contains about 3.29 million trees which are estimated to provide the following services which are conservatively valued at about $8 million per year plus over $50 million in long term carbon storage.

- Carbon sequestration of 8,693 tonnes per year valued at $1.6 million
- Carbon storage of 265,348 tonnes valued at $50.1 million
- Air filtration by removing 147.1 tonnes of pollutants per year valued at $2.7 million
- Air temperature moderation, reducing the demand for seasonal heating and air conditioning, resulting in savings of about $1.89 million annually, and
- Water quantity management, attenuating about 742 million litres of water, a service valued at $1.7 million annually.

Both woodlands and trees outside of natural areas can contribute to water quantity and quality management [36]. However, the extent and value of these services in helping to manage stormwater varies greatly depending on the location and extent of the woodland/treed cover, as well as the extent of built up (or impervious) surfaces, among other factors [30, 42, 43, 44].

In Markham, as can be seen in Figure 6, wooded natural areas are not extensive (i.e., about 1700 hectares or 8% of the land cover in the city [5]) and tend to be focused along the margins of creek and river corridors that run through the city. In addition, these wooded corridors largely occur in extensively built-up landscapes (particularly in the southern and western portions of the city), where the extent of impervious surfaces (e.g., roads, driveways, sidewalks, rooftops, etc.) reduces opportunities for infiltration and increases the amount and intensity of runoff when storms occur [44, 45]. Consequently, the ability of the current woodlands and trees in Markham to significantly help manage flooding is generally limited to, for example, intercepting the first few millimetres of rain [46].

Despite these challenges and limitations, opportunities to enhance stormwater management capacity with combinations of natural and/or enhanced green assets to complement grey infrastructure solutions continue to be explored in Markham on a case-by-case basis [47].

Case Study: York Region Natural Infrastructure Project

In 2019, Infrastructure Canada approved funding to York Region for a natural infrastructure project through the Disaster Mitigation and Adaptation Fund. The goal of this project is to mitigate the impacts of extreme heat, flooding, and erosion in the Region by planting 186,000 trees and shrubs in urban areas, planting 12,500 street trees, designing and constructing 35 km of soil trenches for trees along regional roads in urban areas, creating 100 hectares of woodland by planting 203,500 seedlings, and conducting 10 assisted migration tree species trials.

The project is expected to help protect over 1.2 million residents in the region and provide long-term savings of $23.61 for every $1 invested in avoided recovery and replacement costs following an extreme weather event.

Street tree planting in a rural part of York Region
(Credit: York Region)

5.2 Wetlands

Wetlands are incredibly diverse ecosystems of high value both ecologically and economically. The City of Markham's wetland cover over 630 hectares (3% of the land over in the city) and include the following wetland types: coniferous, deciduous and mixed swamps and thickets (which are wooded wetlands); marshes; and a few treed fens (which are a rare habitat type in southern Ontario).

Both natural and constructed wetland ecosystems, even if they are small, can:

- Help slow the flow of water, preventing soil loss and erosion [40]
- Help regulate water supplies by retaining and gradually releasing water [42]
- Support and enhance local biodiversity [48],and
- Act as living filters, providing a natural water quality treatment [42, 49, 50, 51].

These ecosystem services tend to be more substantial when the wetlands are located in the headwaters or upstream of the receiving waters of interest [49, 50, 51]. In Markham, as shown in Figure 6, many of the wetlands are in the headwater areas of the different streams/rivers and are therefore expected to provide the services above within the city. However, given the limited size and the location of many of these wetlands within floodplains, their ability to retain significant amounts of runoff during storm events (and mitigate flood risk) is limited.

In southern Ontario, wetlands save $4.2 billion annually by filtering and diverting sediments and nutrients from stormwater management facilities while helping to prevent toxic algae blooms in lakes and rivers [49]. Markham could enhance its share of these wetland-related services by investing in wetland creation, particularly in headwater areas and both within and outside of floodplains, as opportunities arise.

Example: The Power of Small Wetlands

Phosphorous deposits into Lake Erie, in combination with warming temperatures, have resulted in increasingly severe toxic algae blooms that have significant social and economic impacts on surrounding communities. Increasing phosphorus deposits can be exacerbated by climate change as shifting precipitation patterns are increasing agricultural and urban runoff.

Ducks Unlimited Canada (DUC) and associated conservation partners conducted the "Determining the Nutrient Retention Capacity of Newly Restored Small Wetlands in Southwestern Ontario" project from 2017 to 2019 [50]. The project consisted of constructing 75 new wetlands and 17 wetland restoration projects in the Lake Erie watershed, followed by a monitoring program.

The monitoring program revealed that these wetlands act as phosphorus sinks with the average wetland retaining 11.7 kilograms of phosphorus per hectare and releasing only a fraction of that over time. The results of this project indicate that wetland creation can be an effective strategy for reducing nutrient pollution in receiving waterbodies.

Creek in the City of Markham
(Credit: City of Markham)

5.3 Meadows

In Markham, meadows as a natural asset type includes two sub-asset types.

- Cultural meadow, which has little tree or shrub cover and is dominated by non-native plant species. In Markham this sub-asset type is widespread and occurs on nearly 1500 hectares of former agricultural crop lands that have been abandoned and have naturalized.
- Open tallgrass prairie, which has little tree or shrub cover and is dominated by prairie grasses (such as Big Bluestem) which are considered native and rare in Ontario. In Markham this sub-asset type occurs on less than half a hectare that has been created and is maintained by the City.

Notably, although cultural meadows are much more common in Ontario than native grasslands, a decline in the their abundance over the past decade has been documented in the Greater Toronto Area [52].

These meadows (which are almost entirely old fields) represent 7% of the land cover in Markham and are a natural asset type known to be able to:

- Store water to help sustain watercourses during droughts
- Filter nutrients and other contaminants that may pollute water supplies
- Sequester carbon, particularly in their roots and soils
- Provide pollination services
- Provide aesthetic and nature appreciation value, and
- Support recreational activities that promote human health and well-being [40, 52, 53, 54, 55].

A recent case study in southern Ontario found that old field and grassland natural assets provided between $2,448 and $3,934 in ecosystem services per hectare per year (in 2022 $CAD) (see below) [54].

Case Study: Economic Valuation of Natural Assets in Halton Region – Focus on Meadows

A recent case study of natural assets for Halton Region, Ontario pulled together valuations for all natural asset types from the current and applicable literature, including for grasslands and old fields [54]. This study found the following mean values (in 2022 $CAD).

Ecosystem Service	Old Fields	Grasslands
Contribute to air quality control	no value provided	$22 per hectare
Carbon sequestration and storage	$486 per hectare	$656 per hectare
Erosion control and water regulation	$16 per hectare	$71 per hectare
Pollination	$1,558 per hectare	$802 per hectare
Aesthetic/cultural value	$194 per hectare	$1,910 per hectare
Recreational/spiritual value	$194 per hectare	$473 per hectare
Totals	**$2,448 per hectare**	**$3,934 per hectare**

Meadow in the City of Markham
(Credit: City of Markham Official Plan)

5.4 Open Water

In this Guide "open water" includes watercourses (e.g., creeks, streams and rivers) and bodies of water that are generally deeper than two (2) metres in Markham (i.e., lakes and ponds, not wetlands) (e.g., Swan Lake).

The City of Markham has nineteen watercourses, including some that feed into the Rouge River [56]. Many of these watercourses are flanked by natural or naturalized strips of land that support habitat for local plants and wildlife while also contributing to the health of the watercourse. These watercourses provide a number of ecosystem services including: water purification, nutrient cycling, flood control, water supply, biodiversity, and carbon sequestration [57].

Naturally occurring and created open water bodies can also be diverse and productive ecosystems that offer a range of ecosystem services including: outdoor recreation (e.g., boating, fishing, swimming), nutrient cycling, carbon sequestration, and water quality and quantity control [54, 58]. The three largest open water areas in Markham (other than watercourses) are Toogood Pond and Milne Dam Park (which were created by damming a river) and Swan Lake (which is a former quarry).

Case Study: Economic Valuation of Natural Assets in Halton Region – Focus on Open Water

A recent compilation of natural asset valuations for Halton Region, Ontario found open water features provided ecosystem services of over $56,000 per hectare per year (in 2022 $CAD) based largely on their water purification/filtration and recreational services [54]. Extrapolating this value results in a City-wide estimate of almost $11 million per year for open water bodies in Markham, excluding watercourses.

Toogood Pond in the City of Markham
(Credit: City of Markham)

5.5 Beach Bars and Open Bluffs

Beaches and open bluffs tend to be habitats found on fairly unstable substrates (like sand) and found in highly dynamic environments constantly changing as a result of waves, winds, storms, tides, and other processes [60,61]. In Markham, small areas of both beach bar and bluff (2 hectares in total) occur on or near steep slopes that have formed along the Rouge River corridor within the Rouge National Urban Park.

Beaches provide multiple recreational and cultural services and can also filter large volumes of water, provide nutrient recycling, and support sediment storage and transport [40, 54, 60]. A recent case study in southern Ontario estimated that beach bar and open bluff natural assets could provide over $51,000 in ecosystem services per hectare per year (in 2022 $CAD) when considering recreational value ($49,816 per hectare) and aesthetic/inspirational value ($1,316 per hectare) alone [54].

