CITY OF MARKHAM NATURAL ASSETS INVENTORY AND EVALUATION STUDY

CONSOLIDATED REPORT APPENDICES

Prepared by

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11 Appendix A: Overview of Data Sources Reviewed

A description and utility of each dataset reviewed for this project is outlined in the Table below.

Table 11-1. Data sources reviewed for this project.

Name	Source	Description	Purpose
Municipal Boundary	York Region	Polygon shapefile featuring municipal boundaries for towns in the York Region in Ontario.	Used to delineate the study area boundary.
CBCL ELC	CBCL / City of Markham	Polygon feature class of an inventory of natural land cover in the study area.	Used as the primary source for natural land cover for the inventory.
TRCA Land Cover	TRCA	Polygon feature class of natural areas within and around the study area.	Used to reclassify certain types of landcover for the NAI.
TRCA Subwatersheds	TRCA	Polygon shapefile of subwatershed and watershed boundaries.	Used to subdivide areas by subwatershed and watershed boundary.
Watercourse	City of Markham	Line shapefile of watercourses in Markham Natural Heritage areas.	Used to estimate length of watercourses (m) in natural assets.
OSM Amenity Dataset	OpenStreetMap	Polygon shapefile showing the extent and location of amenity features, in this case parking.	Used to classify areas as parking in the inventory to remove areas of natural polygons covered by any amount of parking lot.
OSM Powerline Dataset	OpenStreetMap	Line feature class showing powerline location.	Used with elevation data to define tree locations and canopy cover.
Building Footprints	City of Markham	Polygon shapefile showing the extent and location of building footprints.	Used to eliminate non-natural area from polygons with natural classification.
Invasive Species	City of Markham	Point feature class of invasive species locations in the study area.	Used to indicate which assets have points indicating the presence of invasive species within them. Points classified with a species code indicating a given invasive species (s) within the bounds of each asset were estimated, with what each code represents available in the table at this link FloraRanksandScores2020_Final.pdf (trca.ca) and a supplementary table listing which species code are within each asset is included as an output.
Wildlife Data	City of Markham	Point feature class of wildlife locations in the study area.	Used to indicate which assets have points indicating the occurrence of wildlife species within them (a separate datasets from the invasive species dataset above, and not limited to invasive species). The common name for all the species in each asset is listed in a supplementary table for each asset.

Name	Source	Description	Purpose
Aerial Imagery	City of Markham	2 m raster of aerial imagery in study area.	Used to aid in verification and manual delineation where appropriate.
LiDAR Imagery	Government of Canada		Used to perform tree segmentation and canopy cover delineation throughout entire study area.
NACS BBS Stations	City of Markham	Point Shapefile of station locations in Markham Ontario.	Used to obtain a count for the number of stations in different assets.
Stormwater Management Facilities	City of Markham	Polygon feature class of stormwater management faculties in study area.	Used to split/reclassify areas by stormwater management status.
Contours	City of Markham	Line shapefile of contours.	Not used at this time but potentially useful for the risk assessment.
Core Area Enhancement Zones	City of Markham	Point shapefile with one entry and no attributes.	Not currently used, but Metadata to be linked with a given natural asset where applicable.
Core Linkage Enhancement Zones	City of Markham	Line shapefile with no attributes and seven features.	Metadata to be linked with a given natural asset where applicable.
Greenbelt Plan Area	City of Markham	Polygon shapefile of Green Belt area in Markham.	Used to split assets by boundaries of provincial GPA.
Greenway System	City of Markham	Polygon shapefile of the Greenway system area in the study, including overlap with the Greenbelt area in Markham Ontario.	Used to split assets by boundaries of City Greenway System.
Land Use Designation Areas	City of Markham	Polygon shapefile of land use designation areas for Markham Ontario.	Not used in current inventory.
Natural Heritage Network	City of Markham	Polygon shapefile of Natural Heritage Network areas in Markham.	Used to split assets by boundaries of natural heritage network.
Oak Ridges Moraine Conservation Area	City of Markham	Polygon shapefile of conservation area in NE Markham.	Used to split assets by boundaries of provincial ORMCP area.
Parcel	City of Markham	Polygon shapefile of land ownership parcels in Markham.	Not used in current inventory.
Rouge Watershed Protection Areas	City of Markham	Polygon shapefile of Rouge Watershed Protection Area.	Used to split assets by RWPA.
TRCA Flood line boundaries (Shapefile)	City of Markham	Line shapefile of TRCA flood lines in study area.	Not used at this time but potentially useful for the risk assessment.
Trails	City of Markham	Line feature class of trails within the study area.	Not used at this time but potentially useful for the condition assessment and / or level of service assessment.
Zoning	City of Markham	Polygon feature class of zoning boundaries in City of Markham.	Not used in current inventory.
Parks	City of Markham	Polygon feature class of Parks in City of Markham.	Used to identify parklands outside natural areas in City.
Official Plan	City of Markham	Polygon feature class detailing land use/zoning in the study area.	Used to subdivide areas based on land use designation.

Name	Source	Description	Purpose
Don River Subwatershed	City of Markham	Polygon feature class of subwatershed boundary in Markham and surrounding area.	Not used, as TRCA subwatershed boundary file was used to subdivide by subwatershed boundary instead. File used to confirm boundaries matched with TRCA dataset.
Duffins Creek Subwatershed	City of Markham	Polygon feature class of subwatershed boundary in Markham and surrounding area.	Not used, as TRCA subwatershed boundary file was used to subdivide by subwatershed boundary instead. File used to confirm boundaries matched with TRCA dataset.
Highland Creek Subwatershed	City of Markham	Polygon feature class of subwatershed boundary in Markham and surrounding area.	Not used, as TRCA subwatershed boundary file was used to subdivide by subwatershed boundary instead. File used to confirm boundaries matched with TRCA dataset.
Rogue River Subwatershed	City of Markham	Polygon feature class of subwatershed boundary in Markham and surrounding area.	Not used, as TRCA subwatershed boundary file was used to subdivide by subwatershed boundary instead. File used to confirm boundaries matched with TRCA dataset.
Floodline Polygons	City of Markham	Polygon shapefile of TRCA flood lines in study area (appear to be polygon feature class version of TRCA_Floodline_June_2022_Line and TRCA-FLOODLINE.shp).	Used to estimate are of flooding areas within asset boundaries.
TRCA Floodline boundaries (Feature Class)	City of Markham	Line shapefile of TRCA flood lines in study area	Feature class version of above.
Half Meter Contours	City of Markham	Line shapefile of contours within the study area.	Not used in current inventory.
Single Line Road Network	City of Markham	Line feature class of roads in study area.	Not used in current inventory.
Street & Park Tree Inventory	City of Markham	Point feature class of street trees in study area.	Held in a supplementary table, reserved for future analysis and producing asset/subwatershed summaries.
Public Land Parcels	City of Markham	Polygon shapefile of public land parcels in Markham.	Used to identify public lands and estimate extent of public areas within an asset.
Remaining Parcels	City of Markham	Polygon shapefile of non-public parcels.	Used to identify private lands and estimate extent of public areas within an asset.
Official Plan and Zoning Applications	City of Markham	Polygon feature class of official plan and zoning applications in Markham.	Used to estimate extent of plans and applications within each asset.
Site Plan Agreement	City of Markham	Polygon feature class of site plan agreements in Markham.	Used to estimate count and list of site plan agreements within each asset.
Site Plan Application	City of Markham	Polygon feature class of site plan applications in Markham.	Used to estimate count and list of site plan applications within each asset.
Subdivision Agreement	City of Markham	Polygon feature class of subdivision agreements in Markham.	Used to estimate count and list of subdivision agreements within each asset.
Subdivision Application	City of Markham	Polygon feature class of subdivision applications in Markham.	Used to estimate count and list of subdivision applications within each asset.
NRN Road Dataset	City of Markham	Line shapefile of roads in Ontario.	Used to help delineate canopy and tree segmentation from LiDAR data.

Name	Source	Description	Purpose
NRWN Rail Dataset	City of Markham	Line shapefile of railways in Ontario.	Used to help delineate canopy and tree segmentation from LiDAR data.
Approved York Region Urban Areas	City of Markham	Polygon shapefile of approved York Urban areas.	Used to subdivide agriculture assets.
Rouge National Urban Park (RNUP) Boundary	City of Markham	Polygon shapefile of approved urban boundaries in Rouge National Park.	Used to subdivide agriculture assets.

12 Appendix B: Natural Asset Inventory Attributes

Ownership
Ownership data is reflected in the inventory with multiple fields; these include “Private Parcel Area”, “Public Parcel Area”, “Percent of Asset Overlapping with Private Parcels”, “Percent of Asset Overlapping with Public Parcels”. The former two fields are a measure of the extent of private/public parcel land that overlaps with each fully subdivided asset, and the latter two field estimate a percentage of each asset’s area that is either public or private based on the amount of overlap. In addition to private vs public ownership, an additional set of fields, “Markham Owned Area (ha)” and “Percent_Markham_Owned”, were used to estimate the extent of Markham Owned Area that overlapped each asset and what percentage of each asset’s area that Markham owned areas made up.

Urban / Rural Boundary
All assets in the inventory have an attribute field titled “Urban_Rural_V2”, that delineates assets area within either the rural or urban boundaries of Markham. All natural assets that were within a 10 m buffer of the Urban Areas GIS file were classified with the “Urban” value, while anything outside of that area was classified as “Rural”. Slight manual adjustments were made in a few locations to account for differences in scale/boundary segmentation affecting classification. An older field, “Urban_Rural”, that classifies all areas the directly intersect urban boundaries as “Urban” (else they are classified as “Rural”) was retained for a point of comparison between methods, however the V2 files is considered the final one for the purpose of this study.