6 Vulnerabilities of Markham's Natural Assets

Many natural assets in Markham are currently fragmented and subject to a range of impacts associated with being in an urban environment. The recent risk assessment completed for Markham's natural assets identified invasive plants as the top risk to the condition of these assets followed by forest pests/diseases, contaminated run-off or spills into wetlands, ponds and watercourses as the next largest threats. Erosion and sedimentation, extreme wind and ice storms, and drought were also identified as fairly high risks [5]. [31, 32]. Climate change has already begun to, and is expected to continue to, add to and/or exacerbate many of these impacts.

While there remains uncertainty both about how and how fast the climate will shift, and about how different natural assets in different parts of the country and the province will respond, it is certain that climate change is happening and is here to stay for awhile [16, 17, 20, 22]. There may be some shifts associated with climate change that impact some natural assets positively (e.g., extended growing seasons, as shown in Figure 1). However, it is predicted that, on the whole, the impacts will not be beneficial, thereby increasing the risk of natural assets not being able to provide the same range and/or levels of ecosystem services (as described in Section 5) [1, 62].

Key risks and/or impacts to natural assets in urban areas anticipated to be exacerbated by climate change documented in the literature and considered applicable to Markham are summarized in Table 2.

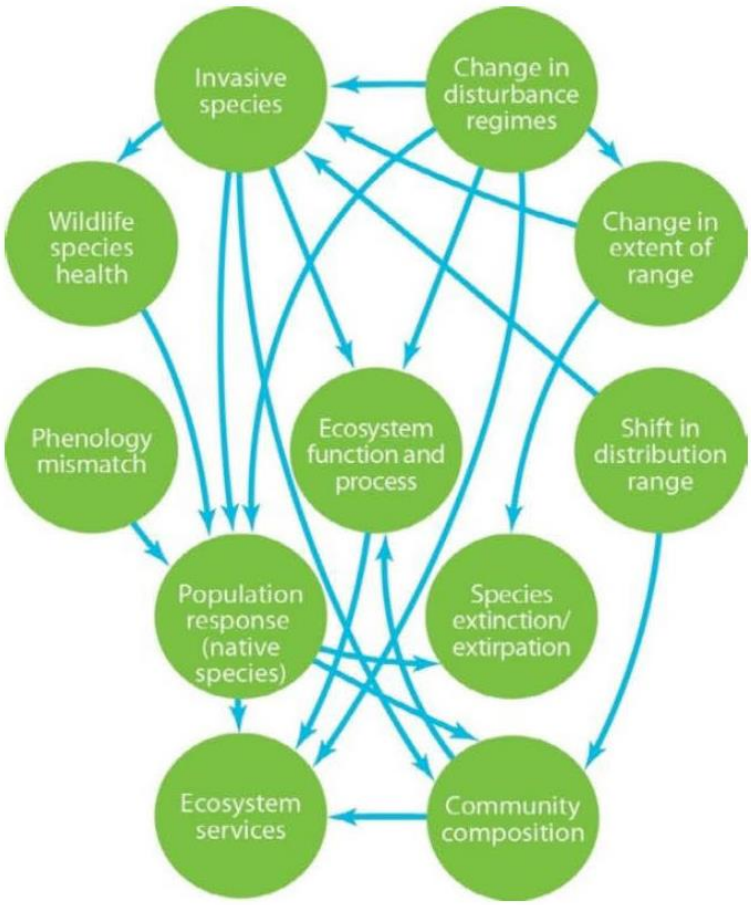


Figure 8: Illustration of the complex interactions among documented or projected responses of species and ecosystem processes to climate change
(Source: Ontario Centre for Climate Impacts and Adaptation Resources [72])

Table 2: Examples of anticipated impacts of climate change on Markham's natural assets by asset type*.
Note: Positive impacts are shown in "O", negative impacts are shown "X".

Impact	Woodlands	Wetlands	Open Water**	Meadows
INVASIVE SPECIES: Warmer winters allowing for the expansion of existing invasive species, pests, pathogens, and diseases northward and the migration of new invasive species [1, 63, 64, 65]	X	X	X	X
CHANGE IN EXTENT OF RANGE: Increased susceptibility to pests/pathogens and greater risk of mortality among species, particularly those at their range limits [1, 66, 67, 74]	X	X	X	X
PRODUCTIVITY: A warmer climate with sufficient precipitation and nutrients increasing plant productivity [1, 63, 65, 66]	O	O	O	O
PHENOLOGY MISMATCH: Altered timing of important life cycle events for some species, affecting seasonally-dependent species relationships and potentially affecting reproductive success [1, 66, 67, 68, 69]	X	X	X	X
CHANGE IN DISTURBANCE REGIMES: More frequent and severe droughts increasing mortality and wildfire risk in woodlands and meadows, and loss of wetlands and water bodies [64, 66, 70, 71]	X	X	X	X
CHANGE IN DISTURBANCE REGIMES: More frequent storm events (e.g., wind and ice storms) damaging woodlands [69, 70]	X			
CHANGE IN DISTURBANCE REGIMES: Variable and unpredictable water levels affecting suitable species' habitat [66, 71, 74]	X	X	X	X
PHENOLOGY MISMATCH: More variable winter temperatures and altered timing of temperature shifts contributing to increased risk of freezing damage following breaking dormancy [66, 71, 74]	X			X
PRODUCTIVITY: Increased winter flows, under-ice habitat, oxygen availability, and year-round flow improving the winter survival rates of some species [71, 73]			O	
PHENOLOGY MISMATCH: Mismatch in the timing of bee emergence and floral resource availability in the spring (resulting in decreased pollination services) [1, 66]	X	X		X

* These anticipated impacts have generally been identified in a context as envisioned under climate change scenario RCP8.5 and to the 2050's, as described in Section 3.

** "Open water" includes watercourses (e.g., creeks, streams and rivers) and bodies of water that are generally deeper than two (2) metres (i.e., lakes and ponds, not wetlands).

7 Strategies for Maintaining and Enhancing Natural Asset Service Provision in Markham in a Climate Change Context

Natural assets in urban areas tend to be subject to urban stressors which are further exacerbated by climate change stressors (as described in Section 6). However, there are many relatively simple strategies that can help natural assets, and the community of Markham, become more resilient to these stressors.

Key opportunities for building natural asset resilience to climate change in Markham are discussed in the following sub-sections along with supporting actions, illustrative examples and selected case studies.

- Building community awareness (Section 7.1)
- Engaging Indigenous communities (Section 7.2)
- Maintaining local hydrology (Section 7.3)
- Maintaining and improving soil health (Section 7.4)
- Maintaining and improving plant diversity (Section 7.5)
- Undertaking targeted asset management, including invasive species control (Section 7.6)
- Creating new natural assets (Section 7.7)
- Proactively managing the urban forest (Section 7.8), and
- Prioritizing equity when investing in natural assets (Section 7.9).

Ontario Provincial Climate Change Impact Assessment (2023)

"Climate change is one of the greatest challenges of our time… Avoiding or reducing the worst impacts of human-induced climate change requires action on parallel fronts: … [including] planned measures to adapt to current and imminent future changes."

"Several adaptation measures can help to build resiliency and reduce risk to Ontario's complex infrastructure systems… Specific adaptation actions can include … valuing and protecting natural assets such as wetlands".

7.1 Building Community Awareness

Broad community awareness and engagement on the topics of natural assets and climate change is key to ensuring sustained tax-based support for investing in natural asset projects and to ensuring their successful implementation [75, 76, 77].

The City's primary focus has been, and is expected to continue to be, on natural asset maintenance and enhancement on public lands. However, the success of these efforts will depend in part on the stewardship of those who access these areas, as well as how other nearby natural assets owned by others are managed. Therefore, it is critical for the community to understand how investing in the maintenance and enhancement of natural assets is one of the simplest and most cost-effective strategies for helping the community adapt to climate change while also providing other valuable ecosystem services (as outlined in Figure 1 and Section 5).

There are many approaches and tools for effective community engagement. Key examples include: strategic use of municipal websites and social media, developing and implementing marketing campaigns, providing opportunities for hands-on involvement, and incentivizing community members and partners to become natural asset stewards.

Some of the important messages to include in community outreach in support of natural assets and climate change adaptation include highlighting human health benefits and social equity objectives that can be achieved by bringing and keeping nature in the city.

Those engaged should be made aware of the key challenges and opportunities related to natural assets (as outlined in Sections 5 and 6), and be empowered to become natural asset stewards on their own lands and/or in support of others on their lands. For communication to be effective, it should be accessible to the target audience(s) and include clear messages and specific calls to action [75, 76, 77]. Communication and awareness can be increased with various activities using the following channels:

- **Online media**: Websites, publication of information on other parties' websites/social media, including newspapers, use of images from previous events, tours, and campaigns, social media channels, newsletters, videos, and seminars
- **"Print" media**: News releases, factsheets, posters, signs at natural asset locations, annual reports, and surveys, and
- **Participatory events**: Guided tours and experiences with natural assets, workshops and focus groups, public meetings and round tables, citizen advisory committees, conferences, seminars, and programming in local schools.

Example: Natural Places Shared Spaces Campaign, Markham, ON

In 2016, Council proclaimed Markham as Canada's First Monarch Friendly City to raise awareness about the decline of the monarch butterfly and the species' need for habitat [78]. This proclamation included commitments to launch a public communications campaign to encourage citizens and community groups to plant monarch and pollinator-friendly gardens (i.e., native milkweeds and nectar-producing plants), and for City staff to continue to identify opportunities for monarch and pollinator-friendly gardens on their lands (like the demonstration garden at City Hall).

Natural spaces sign developed and installed by the City of Markham
(Credit: City of Markham)

7.2 Engaging Indigenous Communities

Natural asset work provides a unique opportunity to learn from and collaborate with local First Nations and other Indigenous organizations, as has been shown in some other jurisdictions [79].

Examples of opportunities that may be appropriate in Markham include:

- Incorporating Indigenous traditional knowledge into conservation planning and sustainable design practices can help reduce risks and prepare for an uncertain future
- Recognizing Indigenous Protected and Conserved Areas (IPCAs) - a direction which as been gaining traction in some parts of Canada [80, 81] but has been slow to advance in Ontario [82]
- Retaining and/or collaborating with Indigenous-led organizations on the design and implementation of natural asset projects and/or stewardship of existing natural assets as a basis for learning and relationship-building while working to build resilience to climate change [83], and
- Engaging with Indigenous communities and organizations on urban forestry initiatives and including information sharing about native trees from an ecological and cultural perspective.

Group photo from an Indigenous-led urban forest project in Ontario
(Credit: Trees Canada)

7.3 Maintaining Local Hydrology

All of Markham's existing natural assets – from its upland woodlands and meadows to its lowland wetlands, beach bars and watercourse banks/floodplains – are adapted to the current hydrologic dynamics in their respective watersheds and subwatersheds. This includes both landscape scale drainage patterns and more area-specific surface water inputs (e.g., both precipitation and runoff). Natural assets, as a whole, have evolved to tolerate a certain range of hydrologic conditions over the course of a given year and from year to year. However, there are limits to these ranges that once surpassed result in the natural asset becoming severely degraded or no longer functioning.

Given that many of Markham's natural assets are already subject to stressors associated with urbanization and are expected to be additionally stressed with climate change (as outlined in Section 6), a good strategy for sustaining existing assets is to try and ensure that their current hydrologic dynamics are generally maintained. Similarly, in the case of natural asset creation, it is generally a good strategy to work with the existing topography, soils and drainage - and to design and install an asset suited to them. This approach helps position natural assets to be able to survive and adapt as climactic conditions shift [45, 48].

Examples of strategies to maintain local hydrologic dynamics for both existing and created natural assets considered appropriate in the context of Markham are outlined below, although the specific applicability of each will vary depending on the site-specific biophysical and land use context, as well as the opportunities identified in relation to a given project.

- Use watersheds and subwatersheds as the units for assessing and prioritizing natural asset protection and restoration efforts
- Protect and prioritize natural asset restoration and creation in headwater areas [43]
- Protect existing wetlands and prioritize online and off-line wetland restoration and creation in floodplains [48]
- Protect and prioritize riparian bank restoration within watercourse corridors and valleylands [48], and
- For development and/or changes in land uses adjacent to protected natural assets:
    - Require feature-based water balances, and best efforts to match pre-development levels, and
    - Encourage and support the integration of low impact development features/measures (such as constructed wetlands, naturalized stormwater ponds, rain gardens, bioswales and vegetated infiltration trenches) as complements to required grey water management infrastructure [45, 48].

7.4 Maintaining and Improving Soil Health

Soils provide critical ecosystem services such as nutrient cycling, organic matter decomposition, and plant performance. In Markham (and elsewhere) human disturbances and modification of natural assets have affected soil biodiversity or resulted in loss of soils altogether. Climate change is expected to further stress extant soils (e.g., through extended periods of drought, more variable freeze-thaw cycles) [1].

Some examples of strategies to improve both the quantity and quality of soils in relation to natural assets as part of the development process include:

- Preserving natural soils *in situ* where possible, where they cannot be preserved *in situ* – salvaging and re-using them (e,g., for natural asset creation on another site nearby) [84]
- Implementing measures to keep all construction and related works outside of protected natural assets before, during and following construction [24, 84]
- Reducing or eliminating permanently covered/paved soil surfaces by using a combination of low impact development measures (such as permeable pavement, infiltration trenches, bioswales) [24]
- Protecting and maintaining the habitats of diverse soil biotas, and
- Keeping soils covered with living plants and/or residue [15].

Case Study: Improving Soil Health in Downsview Park's Urban Forest

Since before its official designation as a park, Downsview Park located in North York has undertaken a range of sustainability projects to enhance its young urban forest. In 2005 old roads, curbs, parking lots, and underground utilities were removed to prepare to churn the soil which at the time was clay based and heavily compacted. The churning made the soil porous allowing for air and water exchange and soil nurturing in advance of extensive tree plantings.

Two decades later, the urban forest in Downsview is a thriving habitat for wildlife that also helps prevent soil erosion and supports local soil moisture retention.

For natural asset restoration and creation projects "soil friendly" strategies include (adapted from [24]:

- Ensuring adequate soil volumes for rooting in the short and longer term
- Preventing or limiting excessive soil compaction, salt accumulation or other contaminants (before, during and following installation)
- Preventing or limiting below-ground conflicts with planted materials, and
- Provide mechanisms for passive surface water infiltration and drainage.

7.5 Maintaining and Improving Plant Diversity

The changing climate (see Section 3) is expected to make conditions less suitable for some plant and wildlife species that currently occur in Markham, and more suitable for others that currently occur in climactic zones to the south of Markham. The responses of different species to these changing conditions are not well understood [74], therefore maintaining existing plant diversity and enhancing it to include some species from slightly more southern climactic zones is considered an appropriate strategy for building resilience in the face of this uncertainty [16, 24, 66, 74].

Natural asset "diversity" can refer to different things, including structural, species and functional diversity. All are important for building resilience in the face of climate change. In addition, restoration efforts should also be based on principles that "nature knows best" and generally seek to align with existing reference habitats known within the region [85]. Markham is fortunate to have the Rouge National Urban Park within its boundaries - an area that contains many examples of natural assets in good ecological condition that provide excellent references in terms of diversity [86]. Notably, natural asset diversification should be undertaken with input from professionals with knowledge of different habitat types found in Markham and their sensitivities, as well as an understanding of how climate may change over time.

Some examples of natural asset plant diversification strategies considered appropriate for Markham are:

- Work to enhance structural, species and genetic diversity across the city's Greenway System
- Consider diversification at multiple scales (e.g., site-specific, sub-watershed, city-wide)
- Manage predominantly monoculture habitats to promote species diversification and succession (e.g., red pine plantations managed to be mixed forests with diverse species in all levels)
- Include a small proportion of non-invasive species and/or nursery stock whose ranges are just south of Markham, and
- Exclude plant species that currently occur in the region and are known to be invasive, as well as species from further south that are potently invasive in Markham and/or associated with serious pests/pathogens.

At the site-specific scale, approaches for sustaining and increasing plant diversity in Markham (adapted from [24]) in a context of climate change include:

- Incorporate "mini" woodland communities in the urban area where opportunities exist
- Plant a mix of species suited to the existing conditions but also include species with tolerances of the anticipated climate conditions
- Plant a higher diversity of species where there is a more extensive and/or well-connected natural heritage network and growing conditions are less stressful (e.g., parks, rural areas), and
- Try to maintain appropriate hydrologic conditions and provide adequate soils.

Monitoring ongoing species and natural asset diversification efforts is also an important component which also applies to many of the other strategies being suggested. Tracking and assessing what is working (and what is not) allows the City to assess its progress towards established natural asset and natural heritage goals, while also allowing for approaches to be refined or changes in response to lessons learned. High-level summaries of progress being made can also be used to help educate and engage the community, partners and decision-makers.

7.6 Undertaking Targeted Invasive Plant Species Management

Markham Forest Study 2022: Technical Report

Invasive plants, pests and diseases pose a threat to the health of the forest, and their spread is expected to be exacerbated by climate change… Out of the 202 plots surveyed, 43 percent of plots had at least one invasive plant species present.

Recommendation 28: Develop a monitoring and action strategy for invasive species…

Invasive plant species are one of the biggest threats facing Markham's natural assets [31, 32] and climate change is both facilitating the range expansion of existing invasive species, and the introduction of new invasive species migrating northwards. While some invasive species' impacts on natural features and areas are relatively easy to contain, other invasive species can have devastating impacts. It is very difficult, if not impossible, to eradicate most invasive species once established. However, it is possible to undertake sustained and targeted work to limit the spread of the most damaging invasive plant species, and to replace them with an appropriate diversity of non-invasive plant species.