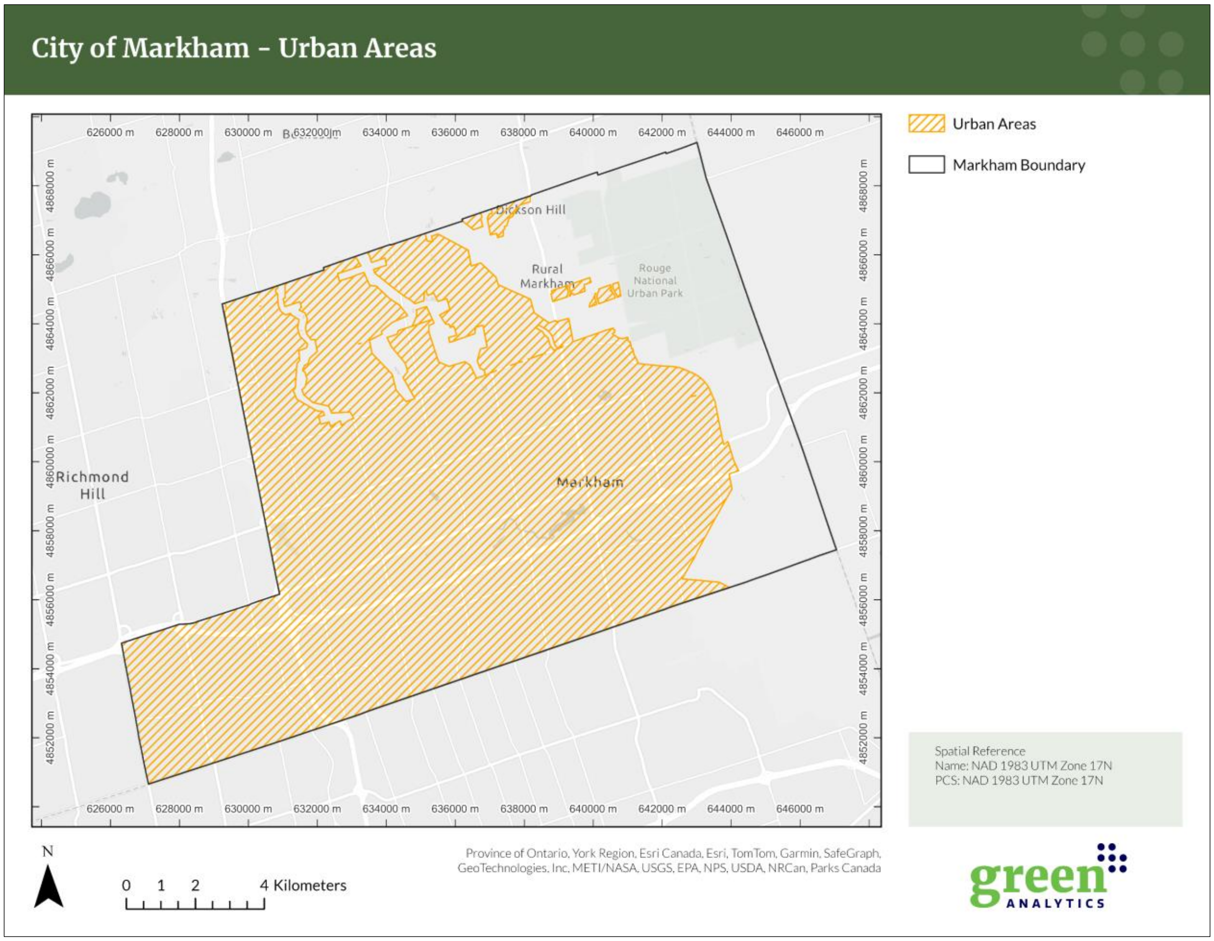

Figure 12-1. Map of Urban Area boundary for Markham, ON.

Stormwater Management Ponds

Stormwater management data was overlaid with the inventory, and all natural assets that fell within the boundaries of the SWM areas were designated as such. This classification is reflected in the FACDEVNAME and FACTYPE attribute fields; the former indicates the name of the SWM facility associated with each asset, and the FACTYPE field lists the type of stormwater management facility (IE, Wet Pond, Dry Pond, etc.).

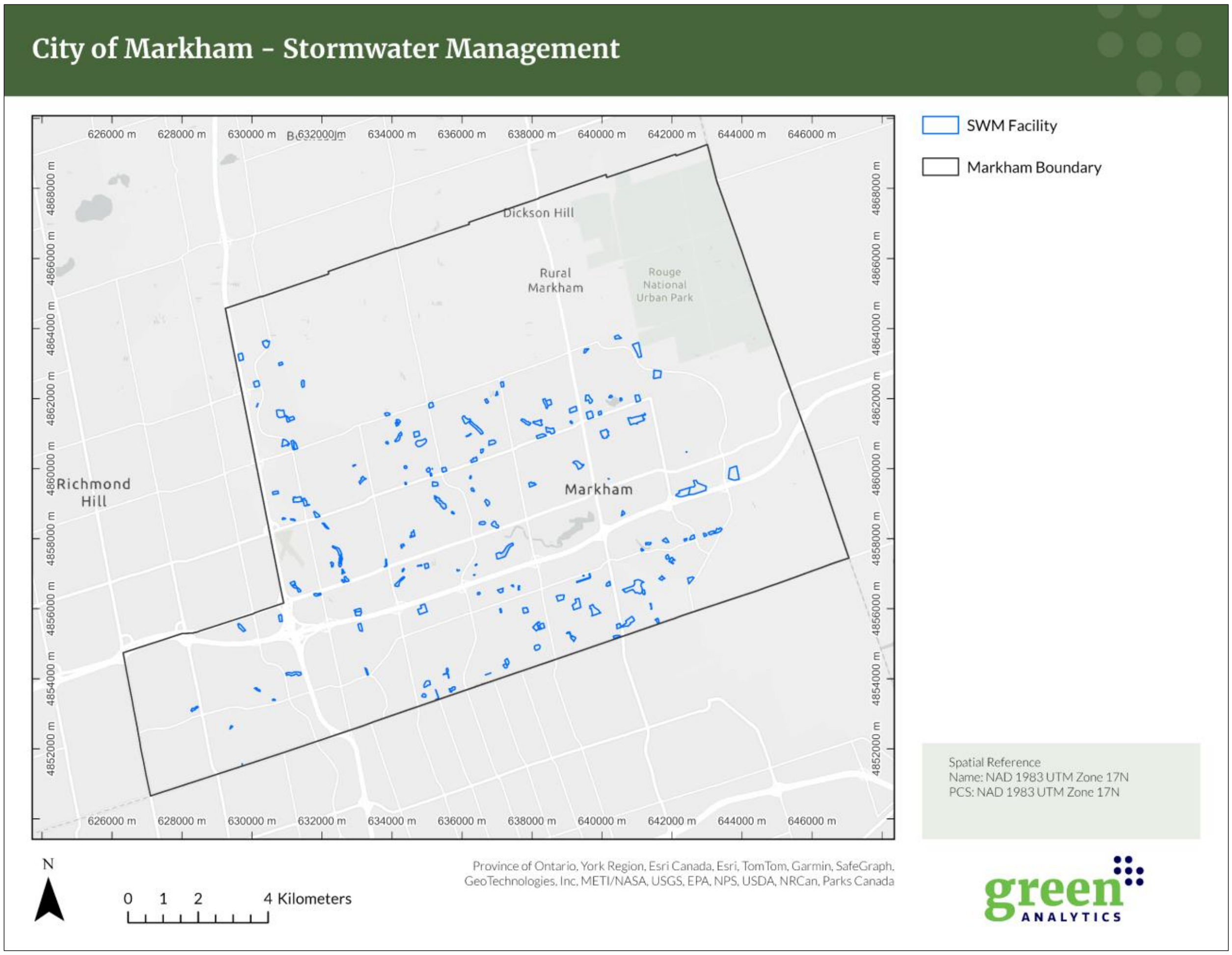

Figure 12-2. Map of stormwater management facilities within Markham, ON.

Greenway System
The Greenway System is reflected in the inventory through the attribute titled "Greenway" attribute field. The greenway boundaries were used to subdivide the asset boundaries, separating them based on these boundaries and designating assets as either entirely within or outside of the Greenway.

Those assets that are within the Greenway have the value "Greenway System" in the Greenway attribute field.