The City of Markham identified the top invasive plants, pests, and diseases at a City-wide scale in its 2022 Forest Study [41]. The City is also committed to assessing its forest pest risks more closely through the Urban Forest Management Plan (which was in progress when this Guide was being finalized).

Measures that can be taken to help manage invasive plant species in Markham's natural assets in a context of climate change include:

- Developing and implementing a strategic invasive species management plan, including identifying priority areas for invasive species management based on an invasive species inventory and updating these priorities as conditions evolve
- Hiring/retaining an invasive species specialist
- Continuing to work with the local conservation authority to undertake targeted invasive plant management, including restoration of areas with appropriate non-invasive plant communities
- Educating the community and municipal staff about invasive species identification and best management practices on private lands
- Embracing volunteer management support on public lands, where safe and feasible
- Working with other levels of governments and businesses to minimize the sale of invasive plant species, and
- Developing new or updating existing by-laws to prevent landowners from planting and/or spreading highly invasive species.

Case Study: Mississauga's Invasive Species Management Plan & Implementation Strategy

In 2021, the City of Mississauga developed a comprehensive Invasive Species Management Plan & Implementation Strategy to address the widespread presence of invasive species and the risks these species pose to the City's Natural Heritage System and the urban forest.

The Plan includes targets and timelines, considers resource allocations, identifies opportunities to engage others, and recommends a communication strategy, all of which are important components of a successful invasive species management plan. The Plan also identifies plant and insect invasive species of concern, provides targeted and specific management tactics, and includes criteria for management activities and a monitoring methodology.

7.7 Creating New Natural Assets

In an urban and a climate change context where natural assets are already fragmented and subject to a wide range of stressors (see Sections 4 and 6), one way to build resilience and enhance the provision of ecosystem services is to restore gaps in the natural heritage network and create new natural areas where opportunities exist. For example:

- Markham's Greenway System [87] includes some natural heritage restoration areas and core area enhancements that could be prioritized, and
- Toronto and Region Conservation Authority 's Updated Target Natural Heritage System (2022) [88]. identifies areas that have high potential for supporting ecosystem functions.

However, it is important to recognize that not all natural asset types can be re-created, and that even natural asset types that can be created require careful planning, site preparation, species selection, installation and post-installation monitoring and management by qualified professionals.

Important considerations for the restoration and creation of new natural as assets [85] include:

- Engage with potential partners including local First Nations and Indigenous communities
- Draw on many types of knowledge, including traditional knowledge, ecology, engineering, hydrology, hydrogeology, and others as appropriate
- Be guided by native and/or intact reference ecosystems in the area
- Work to enable appropriate and applicable ecosystem recovery processes
- Establish clear and specific goals and objectives, with measurable indicators, and
- View each restoration project as part of a continuum within the broader natural heritage system.

Case Study: Don Mills Channel Naturalization and Restoration, Markham, ON

Between 2020 and 2025 the City of Markham will be working with various partners to transform an industrial area into green space to prevent flood damage [89]. In 2019 the Federal government allocated $48.6 million to restore and naturalize a segment of the Don Mills Channel near Woodbine Avenue and Denison Street and an area of about two hectares so that it serves as a natural floodplain.

This project is located in a built-up part of the city that is very vulnerable to flooding. Underground culverts downstream of the floodplain will also need to be replaced as part of this work. The storage is expected to help keep flood water levels 1.5 metres lower on average than they have reached in the past.

Artists' rendering and aerial view of the Don Mills Channel project (Credit: CBC News)

7.8 Proactive Management of the Urban Forest

Protecting and enhancing Markham's urban forest will improve its long-term ability to enhance the City's biodiversity, while also helping the City mitigate and adapt to climate change by contributing to local cooling, cleaner air and cleaner water in the City's creeks, rivers and ponds.

A climate change vulnerability assessment of the urban forest is a key step in understanding the potential climate impacts, associated vulnerability and risks to the system, and what actions can be taken to increase resiliency [90]. Such an assessment was completed as part of the 2022 Markham Forest Study [41]. Some of the recommended actions identified in this study include:

- Developing an Urban Forest Management Plan (which is currently in progress)
- Increasing canopy cover to between 30% and 35% of the municipal land base
- Enhancing tree species diversity, including introducing some species with ranges south of Markham on a limited and trial basis
- Using the Ontario Tree Seed Transfer Policy guidance to determine and plant tree species suitable to the projected changes in climate [91]
- Increasing monitoring of species vulnerable to climate change to assess their condition as climate change continues to accelerate
- Using tools such as the Pest Vulnerability Matrix [92] to ensure pest and disease resiliency and the Sustainable Technology Evaluation Program's Treatment Train Tool [93] to determine the stormwater benefits of planting trees, and
- Using Markham's Trees for Tomorrow Program to educate the public on ecosystem benefits and developing mechanisms to encourage, support, and educate private landowners to protect and enhance their tree canopies and species diversity .

Case Study: Adapting to a Changing Climate - A Report for Southern Region Sustainable Forest License Holders

In 2016, the Forest Gene Conservation Association of Ontario conducted a climate impact assessment on the forests of central Ontario to help forest managers adapt their forests to the changing climate [90]. The assessment involved a species distribution model under potential future climates, concluding that the southern range for species is shrinking quicker than the northern edges are expanding. They found that some species, such as white pine and red maples, may be more resilient, as they are in the middle of their range in Ontario. In contrast, others, such as jack pine and black spruce, may be at risk.

Street tree planting in an urban part of York Region
(Credit: York Region)

7.9 Prioritizing Equity When Investing in Natural Assets

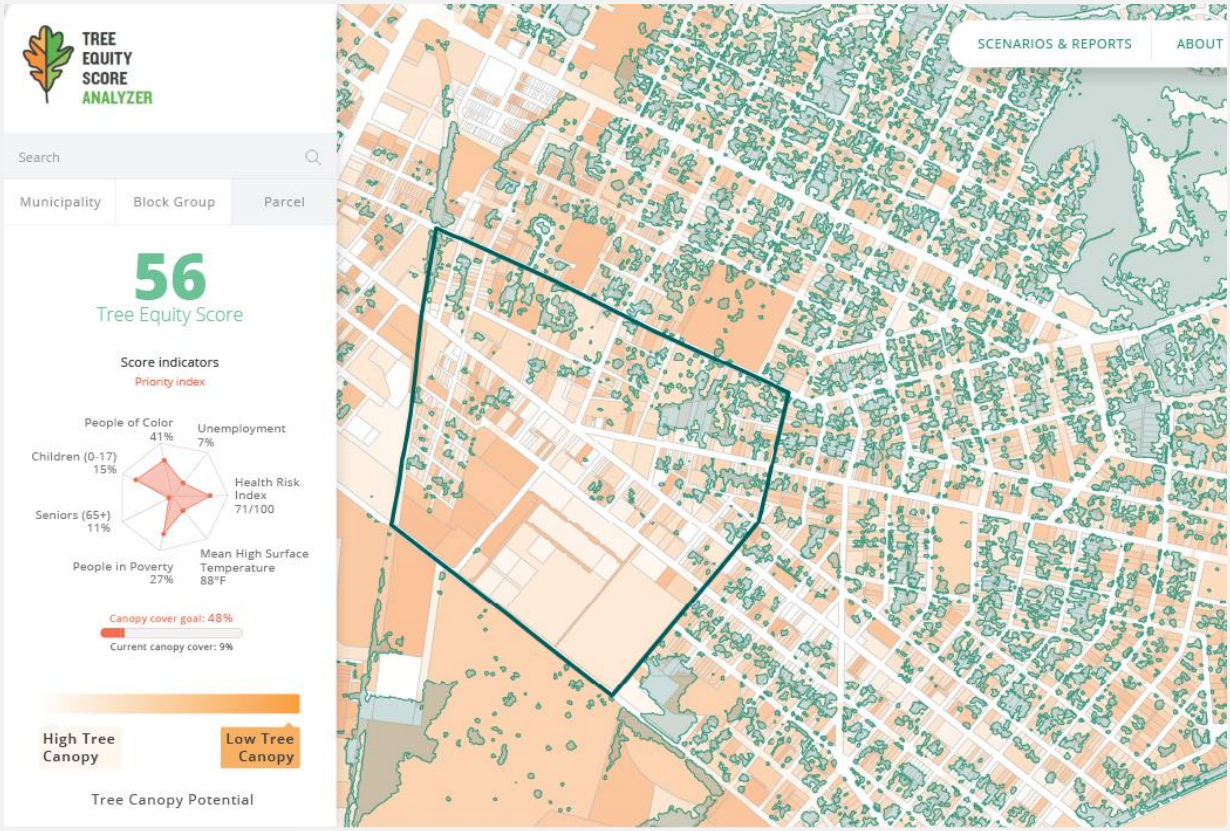
In Markham, as in many urban areas, natural assets are not spread evenly or equitably across the jurisdiction. As a result, neither are the services associated with those natural assets.

Research has shown that the greater availability and quality of greenspaces in urban areas is often (but not always) linked to more affluent neighbourhoods [94, 95], while the positive effects of urban green spaces tend to be more pronounced among lower income groups [96]. Therefore, equity should be a priority consideration when looking to invest in public natural asset restoration and/or creation.

Ideally, locally appropriate strategies and approaches should be developed in collaboration with the community of interest and implemented with their support and assistance. This is recognized as a "win-win" approach that can help address social inequities, while also reducing health risks to those most vulnerable while also providing services to the entire community [97]. Therefore, best practices in Peel should continue to prioritize tree protection and establishment in areas.

Example: City of Toronto Tree Equity Score Analyzer

In 2024, the City of Toronto (in partnership with many others) launched its first Tree Equity Score Analyzer (TESA) [98]. TESA is a map-based application available for free online that allows for the identification of priority or "high need" areas for tree planting and/or woodland restoration. Factors that can be considered include: amount of existing tree canopy, building density, income and employment levels, races and language, surface temperatures, and the relative ages and health of a population in a given neighbourhood.



A sample map from Toronto's Tree Equity Score Analyzer
(Credit: City of Toronto and American Forests)

8 Levers of Change: Plans, Policies and Programs that Enable Nature-based Climate Solutions in Markham

One of the key barriers to advancing the integration of natural assets in municipal planning and management has been the lack of regulatory drivers at the federal or provincial level. This gap was, however, addressed in Ontario with the passing of Ontario Regulation 588/17 (Asset Management Planning for Municipal Infrastructure). O. Reg. 588/17, among other things, requires all municipalities to consider green infrastructure as part of their asset management planning including "natural heritage features and systems".

The City of Markham's approach to its natural features has evolved significantly over the past few decades and has recently started to consider them from an assets perspective. The City undertook its first jurisdiction-wide study of natural features and areas in the 1990's and recently completed a comprehensive update of its natural features mapping and high-level management guidance through its Natural Heritage Inventory and Assessment Study (NHIAS) and Natural Heritage Management Study (NHMS) [31, 32]. The City also has policies in its Official Plan [87] for the protection of significant natural features and areas, and their functions, which date back to the 1980's, which were last updated in 2017, and are due to be reviewed and updated again.

In late 2022, the City initiated their first comprehensive natural assets inventory and evaluation [5]. Policies and guidance in the City of Markham's plans that enable or align with nature-based solutions are summarized in Table 3.

Table 3. Elements in the City of Markham's plans and policies that enable nature-based solutions related primarily to natural assets

Plan/Policy/ Guideline	Component supporting nature-based climate solutions
2019 Asset Management Policy [99]	Policy Statement: "The City of Markham will ensure infrastructure are planned, built and maintained effectively through sound Asset Management principles and practices to meet its strategic goals and deliver services in a socially, economically and **environmentally responsible manner".** Guiding principle E: "The City will make the appropriate decisions and provisions to better enable its assets to meet future challenges, including changing demographics and populations, customer expectations, legislative requirements, technological and **environmental factors".**
2021 Asset Management Plan [100]	Markham's Asset Management Plan includes both Core and Non-Core Infrastructure Assets, including: • Water, wastewater and stormwater assets (Core) • Parks (Non-Core) • Information Technology Infrastructure Hardware (Non-Core). Of the above mentioned assets, the Plan relates **stormwater management ponds** to natural infrastructure With respect to **erosion sites condition assessment**, the City's erosion restoration program has been set up to complete restoration where the movement of the natural drainage system impacts the environment or public health and safety.

Plan/Policy/ Guideline	Component supporting nature-based climate solutions
	Parks in the City's asset inventory have the following service level provisions: • Tree Maintenance is dependent upon a current tree inventory which records all tree inquiries, activity, work orders and the history of each City tree with a unique GIS identification. Response time for work varies from hours for hazards and emergency issues to months for regular pruning.
2014 Official Plan [87]	Markham's Official Plan outlines environmental and ecosystem policies related to: • Watershed and Subwatershed Planning • Groundwater and Surface Water Resources • Stormwater Management • Natural Environment Hazards • Emergency Preparedness Chapter 3 (Environmental Systems) provides details on and general policies for the Greenway system, the urban forest system, and the water system (including watershed planning and stormwater management) as well as key environmental hazards and outlines requirements for environmental reporting.
2020-2026 Strategic Plan [101]	Strategic Plan Goal 3: Safe, Sustainable and Complete Community "*We ensure community safety and* ***enhance the natural environment and built form through sustainable integrated planning, infrastructure management, and services***." Objective 3.3 **Ensure business continuity of our services and infrastructure, and enable community resiliency and community safety**. Objective 3.4 **Protect and enhance our natural environment** and built form.
2011 Markham's Greenprint Sustainability Plan [102]	The guiding framework states that in a sustainable Markham "we **value and restore the natural environment, and protect biodiversity, natural capital and ecosystem services**." Examples of environmental sustainability priorities and objectives in the Plan include: • Water Efficiency - Objective: Develop a water systems plan that integrates all water functions - for example, **Markham can use stormwater management strategies and flood control measures that mimic natural hydrological systems to minimize infrastructure costs and reduce the impact on natural waterways while maintaining efficiency and public safety**. • Ecosystem Integrity - Objective: Increase biodiversity - for example, **Markham can actively acquire lands that enhance or connect wildlife habitat within urban and rural areas and can support habitat enhancement with park planning, maintenance and management of all new and existing landscaped areas**. • Ecosystem Integrity - Objective: **Reach 30% tree canopy and vegetation coverage City-**wide - for example, Markham can develop, promote and maintain an Urban Forest Strategy as part of the Trees for Tomorrow tree planting program, contributing to habitat enhancement, climate change mitigation and other ecological services.

Plan/Policy/ Guideline	Component supporting nature-based climate solutions
	• Energy and Climate - Objective: Net-zero energy, water, waste and emissions by 2050 – for example, Markham can **develop community-level mitigation strategies for reducing and managing waste, reducing and capturing greenhouse gases in carbon sinks (natural areas and organic agriculture)**, and recycling to reuse "waste" water.
2016 Storm Water Management (SWM) Guidelines (103)	In developing the following SWM Guidelines, Markham supports and recognizes: • The requirement to undertake comprehensive environmental studies at the initial stages of the planning process; • The requirement to support innovation, evaluate new approaches, and embrace new technologies and techniques; and • The need to undertake SWM planning and design as part of an interdisciplinary approach. An ecosystem based approach is to be applied to different aspects of stormwater management, including planning and design in line with environmental principles embraced by Markham in its community and neighbourhood planning.
Tree Maintenance Program (104)	Large growing shade providing trees are planted on Markham's streets intentionally so that the many benefits they offer can be enjoyed throughout the community, as the City strives to meet the 30% canopy cover goal.

Wetland in the City of Markham
(Credit: City of Markham Official Plan)

9 Concluding Remarks

The City of Markham is looking to align with the global and national directives which are increasingly supportive of nature-based solutions while also meeting the requirements of O. Reg. 588/17 and the natural heritage objectives of the City's Official Plan and related guiding documents. Accounting for and incorporating its natural assets into the City's broader asset management planning process provides a unique opportunity to consider and prioritize natural heritage protection, management and enhancement based on how it might support provision of environmental services to the community while also helping the community mitigate and adapt to climate change.

This Guide:

- Provides an overview of Markham's natural assets
- Outlines how these assets help the community by providing important and valued ecosystem services
- Flags ways in which these assets are vulnerable to climate change, and
- Identifies some high-level strategies to help the natural assets in Markham remain resilient in the face of climate change so that they can continue to provide important services including supporting climate change adaptation.

Natural assets can be powerful allies as we learn to live with climate change because of their inherent capacity to respond and adapt to changes and extremes in the environment while continuing to sequester carbon, filter the air and water, provide cooling in the summer, and help manage floods and erosion, among other services. However, as biological organisms they can also be vulnerable to environmental stressors, such as severe droughts, windstorms and pest infestations. This Guide is intended to provide a high-level overview of the key challenges and opportunities presented by Markham's natural assets in a climate change context.

Markham Civic Centre
(Credit: City of Markham Official Plan)

10 Sources Cited

(1) CRI (Climate Risk Institute). 2023. "Ontario Provincial Climate Change Impact Assessment" prepared for the Ontario Ministry of the Environment, Conservation and Parks by the Climate Risk Institute in collaboration with Dillon Consulting Limited. Accessed: https://www.ontario.ca/files/2023-11/mecp-ontario-provincial-climate-change-impact-assessment-en-2023-11-21.pdf

(2) FCM (Federation of Canadian Municipalities). 2020. "Guide for Integrating Climate Change Considerations into Municipal Asset Management". 52 pp. Accessed: https://fcm.ca/sites/default/files/documents/programs/mamp/guide-for-integrating-climate-change-considerations-into-municipal-am.pdf

(3) CCME (Canadian Council of Ministers of the Environment). 2021. "Natural Infrastructure Framework: Key Concepts, Definitions and Terms". Accessed: https://ccme.ca/en/res/niframework_en.pdf

(4) FCM (Federation of Canadian Municipalities). 2022. "Asset management concepts: Learn definitions for common asset management terms". Web page accessed 2022-09-01 at: https://fcm.ca/en/resources/mamp/asset-management-concepts

(5) Green Analytics, Planet A Consulting, Grounded Solutions, SLBC Advisory Services, CBCL, Climate Risk Institute and Natural Assets Initiative. 2024. "City of Markham Natural Assets Consolidated Report". Prepared for the City of Markham, April 2024.