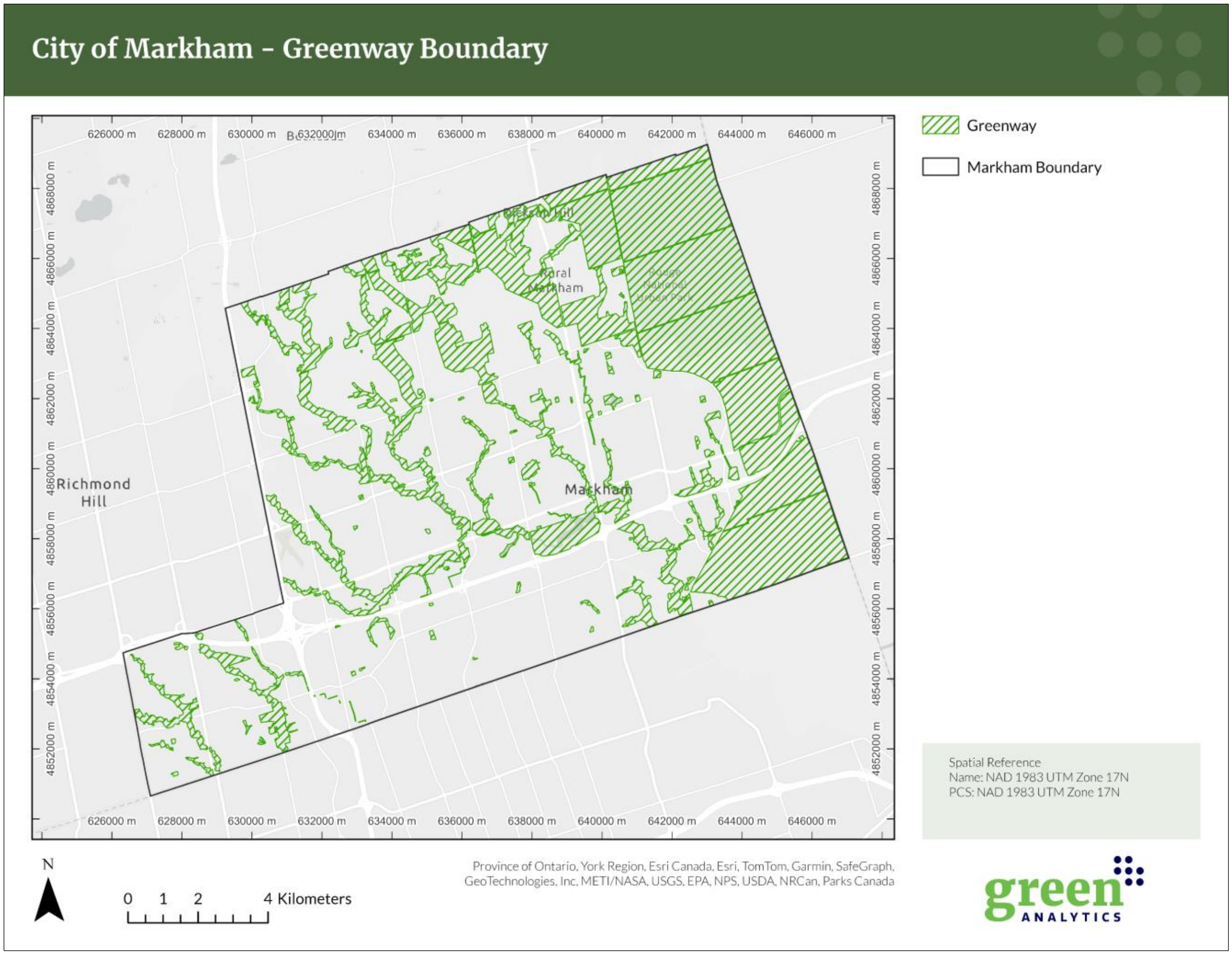

Figure 12-3: Map of greenway areas within Markham, ON.

Greenbelt Plan Area

The boundaries of the greenbelt plan area in the Markham boundary were overlaid with the natural asset inventory to subdivide assets to be either exclusively within or outside the Greenbelt. This is recorded in the "Greenbelt" attribute field, with polygons with a classification of "Greenbelt Plan Area" referring to assets within the Greenbelt, and polygons lacking this classification being outside the Greenbelt.

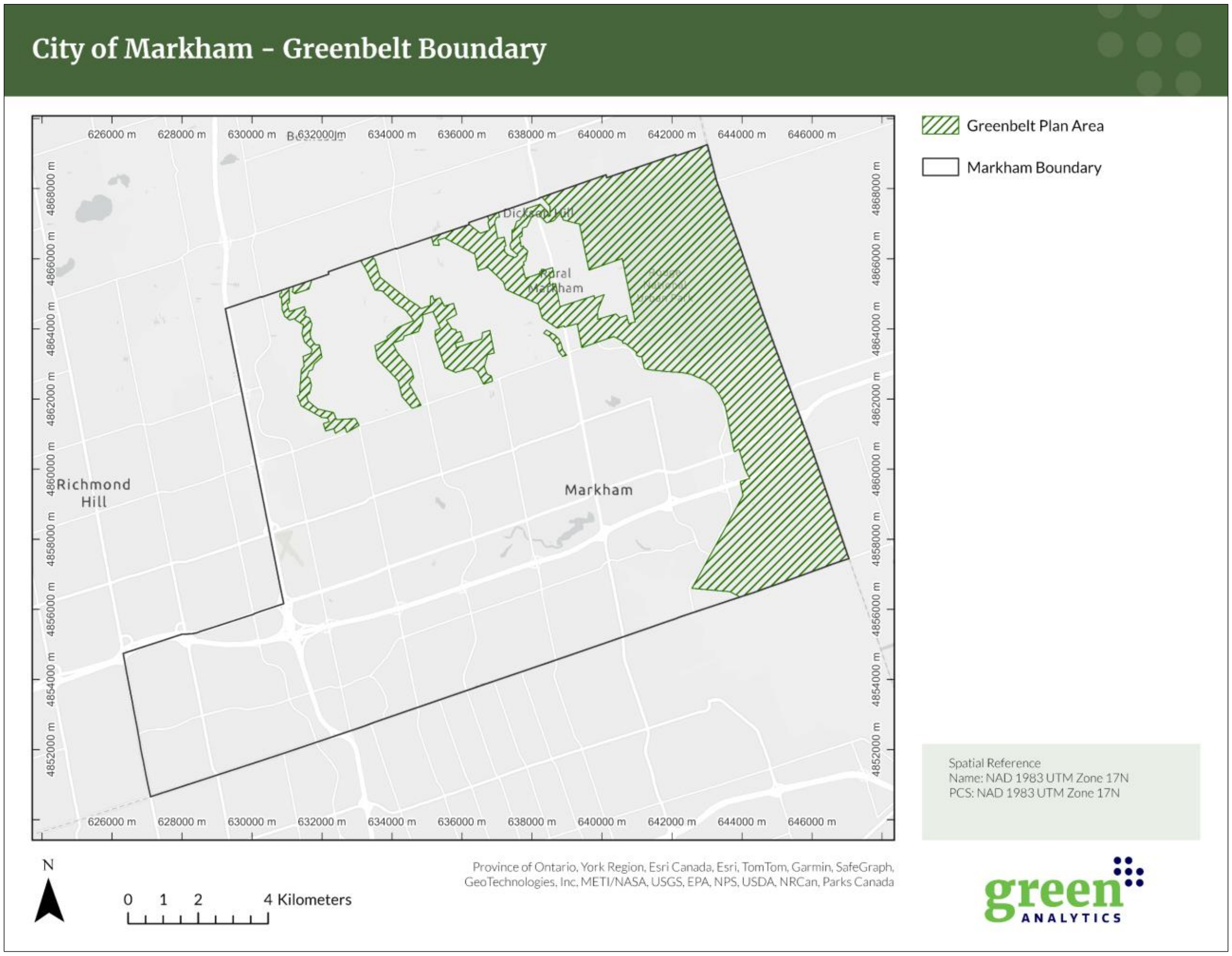

Figure 12-4. Map of Greenbelt areas within Markham, ON.

Rouge Natural Urban Park (RNUP)

The boundary of the Rouge Natural Urban Park boundary was applied only to agricultural assets; the boundary of the RNUP was overlaid on top of these assets, and the boundary of the agricultural assets were subdivided by the boundaries of the RNU. Agricultural assets within the RNUP were then classified as "In Rouge National Urban Park" in the attribute field titled "Agricultural Asset location".

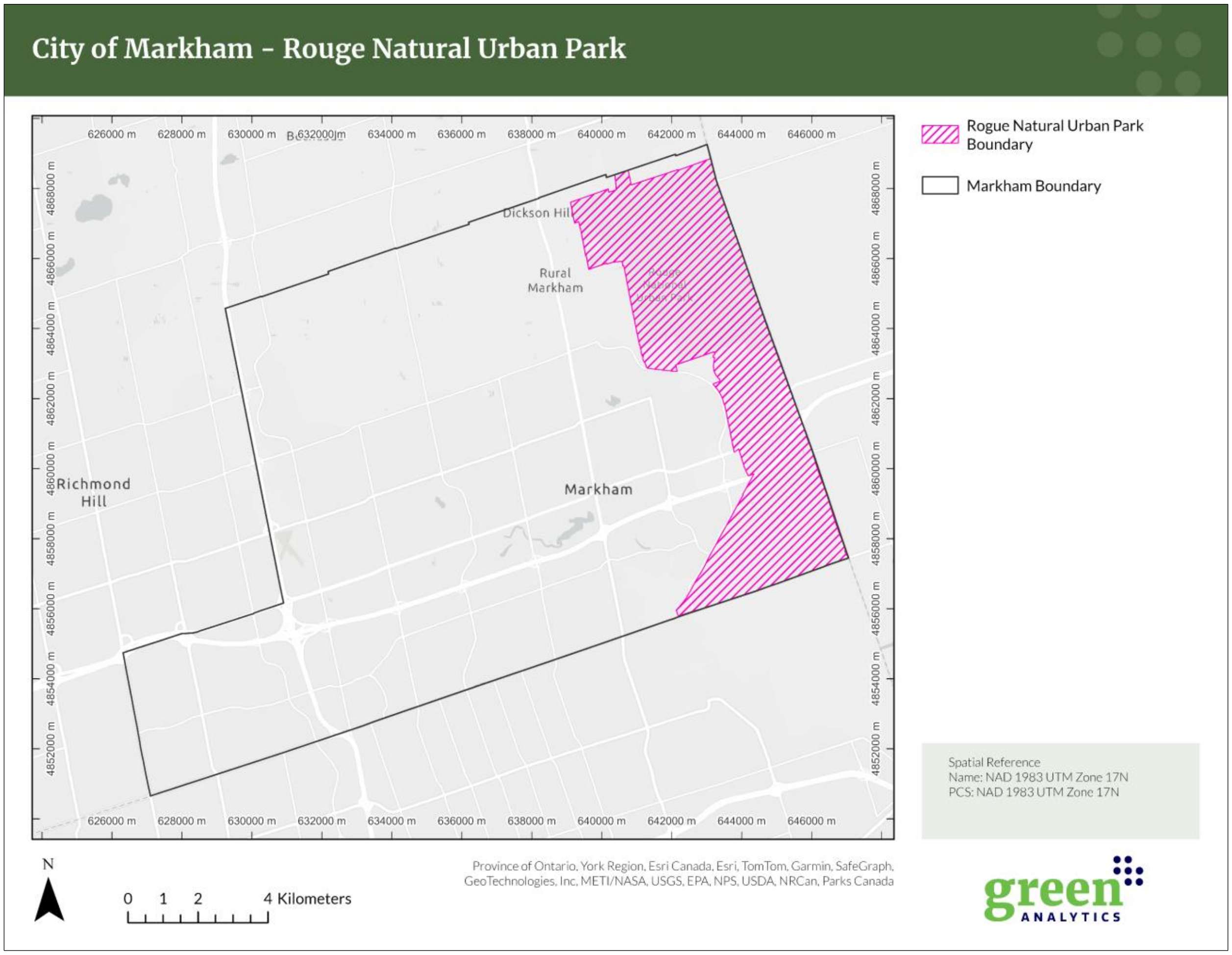

Figure 12-5. Map of Rouge Natural Urban Park area within Markham, ON.