(6) The Association of Consulting Engineering Companies Canada (ACEC), the Canadian Construction Association (CCA), the Canadian Parks and Recreation Association (CPRA), the Canadian Public Works Association (CPWA), the Canadian Society for Civil Engineering (CSCE), the Canadian Urban Transit Association (CUTA), the Canadian Network of Asset Managers (CNAM), and the Federation of Canadian Municipalities (FCM). 2019. "2019 Canadian Infrastructure Report Card". Accessed: http://canadianinfrastructure.ca/downloads/canadian-infrastructure-report-card-2019.pdf

(7) Bloomberg., M. R. and C. Holloway. 2018. "NYC Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways". Published by New York Environmental Protection. Accessed: https://b-ok.cc/book/2953717/7c6e35

(8) OECD (Organisation for Economic Co-operation and Development). 2021. "Nature-based solutions for adapting to water-related climate risks". Accessed: https://www.oecd-ilibrary.org/environment/nature-based-solutions-for-adapting-to-water-related-climate-risks_2257873d-en

(9) Crouse, L. L. Pinault, A. Balram, P. Hystad, P. A. Peters, H. Chen, A. van Donkelaar, R. V. Martin, R. Ménard, A. Robichaud, and P. J. Villeneuve. 2017. "Urban greenness and mortality in Canada's largest cities: a national cohort study". Accessed: https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(17)30118-3/fulltext

(10) Twigg, M. 2021. "The Nature of Health Integrating Health Considerations in Urban Nature-Based Solutions", SPI (Smart Prosperity Institute), 99 pp. Accessed: https://institute.smartprosperity.ca/sites/default/files/EN_Report_NBS_Final.pdf

(11) Health Canada. 2020. "Reducing urban heat islands to protect health in Canada: An Introduction for public health professionals". Queen's Press, 53 pp. Accessed: https://www.canada.ca/content/dam/hc-sc/documents/services/health/publications/healthy-living/reducing-urban-heat-islands-protect-health-canada/Reducing-Urban-Heat-EN.pdf

(12) Kroeger, T., McDonald, R. I., Boucher, T., Zhang, P., and Wang, L. 2018. "Where the people are: Current trends and future potential targeted investments in urban trees for PM10 and temperature mitigation in 27 US cities". Landscape and Urban Planning, 177, 227-240. Accessed: https://www.sciencedirect.com/science/article/pii/S0169204618303542

(13) Global Commission on Adaptation. 2019. "Adapt Now: A Global Call for Leadership on Climate Resilience". Accessed: https://gca.org/reports/adapt-now-a-global-call-for-leadership-on-climate-resilience/

(14) Brooke, R., S. J. O'Neil, and S. Cairns. 2017. "Defining and Scoping Municipal Natural Assets Final Design Report". Accessed: https://mnai.ca/media/2018/02/finaldesignedsept18mnai.pdf

(15) Sun, X. , C. Liddicoat, A. Tiunov, B. Wang, Y. Zhang, C. Lu, Z. Li, S. Scheu, M. F. Breed, S. Geisen and Y. Zhu 2023. "Harnessing soil biodiversity to promote human health in cities," Urban Sustainability 3(1): February 2023. Accessed: https://www.nature.com/articles/s42949-023-00086-0

(16) ICLEI (Local Governments for Sustainability Canada). 2015. biodiverCities - A Handbook for Municipal Biodiversity Planning and Management." Accessed: https://icleicanada.org/wp-content/uploads/2019/05/BiodiverCITIES-Handbook_Final.pdf

(17) IPCC (Intergovernmental Panel on Climate Change). 2018. "Annex I: Glossary [Matthews, J.B.R. (ed.)]. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 541-562. https://doi.org/10.1017/9781009157940.008. Accessed: https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

(18) IPCC (Intergovernmental Panel on Climate Change). 2018. "Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 3-24. https://doi.org/10.1017/9781009157940.001.Accessed: https://www.ipcc.ch/sr15/chapter/spm/

(19) X. Zhang, G. Flato, M. Kirchmeier-Young, L. Vincent, H. Wan, X. Wang, R. Rong, J. Fyfe, G. Li, and V. Kharin. 2019. "Changes in Temperature and Precipitation Across Canada". Accessed: https://natural-resources.canada.ca/sites/www.nrcan.gc.ca/files/energy/Climate-change/pdf/CCCR-Chapter4-TemperatureAndPrecipitationAcrossCanada.pdf

(20) E. Bush and D. S. Lemmen. 2019. "Canada's Changing Climate Report," Government of Canada, Ottawa, Ontario, 444 p., 2019. [Online]. Accessed: https://changingclimate.ca/CCCR2019/

(21) Technische Universitaet Muenchen. 2014. "Climate change: How does soil store carbon dioxide?" Accessed: www.sciencedaily.com/releases/2014/01/140108102441.htm

(22) IPCC Working Group III. 2022. "Climate Change 2022: Mitigation of Climate Change. Summary for Policymakers," Cambridge Univ. Press, no. 1, pp. 1–64, 2022, Accessed: https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SummaryForPolicymakers.pdf

(23) M. Molnar, P. Olmstead, M. Mitchell, C. Raudsepp-Hearne, and M. Anielski. 2021. "Ecosystem Services: Chapter 5 in Canada in a Changing Climate National Issues Report". Accessed: https://changingclimate.ca/site/assets/uploads/sites/3/2020/05/Chapter-5_Ecosystem-Services_Final_EN-1.pdf

(24) PCCP (Peel Climate Change Partnership), "Peel Region Urban Forest Best Practice Guide 5 - Working with Trees: Best Practices for a Resilient Future", October 2021.

(25) Geomorphic Solutions, Sernas Group Inc., Toronto and Region Conservation Authority and LGL Limited. 2009. "Evaluating the Effectiveness of 'Natural' Channel Design Projects: An Introduction and Preliminary Assessment of Sites in TRCA's Jurisdiction". February 2009. 259 pp. Accessed: https://sustainabletechnologies.ca/app/uploads/2013/01/NCD-1-2009.pdf

(26) IISD (International Institute for Sustainable Development). 2021. Natural Infrastructure Solutions for Climate Resilience". Accessed: https://www.iisd.org/articles/explainer/natural-infrastructure-solutions-climate-resilience

(27) Fausto, E. , G. Milner, V. Nikolic, L. Briley, S. Basile, K. Behan and E. Trainor, "Historical and Future Climate Trends in York Region," 2015. [Online]. Accessed: https://climateconnections.ca/app/uploads/2015/02/Historical-and-Future-Climate-Trends-in-York-Region_Report-1.pdf

(28) Climatedata.ca {online resource]. 2023. "Understanding Shared Socio-economic Pathways." Accessed: https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/

(29) Muir, R. 2023. "Southern Ontario Extreme Rainfall Intensity Trends - Update from Environment Canada Engineering Climate Datasets". Accessed: https://www.cityfloodmap.com/2023/05/southern-ontario-extreme-rainfall.html

(30) Muir, R., F. Papa, FP&P HydraTek Inc., City of Markham, Dillon Consulting Limited, R.V. Anderson Associates Limited, Toronto and Region Conservation Authority and University of Toronto. Department of Civil Engineering. 2021. "Guidelines on undertaking a comprehensive analysis of benefits, costs and uncertainties of storm drainage and flood control infrastructure in a changing climate". Accessed: https://nrc-publications.canada.ca/eng/view/object/?id=27058e87-e928-4151-8946-b9e08b44d8f7

(31) CBCL. 2022. "Natural Heritage Management Study, City of Markham. 2022 Vegetation Analysis, Technical Memorandum". Prepared for the City of Markham. Dec. 8, 2022. 59 pp.

(32) NSEI and DAI (North-South Environmental Inc. and Dougan and Associates Inc.) 2021. "Markham Natural Heritage Inventory and Assessment Study". Prepared for the City of Markham.

(33) Smukler, S. M. 2019. "Managing Canadian Croplands to Maximize Carbon Sequestration and Minimize Other Ecosystem Service Trade-Offs Paper prepared for CAPI," no. April, p. 19, 2019. Accessed: https://capi-icpa.ca/wp-content/uploads/2019/04/2019-02-21-CAPI-land-use-dialogue_Smukler-Paper-WEB-3.pdf

(34) MNAI (Municipal Natural Assets Initiative). 2019. "What Are Municipal Natural Assets: Defining and Scoping Municipal Natural Assets - Decision-Maker Summary," Accessed: https://mnai.ca/media/2019/07/SP_MNAI_Report-1-_June2019-2.pdf

(35) CVC (Credit Valley Conservation), 2020, "Life Cycle Costing of Restoration and Environmental Management Actions: Costing Natural Assets in Peel Region". Prepared by: Beacon Environmental Limited with Green Analytics and Associated Engineering, December 2020. https://cvc.ca/wp-content/uploads/2021/09/2020-12-15_CVC_NatAssetLifeCycleReport_220046_FINAL_cover-page.pdf.