Other Natural Heritage Designations

Three other land planning and conservation datasets were used to subdivide and classify Markham's Green Space and Agricultural Lands asset inventory: the Natural Heritage Network, Rouge Watershed Protection Area, and Oak Ridge Moraine Conservation Area. The boundaries of each of these were used to assign a category indicating if they were within one or more of these three boundaries, or not. The attribute fields and values indicating the presence/absence of each asset within one of the three boundaries is summarized in Table 11-1.

Table 12-1. Breakdown of attribute fields and values used to classify location of assets within boundaries of protected areas.

Boundary	Field Name	Value in Field Indicating Presence / Absence
Natural Heritage Network	NHN	Natural Heritage Network / Null
Rouge Watershed Protection Area	RWPA	Rouge Watershed Protection Area / Null
Oak Ridge Moraine Conservation Area	ORM	Oak Ridges Moraine Conservation Plan Area / Null

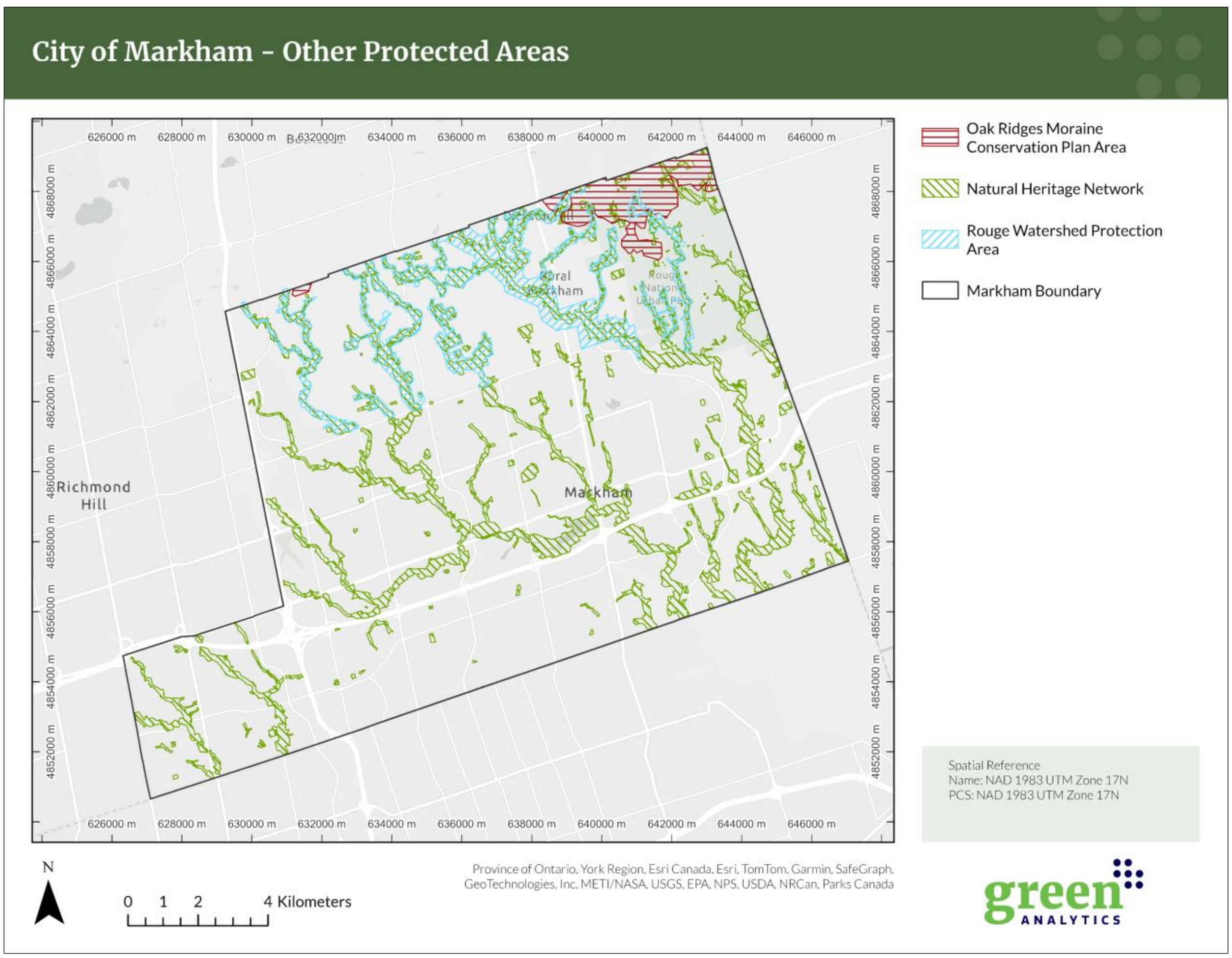

Figure 12-6. Map of other natural heritage designations within Markham, ON.

13 Appendix C: Additional Examples of Inventory Mapping Outputs

Sample mapping outputs from the Manicured Green Spaces and Agricultural Lands components of the City's Green Spaces and Agricultural Lands assets inventory.

Figure 13-1. Manicured open space assets (at Level 2).

Table 13-1. Area of manicured open space assets within location classification of Markham.

Agricultural Asset Location	Area (ha)
City-Owned Golf Course Greens	16.16
City-Owned Manicured Parklands for Passive Uses	410.76
Total	**426.92**

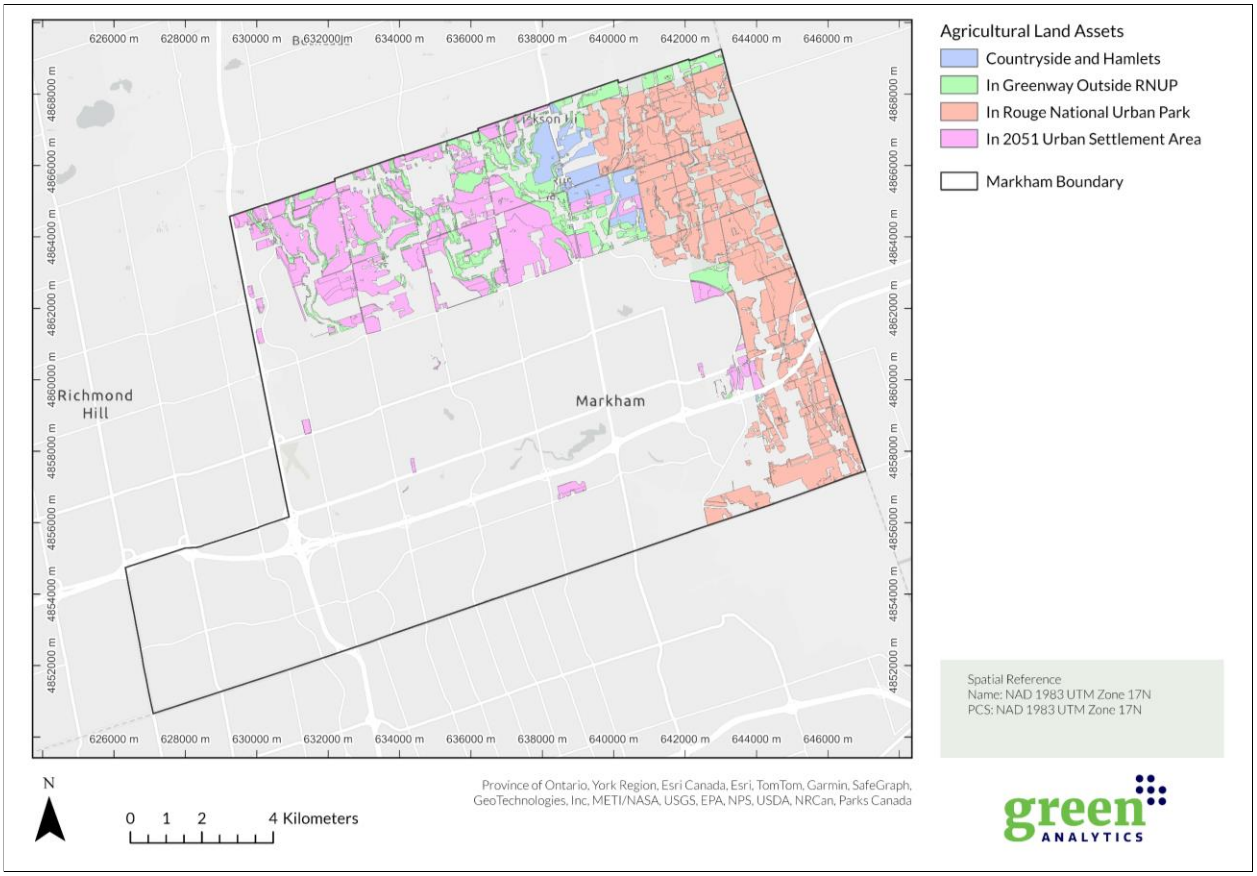

Figure 13-2. Agricultural land asset types (at Level 3).

Table 13-2. Area of agricultural asset types at Level 3 (on public and private lands).

Agricultural Land Asset Types (Level 3)	Area (ha)
In Countryside and Hamlets (i.e., Greenbelt Area)	342.25
In Greenway System but outside RNUP	852.57
In Rouge Natural Urban Park (RNUP)	2,460.74
In 2051 Urban Settlement Area	1,829.30
Total	**5,484.86**

14 Appendix D: Condition Assessment Approach Details and Results

Through a collaborative process with the City of Markham project team and TAC, the following suite of five condition indicators were identified. The indicators are evenly weighted to determine overall condition.

CRITERIA FOR PHYSICAL CONTEXT:

1. Natural Area Patch Size and Shape
2. Natural Asset Proximity to Watercourses

CRITERION FOR ECOLOGICAL CONDITION:

3. Relative Habitat Quality

CRITERIA FOR LANDSCAPE CONTEXT:

4. Extent of Adjacent Complementary Land Uses
5. Intensity of Encroachments

For each of these indicators this appendix provides:

- A brief description of the indicator.
- The rationale for using this indicator to reflect natural asset condition.
- The approach used (including scoring) for assessing the asset condition.
- The results based on the available data and approach used.