(36) WWF (World Wildlife Fund). 2020. "Why Forests are so Important," World Wide Fund For Nature. Accessed: https://wwf.panda.org/discover/our_focus/forests_practice/importance_forests/

(37) Ontario Biodiversity Council. 2020. "State of Ontario's Biodiversity: 2020 Summary," Accessed: http://sobr.ca/_biosite/wp-content/uploads/state-of-biodiversity-report-2020-Final-2.pdf

(38) Keen, R. 2019. "Disaster Mitigation and Insurance: The Role of Forests in Mitigating Extreme Weather Events," Jun. 2019. Accessed: https://forestsontario.ca/en/resource/disaster-mitigation-and-insurance-the-role-of-forests-in-mitigating-extreme

(39) Federation for Ontario Cottagers' Association. 2017. "Managing Your Woodlot in a Changing Climate". Accessed: https://docs.ontario.ca/documents/4491/managing-your-woodlot-in-a-changing-climate.pdf

(40) Wilson, S. 2008. "Ontario's Wealth, Canada's Future: Appreciating the Value of the Greenbelt's Eco-Services," Accessed: https://davidsuzuki.org/wp-content/uploads/2018/02/ontario-wealth-canada-future-value-greenbelt-eco-services.pdf

(41) Toronto and Region Conservation Authority. 2023. "Markham Forest Study 2022: Technical Report," March 2023.

(42) A. M. Bassi, G. Pallaske, L. Wuennenberg, L. Graces, and L. Silber. 2019. "Sustainable Asset Valuation Tool: Natural Infrastructure". Accessed: https://www.iisd.org/system/files/publications/sustainable-asset-valuation-tool-natural-infrastructure.pdf

(43) The Mersey Forest. 2014. "Urban catchment forestry". Accessed: https://www.merseyforest.org.uk/files/documents/1310/Urban%20Catchment%20Forestry%20prospectus%20-%20final%20-%20Oct%202014.pdf

(44) United States Environmental Protection Agency. 2023 {online]. "Urbanization - Stormwater Runoff". Accessed: https://www.epa.gov/caddis/urbanization-stormwater-runoff

(45) Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. "Urban Subwatershed Restoration Manual Series". Accessed: www.stormwatercenter.net

(46) Muir, R. J., Manager of Stormwater at the City of Markham, personal communications, spring 2023.

(47) Toronto and Region Conservation Authority. 2015. "Hydrologic Assessment of LID Honda Campus, Markham, ON". Sustainable Technologies Evaluation Program (STEP) Technical Brief. Accessed: https://sustainabletechnologies.ca/app/uploads/2015/07/Honda_TechBrief_July2015.pdf

(48) United Nations Environment Programme. 2014. "Green infrastructure: Guide for Water Management," UNEP, 2014. Accessed: https://www.unep.org/resources/publication/green-infrastructure-guide-water-management

(49) Aziz, T. and P. Van Cappellen. 2021. "Economic valuation of suspended sediment and phosphorus filtration services by four different wetland types: A preliminary assessment for southern Ontario, Canada". Hydrologic Processes 35(12): Dec. 2021. Accessed: https://www.researchgate.net/publication/356584454_Economic_valuation_of_suspended_sediment_and_phosphorus_filtration_services_by_four_different_wetland_types_A_preliminary_assessment_for_southern_Ontario_Canada

(50) Page, B., P. Arminian and O. Steele. 2022. "Determining the Nutrient Retention Capacity of Newly Restored Small Wetlands in Southwestern Ontario for a Second Water Year". Prepared for Ducks Unlimited, 84 pp. Accessed: https://www.ducks.ca/assets/2022/03/Final-report_Ontario-Small-Wetlands-Year-2_Feb-2022_sm.pdf

(51) Cheng, F. Y., J. Park, M. Kumar and N. B. Basa. 2023. "Disconnectivity matters: the outsized role of small ephemeral wetlands in landscape-scale nutrient retention". Environmental Research Letters 18(2): January 2023. Accessed: https://iopscience.iop.org/article/10.1088/1748-9326/acab17

(52) Toronto and Region Conservation Authority.2023. Story map: "Natural Heritage System". Accessed: https://storymaps.arcgis.com/collections/8c517b063c81449d8fba71ca02d4278f?item=5

(53) Snow, M. 2020. "The Value of Meadows," U.S Fish and Wildlife Services, Aug. 20, 2020. Accessed: https://www.fws.gov/story/2020-08/value-meadows

(54) DeLoyde, C. N. M., and W. E. Mabee. 2023. "Ecosystem service values as an ecological indicator for land management decisions: A case study in southern Ontario, Canada". Ecological Indicators 151 (2023: 110344. Accessed: https://www.sciencedirect.com/science/article/pii/S1470160X23004867

(55) Sturm, A. and S. Frischie. 2020. "Mid-Atlantic Native Meadows: Guidelines for Planning, Preparation, Design, Installation, and Maintenance". Accessed: https://xerces.org/sites/default/files/publications/19-052_MidAtlantic_Meadow_guidelines_web.pdf

(56) City of Markham. 2023 [online]. "Surface Water Quality." Accessed: https://www.markham.ca/wps/portal/home/neighbourhood-services/water-sewer/systems-overview/04-surface-water-quality

(57) Ferreira, V., R. Albariño, A. Larrañaga, C. J. LeRoy, F. O. Masese, and M. S. Moretti. 2022. "Ecosystem services provided by small streams: an overview". Hydrobiologia 850(12-13):1-55. Accessed: https://www.researchgate.net/publication/365850195_Ecosystem_services_provided_by_small_streams_an_overview

(58) Janssen, A. B. G., S. Hilt, S. Kosten, J. J. M. Klein, H. W. Paerl, and D. B. Van de Waal. 2021. "Shifting states, shifting services: Linking regime shifts to changes in ecosystem services of shallow lakes." Freshwater Biology 66(1): 1–12. Accessed: https://onlinelibrary.wiley.com/doi/10.1111/fwb.13582

(59) Green Analytics. 2017. "Valuing natural capital in the Lake Simcoe Watershed." Prepared for the Lake Simcoe Region Conservation Authority, Dec. 8, 2017. Accessed: https://lsrca.on.ca/wp-content/uploads/2023/07/Ecosystem-Service-Values-1.pdf

(60) King, P., C. Nelsen, J. Dugan, D. Hubbard, K. Martin, and R. Battalio. 2018. "Valuing beach ecosystems in an age of retreat". Shore & Beach 86(4): 45–58. Accessed: https://par.nsf.gov/servlets/purl/10123373

(61) National Geographic. 2022. "Bluff". Accessed: https://education.nationalgeographic.org/resource/bluff/

(62) York Region. 2023. "York Region Climate Change and Health Vulnerability Assessment". Accessed: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwifi5ySw_f-AhWqk4kEHc9oCMQQFnoECBgQAQ&url=https%3A%2F%2Fwww.york.ca%2Fmedia%2F93511%2Fdownload&usg=AOvVaw2H5_prGUOrkij7fjTObblf

(63) Wuebbles, D., et al. 2019. "An Assessment of the Impacts of Climate Change on the Great Lakes". Accessed: http://elpc.org/wp-content/uploads/2019/03/Great-Lakes-Climate-Change-Report.pdf

(64) Barwinsky, M. 2019. "Urban Forests and Climate Change," Climate Atlas of Canada, 2019. Accessed: https://climateatlas.ca/urban-forests-and-climate-change

(65) Candau, J. N., R. A. Fleming, and X. Wang. 2018. "Ecoregional patterns of spruce budworm-wildfire interactions in central Canada's Forests". Forests 9(137): 17, Mar. 2018, Accessed: https://www.researchgate.net/publication/324013564_Ecoregional_Patterns_of_Spruce_Budworm-Wildfire_Interactions_in_Central_Canada's_Forests

(66) Tu, C., G. Milner, D. Lawrie, N. Shrestha and S. Hazen. 2017. "Natural Systems Vulnerability to Climate Change in Peel Region". Technical Report. Toronto, Ontario: Toronto and Region Conservation Authority and Ontario Climate Consortium Secretariat.

(67) Minns, S. , C., Shuter, B., Fung. 2014. "Regional Projections of Climate Change Effects on Ice Cover and Open-Water Duration for Ontario Lakes Using Updated Ice-Date Models," Accessed: https://climateontario.ca/scripts/MNR_Pub/publication_summary.php?pubId=54

(68) Chu, C. 2015. "Climate Change Vulnerability Assessment for Inland Aquatic Ecosystems in the Great Lakes Basin, Ontario". Report CCRR-43. Accessed: https://www.researchgate.net/publication/379445013_Climate_Change_Vulnerability_Assessment_for_Inland_Aquatic_Ecosystems_in_the_Great_Lakes_Basin_Ontario

(69) Hamersma, R., T. Young, and J. Llewellyn. 2022. "Common disorders of broad-leaved trees," Ministry of Agriculture, Food and Rural Affairs, Jul. 18, 2022.

(70) Trees Canada. 2018. "Canadian Urban Forest Strategy". Accessed: https://treecanada.ca/research-engagement/canadian-urban-forest-strategy/

(71) Dove-Thompson, D., C. Lewis, and P. A. Gray. 2011. "A Summary of the Effects of Climate Change on Ontario's aquatic ecosystems". Accessed: https://files.ontario.ca/environment-and-energy/aquatics-climate/stdprod_088243.pdf

(72) Ontario Centre for Climate Impacts and Adaptation Resources (OCCIAR). 2015. "Climate Change Impacts & Adaptation in Ontario: Biodiversity and Protected Areas". Accessed: https://pub-brantford.escribemeetings.com/filestream.ashx?DocumentId=14764

(73) Niagara Region. 2019. "New Niagara Official Plan: Climate Change Discussion Paper". Accessed: https://www.niagararegion.ca/projects/rural-and-natural-systems/pdf/climate-change-discussion-paper.pdf

(74) Brinker, S. R., M. Garvey, and C. D. Jones. 2018. "Climate change vulnerability assessment of species in the Ontario Great Lakes Basin". Climate Change Research Report CCRR-48. Accessed: https://www.natureserve.org/sites/default/files/ccrr-48_1.pdf

(75) Khatibi, F. S., A. Dede Korkut-Howes, M. Howes, and E. Torabi. 2021. “Can public awareness, knowledge and engagement improve climate change adaptation policies?,” Discov. Sustain., 2(1): Mar. 2021. Accessed: https://www.researchgate.net/publication/350325970_Can_public_awareness_knowledge_and_engagement_improve_climate_change_adaptation_policies

(76) Interreg. 2019. “Communicating to local people and visitors the value of nature to the local economy”. Local Economy and Nature Conservation in the Danube Region, 62 pp. Accessed: https://wwfeu.awsassets.panda.org/downloads/communicating_to_local_people_and_visitors_the_value_of_nature_en.pdf

(77) Carmen, E., I. Fazey, H. Ross, M. Bedinger, F. M. Smith, K. Prager, K. McClymont and D. Morrison. 2022. “Building community resilience in a context of climate change: The role of social capital.” Ambio 51: 1371-1387. Accessed: https://link.springer.com/article/10.1007/s13280-021-01678-9?fromPaywallRec=false

(78) City of Markham. 2016. “Report to Council: Canada's First Monarch Butterfly Friendly City”. Accessed: https://www.markham.ca/wps/wcm/connect/markham/c7f5d8dd-6197-4431-951e-896362d7aa12/Butterfly%2BReport.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_2QD4H901OGV160QC8BLCRJ1001-c7f5d8dd-6197-4431-951e-896362d7aa12-mPfaJnc

(79) Bear, J., Bill, L., Winnipeg Metropolitan Region and Municipal Natural Assets Initiative (MNAI). 2023. “The Journey So Far: Reconciling First Nations’ Worldview and Perspectives with Natural Asset Management”. Accessed: https://mnai.ca/the-journey-so-far

(80) David Suzuki Foundation. 2018. “Tribal Parks and Indigenous Protected and Conserved Areas: Lessons Learned from B.C. Examples”. Accessed: https://davidsuzuki.org/wp-content/uploads/2018/08/tribal-parks-indigenous-protected-conserved-areas-lessons-b-c-examples.pdf

(81) CBC News. 2023. “Simpcw First Nation declares watershed as Indigenous conservation area”. Accessed: https://www.cbc.ca/news/canada/british-columbia/simpcw-raush-valley-indigenous-protected-conserved-area-1.6797019

(82) Ontario Nature, Plenty Canada, Walpole Island Land Trust, and the Indigenous Environmental Studies and Sciences Program at Trent University. 2018. “Transforming Conservation: Indigenous Protected and Conserved Areas in Ontario”. Accessed: https://ipcaknowledgebasket.ca/transforming-conservation-indigenous-protected-and-conserved-areas-in-ontario

(83) Deloitte. 2024. “Bringing carbon down to earth: Indigenous leadership in nature-based solutions”. Accessed: https://natureinvestmenthub.ca/wp-content/uploads/2024/01/ca-en-about-bringing-carbon-down-to-earth-aoda-V4.pdf

(84) Credit Valley Conservation. 2017. “Healthy Soils Guideline for the Natural Heritage System”. Accessed: https://files.cvc.ca/cvc/uploads/2017/09/CVC-Healthy-Soils-Guidelines-NHS-Web-V5.pdf

(85) Gann G.D., McDonald T., Walder B., Aronson J., Nelson C.R., Jonson J., Hallett J.G., Eisenberg C., Guariguata M.R., Liu J., Hua F., Echeverría C., Gonzales E., Shaw N., Decleer K., Dixon K.W., "International principles and standards for the practice of ecological restoration", 2019, Second edition. Restoration Ecology 27(S1): S1–S46.

(86) Government of Canada, “Rouge National Urban Park,” website accessed 2023-05-08 at https://parks.canada.ca/pn-np/on/rouge

(87) City of Markham. 2018. City of Markham Official Plan”. April 9, 2018 Office Consolidation. Accessed: https://www.markham.ca/wps/portal/home/business/planning/sa-official-plan/01-official-plan

(88) Toronto and Region Conservation. 2024 [online]. “Natural Hertiage System”. Accessed: https://trca.ca/conservation/terrestrial-ecosystems/natural-heritage-system/

(89) CBC News. 2019. “Markham to transform industrial area into green space to prevent flood damage”. Accessed: https://www.cbc.ca/news/canada/toronto/markham-don-river-flood-plain-damage-1.5203156

(90) G. Nielsen, M. Spearing, and B. Boysen. 2017. “Adapting to a Changing Climate: A Report for Southern Region Sustainable Forest License Holders”. Kemptville, ON. Accessed: www.fgca.net

(91) Ministry of Natural Resources and Forestry. 2020. “Ontario Tree Seed Transfer Policy”. Accessed: https://files.ontario.ca/mnrf-ontario-tree-seed-transfer-policy-en-2021-01-11-v2.pdf

(92) Lacan, I. and J. R. McBride. 2008. “Pest Vulnerability Matrix (PVM): A graphic model for assessing the interaction between tree species diversity and urban forest susceptibility to insects and diseases”. Urban Forestry & Greening 7(4): 291-300. Accessed: https://www.sciencedirect.com/science/article/abs/pii/S1618866708000289#:~:text=PVM%20calculates%20the%20percentage%20of,the%20most%20vulnerable%20tree%20species

(93) Sustainable Technologies Evaluation Program. 2024 [online]. “Low Impact Development Treatment Train Tool”. Accessed: https://sustainabletechnologies.ca/lid-ttt/

(94) CFS (Canadian Forest Service) and UBC (University of British Columbia, Forestry). 2016. The Social and Economic Values of Canada’s Urban Forests: A National Synthesis. April 16, 2015. Accessed at: http://urbanforestry.sites.olt.ubc.ca/files/2016/09/The-Social-and-Economic-Values-of-Canada’s-Urban-Forests-A-National-Synthesis-2015.pdf

(95) Chuang, W., C. G. Boone, D. H. Locke, J. M. Grove, A. Whitmer, G. Buckley and S. Zhang. 2017. Tree canopy change and neighborhood stability: A comparative analysis of Washington, D.C. and Baltimore, MD. Urban forestry & Urban Greening 27: 363-372. Accessed at: https://www.fs.fed.us/nrs/pubs/jrnl/2017/nrs_2017_chuang_001.pdf

(96) Mitchell, R. and F. Popham. 2007. Greenspace, Urbanity and Health: Relationships in England. Journal of Epidemiology and Community Health 61(8): 681–683.

(97) WBG (World Bank Group) and WRI (World Resources Institute). 2019. Integrating Green and Gray: Creating the Next Generation of Infrastructure. By Greg Browder, Suzanne Ozment, Irene Rehberger Bescos, Todd Gartner, and Glenn-Marie Lange. Accessed at: https://openknowledge.worldbank.org/handle/10986/31430

(98) American Forests. 2024 [online tool]. “Tree Equity Score Analyzer: Toronto, ON”. Accessed: https://www.treeequityscore.org/analyzer/toronto

(99) City of Markham, “Asset Management Policy,” 2019. [Online]. Accessed: https://www.markham.ca/wps/wcm/connect/markham/56b61d14-c7ab-404c-9e81-5951be6d1185/Asset+Management+Policy.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_2QD4H901OGV160QC8BLCRJ1001-56b61d14-c7ab-404c-9e81-5951be6d1185-nMeWBX6

(100) City of Markham. 2021. “Asset Management Plan”.

(101) City of Markham. 2020. “Building Markham’s Future Together (BMFT) – Council’s Strategic Plan 2020 to 2026”. Accessed: https://www.markham.ca/wps/portal/home/about/city-hall/strategic-priorities/strategic-plan/

(102) City of Markham. 2011. “Markham’s Greenprint Sustainability Plan”.

(103) City of Markham. 2016. “Storm Water Management Guidelines”.

(104) City of Markham, “Tree Maintenance Program”. Accessed: https://www.markham.ca/wps/portal/home/neighbourhood-services/trees/tree-maintenance-program/06-tree-maintenance-program