14.1 Natural Areas Patch Size and Shape

INDICATOR: This indicator measures the relative size and shape of contiguous natural asset areas across the city, with larger patches that are more round or square rather than linear being considered of higher quality than smaller patches that are more linear with little or no “interior” habitat (i.e., all edge).

RATIONALE: The objective of this indicator is to create a proxy for condition based on the relative size and shape of contiguous patches of natural assets. In general, larger blocks of habitat (whether they be meadow, forest, and/or wetland) tend to support a greater diversity of plants and wildlife, including habitat specialists that require or benefit from conditions only found somewhat removed from a non-natural land cover type (e.g., roads, residential, institutional, or commercial development). In an urban or urbanizing context, as the distance from the edge of a natural area towards the interior of that area increases, the human-related disturbances and encroachments that can negatively impact certain species associated with those habitats decrease (Environment Canada 2013).

In urban settings there are generally very few large blocks of any one type of habitat that provide genuine interior conditions, and this is the case in Markham where the largest contiguous blocks of habitat tend to be mixtures of upland habitats (e.g., cultural meadows and woodlands) with some wetlands interspersed. Contiguous blocks of any habitat type can be assumed to have a higher level of ecological function due to being larger in size, having less edge and having more consolidated “interior” habitat.

Given this context and recognizing the landscape ecology principle of large “blocks” of habitat generally provide a greater range of habitats of better quality, we have developed a scoring system based on established federal guidance but tailored to allow for meaningful application in Markham.

APPROACH: “Interior” habitat – at least in woodlands - is typically measured starting at 100 m inwards from the feature edge (e.g., Environment Canada 2013). However, most of Markham’s natural assets are associated with long, sinuous valley corridors and tend to be somewhat linear rather than “blocks”, with limited “interior” habitat. In addition, NSEI and DAI (2021) found that over 78% of the natural assets in the Greenway System are linked by corridors that are at least 50 m wide while just over 60% of habitat patches are linked by corridors of at least 100 m wide. Therefore, to capture differences among and between habitat patches in Markham it was considered appropriate to establish scoring where the presence of any interior habitat was considered “very good” at 100 m from the patch edge (i.e., so a patch of at least 200 m wide), and then scaled back at equal increments to patches of 50 m wide (as measured at 25 m from the edge) being rated as “poor” for this condition.

This condition indicator was applied to “patches” (i.e., Level 1 natural assets). The extent of “interior” area within the natural area patches was assessed on a sliding scale based on the amount of distance in from the edge of the overall area, and transferred to each natural asset polygon (i.e., ELC Community Series) at Level 3 of the inventory within each natural area “patch”. Ratings were allocated as defined in Table 13-1.

Table 14-1. Natural asset patch size and shape condition score.

Rating	Description
Very good	An asset within a habitat patch with an interior area measured 100 m from the feature edge
Good	An asset within a habitat patch with an interior area measured 75 m from the feature edge and not already captured as “excellent”
Fair	An asset within a habitat patch with an interior area measured 50 m from the feature edge and not already captured as “excellent” or “good”
Poor	An asset within a habitat patch with an interior area measured 25 m from the feature edge and not already captured as “excellent”, “good”, or “fair”
Very poor	Any asset with no interior area measured at 25 m from the feature edge

RESULTS:

Figure 14-1. Natural asset patch size and shape condition results.

Table 14-2. Natural Asset Patch Size and Shape Condition Results.

Level 2 Asset Type	Very Good	Good	Fair	Poor	Very Poor
Woodland	1,153.36	225.76	190.45	104.27	33.43
Meadow	927.78	163.57	196.93	160.22	50.42
Wetland	482.33	56.46	57.97	30.01	6.09
Open Water	118.39	19.63	32.14	12.54	13.63
Hedgerow	53.33	3.19	8.05	0.99	5.24
Beach / Bar / Bluff	2.00	0	0	0	0
Total Area (ha)	**2,737.20**	**468.62**	**485.55**	**308.02**	**108.82**

14.2 Natural Asset Proximity to Watercourses

INDICATOR: The distance each asset is to the nearest watercourse line file was measured.

RATIONALE: As in many municipalities across southern Ontario, valleylands with watercourses running through them form the "backbone" of Markham's natural heritage system (referred to as the City's Natural Heritage Network (NHN)), as can be seen in the City's Official; Plan Map 6 (see Figure 13-2).

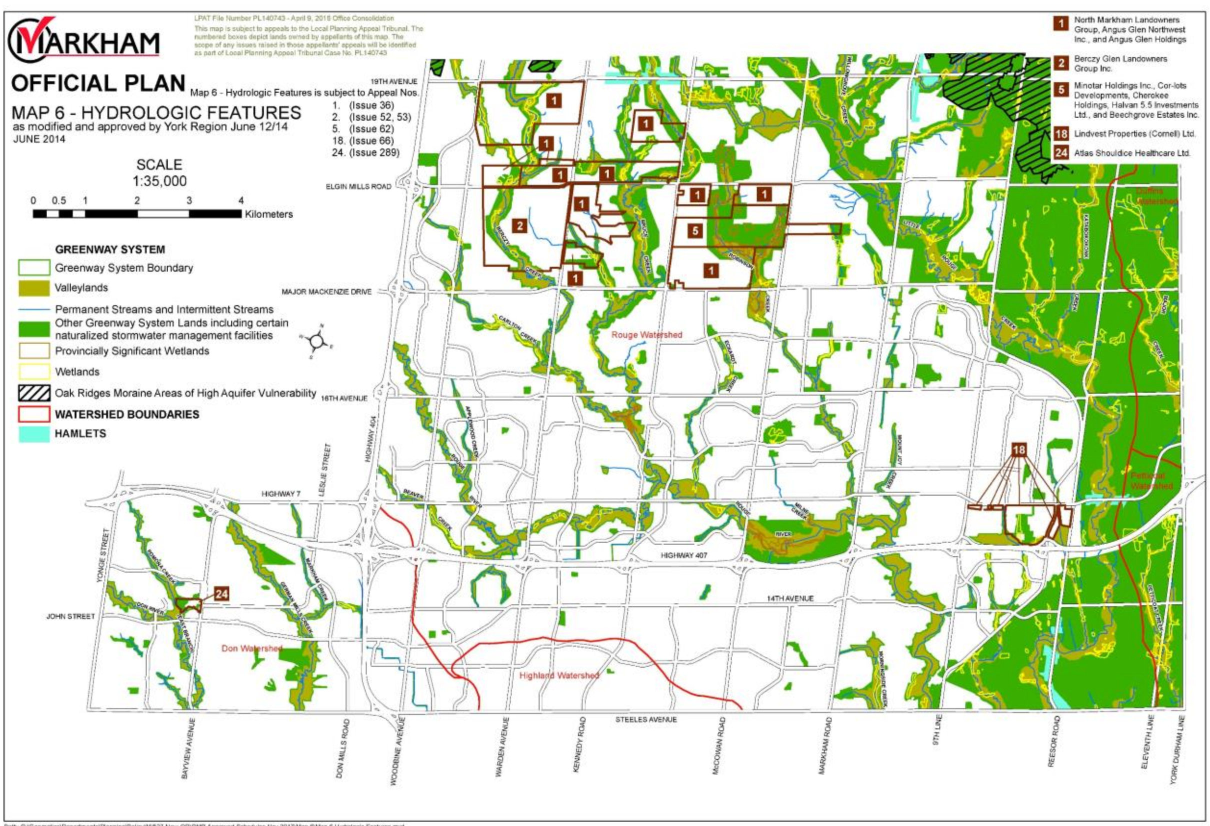

Figure 14-2. Markham's Official Plan map of hydrologic features including valleylands and associated watercourses shown in the context of the Greenlands System.

In addition to a natural area's intrinsic size and shape, its location in relation to other natural assets and features within a given area also influence the types of ecological functions it can provide.

Proximity of a terrestrial natural asset to water, or having a hydrologic feature within a terrestrial asset, is generally considered something that contributes positively to its function. Environmental Canada's habitat guidelines for southern Ontario (EC 2013) and the Province's Natural Heritage Reference Manual (MNRF 2010) both ascribe ecological significance to terrestrial habitats that contain or are close to hydrological features such as wetlands that occur within floodplains (which are associated with watercourses), woodlands with wetlands and/or watercourses within them, and grassland/meadow habitats adjacent or close to riparian and/or wetland habitats.

Specific distances / thresholds cited in these documents noted as heightening feature functions are:

- Naturalized riparian habitat within at least 30 m of a watercourse edge (i.e., top of bank) (EC 2013).
- Woodlands within 50 m of a watercourse (MNRF 2010).
- Woodlands within 30m of a watercourse or wetland (Markham Official Plan).

In addition, Markham's official plan identifies woodlands over 0.5 ha within 30m of a watercourse or wetland to be significant and 120 m is the standard distance used for considering adjacency to an identified natural asset in terms of the lands within which negative impacts to an asset may occur.

APPROACH: Watercourse centre lines were provided by the City and incorporated into the natural asset registry. The distance between Level 3 assets and the watercourse lines was measured. Ratings were allocated as defined in Table 13-3.

Table 14-3. Natural asset patch size and shape condition score.

Condition Rating	Description
Very good	Assets that directly intersect a watercourse.
Good	Assets that are within 30 m of a watercourse but do not directly intersect it.
Fair	Assets that are within 30 - 120 m of a watercourse.
Poor	Assets that are within 120 – 240 m of a watercourse.
Very poor	Assets that are greater than 240 m away from a watercourse.

RESULTS:

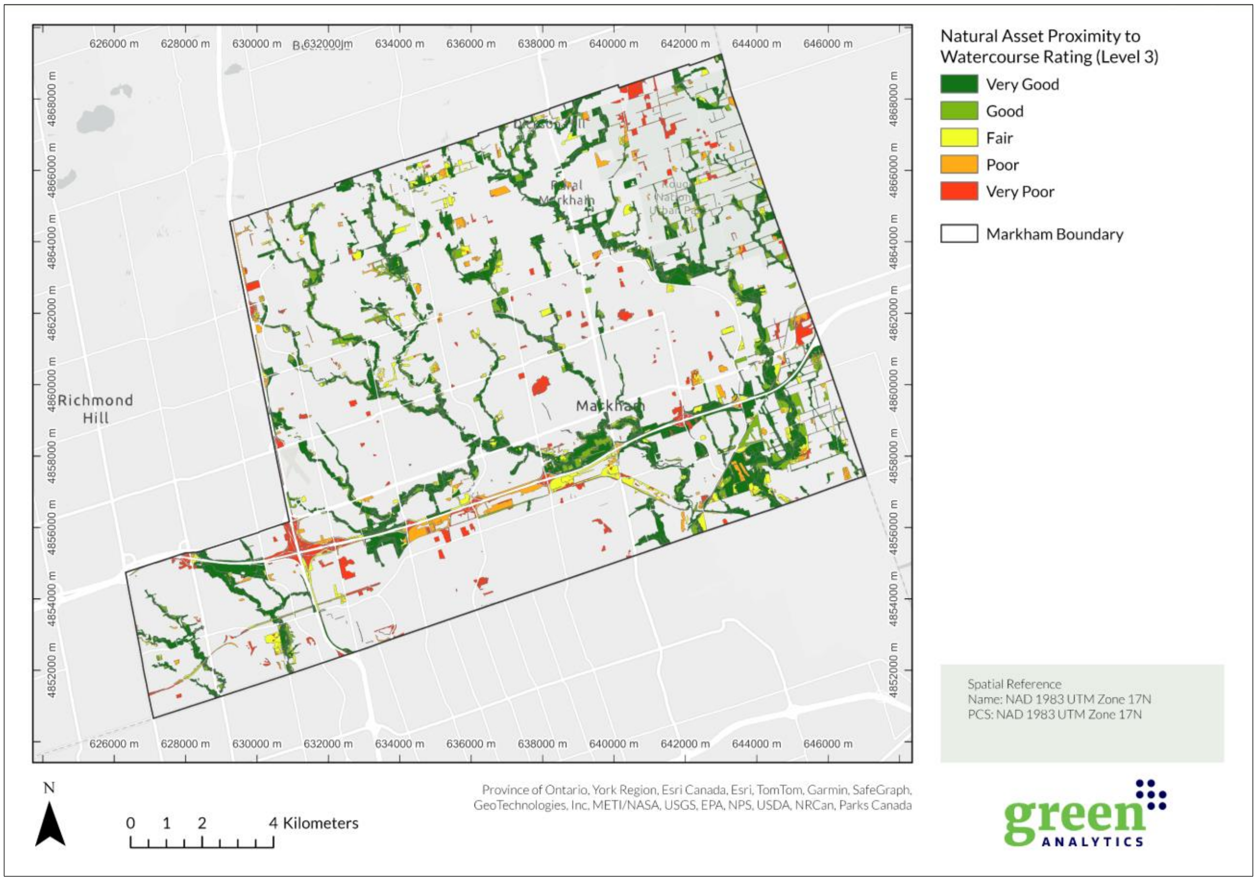

Figure 14-3. Natural asset proximity to watercourse condition results.

Table 14-4. Natural asset proximity to watercourse condition results.

Level 2 Asset Type	Very Good	Good	Fair	Poor	Very Poor
Woodland	1,043.45	264.61	161.51	106.02	131.68
Meadow	753.16	145.81	204.53	171.20	224.24
Wetland	453.55	52.74	57.77	26.23	42.77
Open Water	125.41	15.26	26.57	6.40	22.70
Hedgerow	21.40	12.87	21.25	8.73	6.55
Beach / Bar / Bluff	2.00	0	0	0	0
Total Area (ha)	**2,398.97**	**491.30**	**471.43**	**318.57**	**427.94**

14.3 Relative Habitat Quality

INDICATOR: This metric is intended to capture asset quality as reflected in the relative proportion of native and significant species within the asset.

RATIONALE: Invasive plant species in Markham's natural assets are known to be a significant, widespread, and well-documented risk to the condition of these assets – both on City- and non-City-owned natural assets (NSEI and DAI 2021, CBCL 2021, CBCL 2022). These studies found that invasive and non-native species were abundant or dominant in about half of the forested and swamp polygons (i.e., deciduous and coniferous forest and all types of swamps) as well as in more than two thirds of the cultural polygons (i.e., cultural woodlands, cultural thickets and cultural savannas). Invasive plant species are known to present a significant threat to the function and native diversity of local habitats. Therefore, natural asset polygons and patches with relatively high proportions of non-invasive and native species are considered of better quality, and therefore better condition. Significant plant species are also often used as an indicator of habitat condition since, in general, only habitats in fair to very good condition are able to support such species.

APPROACH: Natural area surveys of City of Markham land holdings were completed in 2020, 2021 and 2022 and linked to the City's ELC spatial data (NSEI and DAI 2021, CBCL 2021, CBCL 2022). As part of that data collection process, the different native plant species and of provincially/regionally/locally significant plant species were identified within natural assets owned by the City of Markham. Drawing on this information, a condition rating was developed based on (a) the number of native plant species and (b) number of significant plant species within each natural asset polygon, as summarized in the scoring table below. The ranges for numbers of native plant species for each scoring level was adopted from the NSEI and DAI (2021) study that used these ranges to identify native plant species "hotspots" in the context of Markham based on the data collected.

This condition indicator was applied to Level 3 natural assets, but only to those sections directly derived from the ELC data. However, this metric could only be applied to City-owned natural assets and those directly connected to them because it is only within those lands that additional site-specific field work was undertaken to collect this data. A count of the number of unique species present in the Level 3 inventory of assets was used to assign a rating of relative habitat quality.

SCORING: Ratings were allocated based on an "OR" condition meaning the highest rating of native plant species or significant plant species was used to set the condition rating. Specific definition for each condition rating are shown in Table 13-5.

Table 14-5. Natural asset relative habitat quality condition score.

Condition Rating	Native plant species	Significant plant species
Very good	+62 native species occurrences	17-24
Good	37-62 native species occurrences	9-16
Fair	21-36 native species occurrences	2-8
Poor	1-20 native species occurrences	1
Very poor	0 native species occurrences	0

RESULTS:

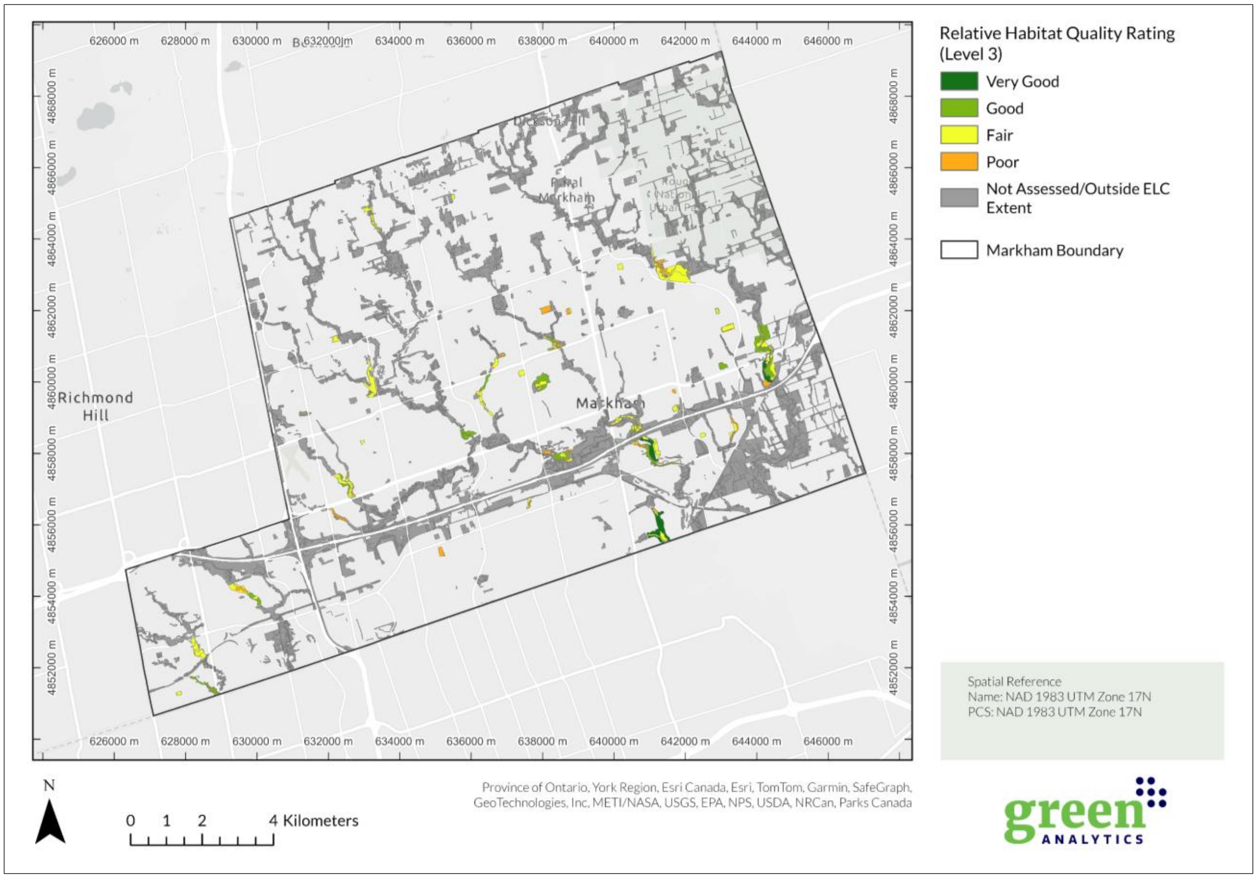

Figure 14-4. Natural asset relative habitat quality condition results.

Table 14-6. Natural asset relative habitat quality condition results.

Level 2 Asset Type	Very Good	Good	Fair	Poor	Not Assessed
Woodland	34.00	69.60	106.19	25.51	1,471.98
Meadow	0	0.06	39.16	2.01	1,457.70
Wetland	0	11.67	20.36	14.06	586.77
Open Water	0	0	0	6.16	190.18
Hedgerow	0	0	0	0	70.80
Beach / Bar / Bluff	0	0	0.01	0.27	1.72
Total Area (ha)	**34.00**	**81.34**	**165.71**	**48.00**	**3,779.16**

14.4 Extent of Adjacent Complementary Land Uses

INDICATOR: Extent of complementary land uses within 50m of assets less than 1 ha in size and 120 m of all other asset sizes (applied at Level 1).

RATIONALE: How and the extent to which a given natural area is influenced by drainage in the adjacent landscape varies depending on factors such as local topography and soils, where the feature "sits" in the landscape (e.g., upland versus lowland) and the size and nature of the feature itself. However, it is well-established that the condition of a terrestrial natural feature in an urban context tends to be negatively impacted when more of the surrounding land uses are impervious (i.e., paved, concrete or buildings) as this tends to alter pre-existing drainage and infiltration pathways, that can cause a natural area to receive more, or less, drainage than prior to being in an urban context. Urban runoff also typically carries a host of sediments and contaminants, and when such runoff is directed to natural areas and not properly treated, it can also negatively impact the feature and its functions.

Increases in the extent of impervious surfaces within a given watershed or catchment area are generally known to have negative impacts to natural features in that watershed or catchment area, particularly for features downstream of the impervious areas, resulting in a push towards planning that limits impervious surfaces and incorporates low impact development measures that facilitate local infiltration (e.g., Government of Ontario 2006, Government of Ontario 2018). Environment Canada's (2013) guidance for streams/watercourses in urbanized watersheds in southern Ontario states that "impairment in stream water quality and quantity is highly likely above 10% impervious land cover and can often begin before this threshold is reached. In urban systems that are already degraded, a second threshold is likely reached at the 25 to 30% level".

However, land cover types with extensive pervious surfaces that are not "natural" per se but occur in the lands adjacent to natural areas, such as manicured parks/open spaces and agricultural lands, are recognized as potentially supporting the functions of nearby natural areas in some regards by providing one or more of the following:

- Permeable surfaces (and therefore potentially supporting hydrologic regimes).
- Temporary or permanent vegetation (e.g., isolated or small groupings of trees/landscaped areas, agricultural crops), and/or
- Intervening land uses between natural areas and built areas that are used less frequently and/or less intensively by people.

Therefore having, for example, manicured greenspace between a wooded valley and medium to high density residential area, is generally considered preferable to having the medium to high density residential area directly abutting the natural valley.

As an urbanizing area continually seeking to balance growth and development with environmental protections, the City of Markham has been working to place complementary land uses beside protected natural areas. This indicator is intended to capture these scenarios and acknowledge their contributions to natural asset condition.

APPROACH: A 50m (for assets less than or equal to 1 ha) or 120 m (for assets greater than 1 ha) buffer was drawn around each natural asset "patch" at Level 1 (i.e., contiguous area of adjacent natural asset types). The cut off was assessed based on histograms of the natural area extent of level 1 areas. The extent of landcover associated with complementary land uses and natural assets was estimated. Areas of complementary uses include agriculture, built-up pervious and golf courses.

The area of the buffers were estimated in hectares, and the percentage of each buffer comprised of the complementary land uses was determined. Scoring is based on the percentage of an asset's adjacent lands (i.e., measured at 50 or 120 m) that is composed of complementary land uses as per Table 13-7.

Table 14-7. Extent of adjacent complementary land uses condition score.

Condition Rating	Description
Very good	51 to 100% complementary land uses within buffer
Good	31% to 50% complementary land uses within buffer
Fair	16% to 30% complementary land uses within buffer
Poor	1% to 15% complementary land uses within buffer
Very poor	0% complementary land uses within buffer

RESULTS:

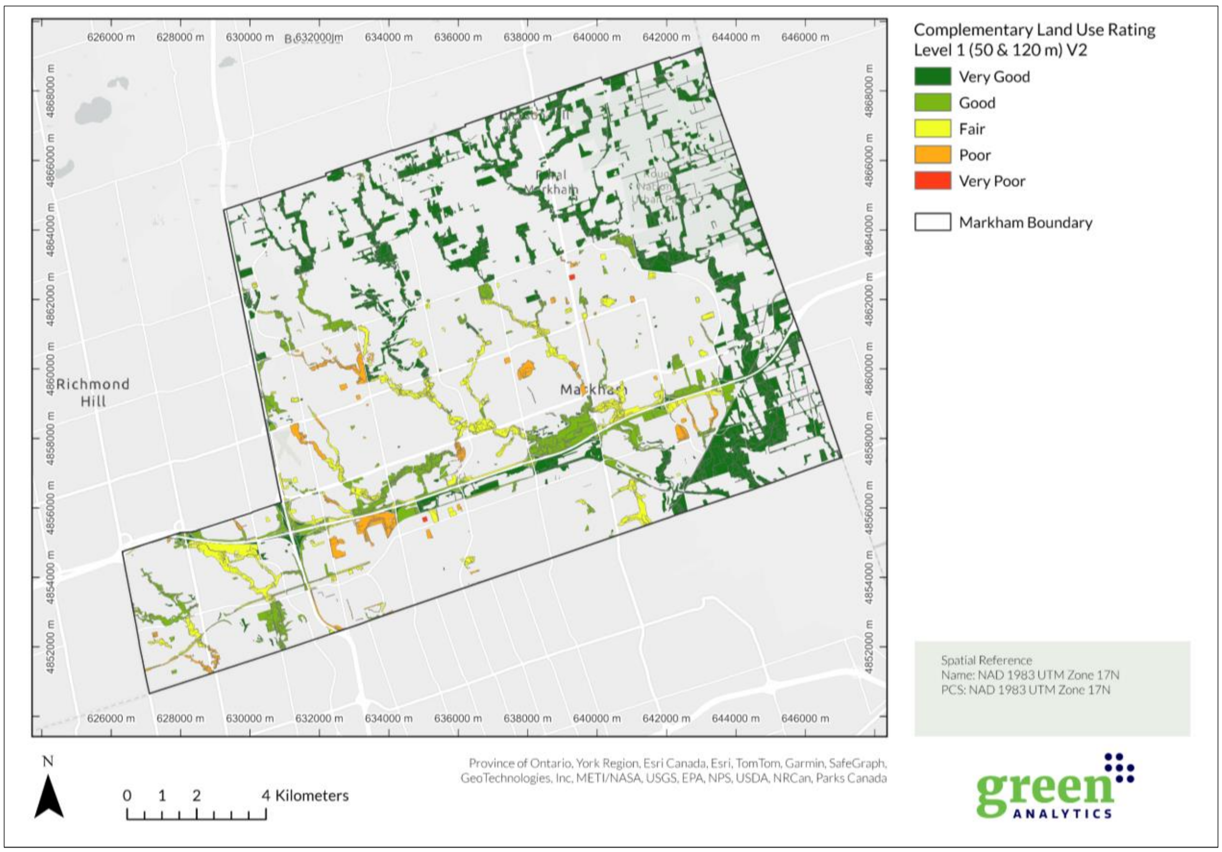

Figure 14-5. Extent of adjacent complementary land uses condition results.

Table 14-8. Extent of adjacent complementary land uses condition results.

Level 2 Asset Type	Very Good	Good	Fair	Poor	Very Poor
Woodland	952.97	318.14	328.22	107.94	0
Meadow	797.42	358.05	232.43	106.30	4.73
Wetland	484.47	68.13	45.44	34.82	0
Open Water	71.15	63.72	47.07	14.28	0.11
Hedgerow	66.94	3.82	0.04	0	0
Beach / Bar / Bluff	1.11	0.63	0.27	0	0
Total Area (ha)	**2,374.06**	**812.50**	**653.47**	**263.34**	**4.84**

14.5 Intensity of Human-related Encroachment/Disturbances

INDICATOR: The number and degree of human-related encroachments/disturbances from adjacent land uses documented within the natural asset.

RATIONALE: The City recognizes the importance and value of providing appropriate levels and types of human access to public greenspaces, including publicly-owned natural areas. However, in rapidly urban and urbanizing jurisdictions like Markham, balancing the provision of access with the need to try and protect and sustain the ecological features and functions associated with these natural areas requires ongoing monitoring and management, including working with local user groups. There are many types of unauthorized activities that occur in public natural areas that are known to compromise the structure and ecological functions of these areas. These are often referred to as “encroachments” and include things like unauthorized trail creation, off-trail cycling, dumping yard or other waste, plantings of non-native and invasive species, mowing and/or removal of native vegetation, etc. (e.g., Park 2020).

APPROACH: In the City of Markham, field data related to the types and extent of visually evident encroachments within the City-owned natural assets has been documented over the past few years (NSEI and DAI 2021, CBCL 2021, CBCL 2022). Surveys of City of Markham owned lands were completed in 2020, 2021 and 2022 and linked to the City’s ELC spatial data. These surveys noted several different types of encroachments. We therefore have a reasonably robust database on which to capture the relative level of unauthorized human use / activity occurring in the City’s natural assets. Drawing on this data, encroachments were organized around two broad categories as noted below. Descriptions of each type are provided based on the initial documentation from the 2020 surveys (NSEI and DAI 2021).

Recreation:

- Tracks and trails - Tracks and trails were recorded as they generally indicate the intensity of recreational use in an area. Formal trails were not differentiated from informal trails as a well-marked trail was usually accompanied by the same level of disturbance, whether it was a wide formal or informal trail. Tracks and trails were reported as well-marked tracks or roads, or faint. For the condition rating, tracks and roads were considered “heavy”, well-marked trails were considered “moderate”, and faint trails were considered “light”.
- Evidence of other unauthorized activities – Impacts from unauthorized activities include trampled vegetation, soil compaction, spread of non-native species and disruption of breeding in wildlife species. Activities noted in the data include partying, trampling of vegetation, vegetation removal, and built bike jumps. For the condition rating, evidence of unauthorized activities was recorded as light, moderate, or heavy.

Disturbances:

- Planting - Planting was recorded as it is generally accompanied by large-scale disturbance or can be an indication of previous cultural origins for a community. Planting was reported as occasional (considered "light"), abundant (considered "moderate"), or dominant (considered "heavy").
- Dumping - Dumping is an indicator of disturbance as it is associated with compaction of soils and potential for introduction of non-native species. It was indicated by piles of dead leaves, building debris, litter and compost piles. Dumping was reported as light, moderate, or heavy.
- Earth displacement - Earth displacement was recorded if signs of site alteration were noted such as excavation or piles of soil. These are important indicators of disturbance as site alteration can compact soils and promote the spread of non-native species. Earth displacement was noted as light, moderate, or heavy.

This analysis was conducted at Level 3, however it was limited to areas within the ELC-derived sections, to the exact areas surveyed for this metric. Based on the number and intensity of encroachments, condition was applied as outlined in Table 13-9. Notably field surveys for this metric were only completed on the City-owned properties, therefore the condition ratings could only be applied to those lands.

Table 14-9. Natural asset encroachment condition score.

Condition Rating	Encroachments
Very good	None documented
Good	Only 1 type, moderate or light
Fair	1 heavy OR 2 moderate or light
Poor	2 heavy OR 3 moderate or light
Very poor	4-5 any

RESULTS:

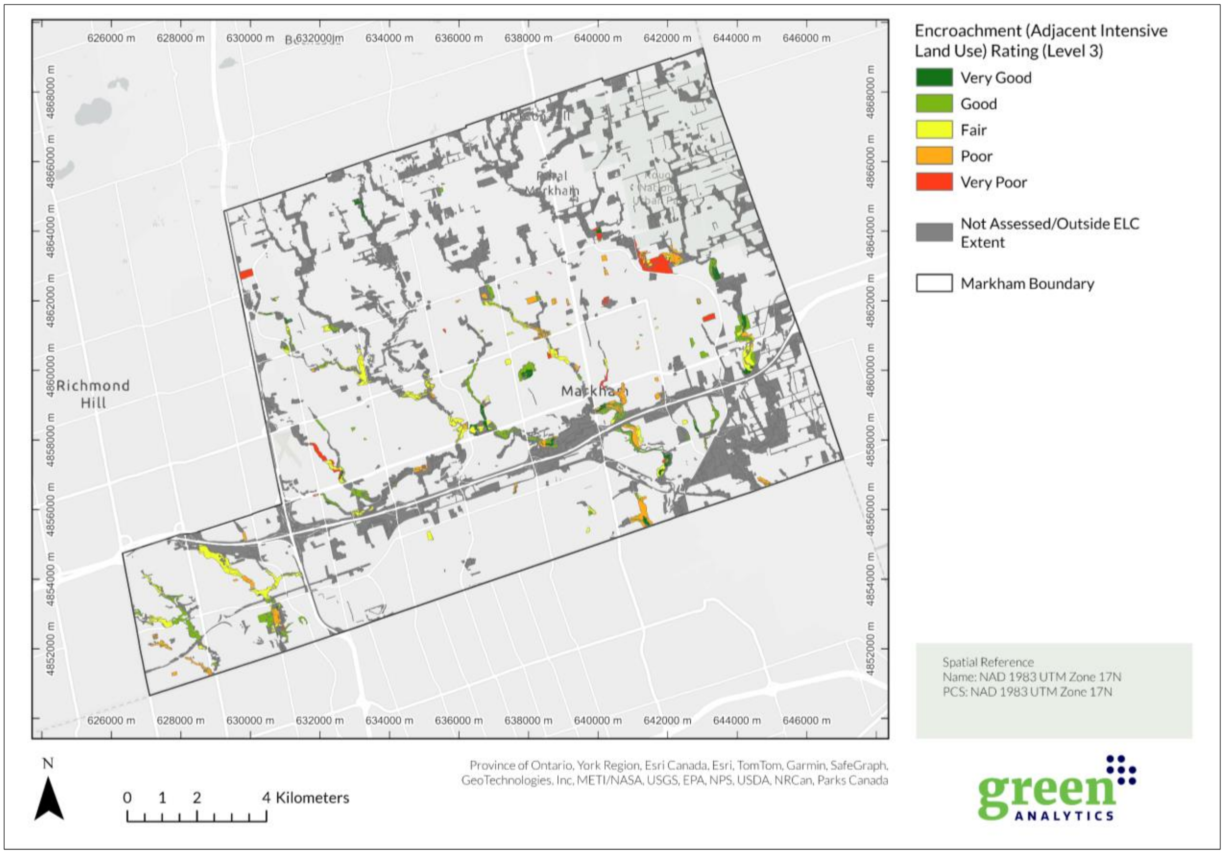

Figure 14-6. Natural asset encroachment condition results.

Table 14-10. Natural asset encroachment condition results.

Level 2 Asset Type	Very Good	Good	Fair	Poor	Very Poor	Not Assessed
Woodland	37.25	135.24	187.88	114.98	28.88	1,203.04
Meadow	7.85	32.47	18.55	18.16	41.98	1,380.01
Wetland	21.19	36.27	6.69	6.50	0	562.22
Open Water	3.00	0.38	1.39	0	0.32	191.25
Hedgerow	0	0	0	0	0	70.80
Beach / Bar / Bluff	0.01	0.27	0	0	0	1.72
Total Area (ha)	**69.30**	**204.63**	**214.50**	**139.64**	**71.08**	**3,409.05**

15 Appendix E: Risk Assessment Approach

15.1 Risk and the Natural Assets Hierarchy

The risk scores described in this report were applied to Markham's natural asset inventory. Table 15-1 provides a reminder of the natural asset hierarchy.

Table 15-1. Level hierarchy for natural assets.

Level 1 Asset Type	Level 2 Asset Type	Level 3 Asset Type
Natural Assets	Woodlands	Coniferous Forest
		Deciduous Forest
		Mixed Forest
		Cultural Woodland
		Plantation
		Cultural Savanah
		Cultural Thicket
		Treed Bluff
	Wetlands	Coniferous Swamp
		Deciduous Swamp
		Mixed Swamp
		Thicket Swamp
		Meadow Marsh
		Shallow Marsh
		Treed Fen
		Floating-leaved Shallow Aquatic
		Submerged Shallow Aquatic
	Meadows	Cultural Meadow
		Open Tallgrass Prairie
	Waterbody	Open water
	Hedgerow	Hedgerow
	Beach/Bar/Open Bluff	Open Beach/Bar
		Shrub Beach/Bar
		Open Bluff

15.2 Overview of the Hazards Risk Assessment

On October 20, 2023, the project team hosted a workshop focused on exploring and rating a range of hazards that could negatively affect Markham's natural assets.

The objective of a hazards risk assessment is to identify and rank (for impact and likelihood) the hazards that may negatively impact a community's natural assets.

The general steps to undertaking this type of assessment are:

a) Identify the range of potential hazards.
b) Rank the impact of each hazard.
c) Rank the likelihood of each hazard.
d) Calculate an overall risk score (impact * likelihood).
e) Allocate risk scores to relevant natural assets.

These steps and the results of this exercise are described below.

2a. Identify the Range of Potential Hazards

The first step in the assessment was to identify the range of hazards that could negatively impact Markham's natural assets. During the October 20th workshop, the project team presented City of Markham staff with a list of potential hazards. The list was discussed and refined. The result was a list of 14 hazards for closer consideration (Table below).

Table 15-2. Range of potential hazards.

Hazards to Natural Assets	Description	Examples
Invasive species	Invasive plant species able to negatively impact a natural asset such that its ability to provide the services for which it is being assumed / maintained is impaired.	FORESTS - Buckthorn, Garlic Mustard; WETLANDS, BEACH BAR - Phragmites
Pests and disease	Pests (primarily insects) and diseases able to negatively impact a natural asset such that its ability to provide the services for which it is being assumed / maintained is impaired.	TREE & FOREST PESTS - Emerald Ash Borer, Asian Long-horned Beetle, Spruce Budworm; TREE DISEASES - Butternut Canker, Beech Bark Disease, Dutch Elm Disease
During construction impacts	Impacts resulting from activities during construction within or adjacent to natural assets able to negatively impact the natural asset such that its ability to provide the services for which it is being assumed / maintained is impaired.	WETLANDS - Silt going into asset due to absent or poor ESC maintenance; FORESTS - Individual trees or trees on edge of feature damaged / killed by machinery due to absent or poor tree protection
Unauthorized edge encroachments and disturbances	Impacts resulting from inappropriate** and unauthorized activities adjacent to and within natural assets (post-construction) able to negatively impact the natural asset such that its ability to provide the services for which it is being assumed / maintained is impaired.	ALL ASSETS - Dumping of yard or other waste from adjacent land use; FORESTS, WETLANDS & BEACH/BAR/BLUFF - Installation of forts, sheds, jumps for motorized and non-motorized bicycles, or other structures; Mowing or other gardening; Creation of informal trails;
Flooding	Naturally occurring risk exacerbated by both urbanization (i.e., reduced permeable surfaces with inadequate stormwater management controls in some areas of the city or upstream) and climate change (i.e., increased frequency and intensity of storm events) .	OPEN WATER - Overtopping existing top of banks and inundating adjacent lands and/or WETLANDS - Exceeding typical range of water levels for extended periods - resulting in loss of riparian habitats and associated functions including erosion control and water quality control, increased sedimentation.

Hazards to Natural Assets	Description	Examples
Erosion and sedimentation	Naturally occurring risk exacerbated by flooding, urbanization (i.e., reduced permeable surfaces with inadequate stormwater management controls in some areas of the city or upstream) and climate change (i.e., increased frequency and intensity of storm events).	NATURAL ASSETS ALONG EDGE OF OPEN WATER - Erosion along banks and sedimentation in waterways, loss of riparian habitats.
Extreme Wind	Naturally occurring risk exacerbated by climate change (i.e., increased frequency and intensity of extreme wind events). Applies to forested features only.	FORESTS / HEDGEROWS - Severe and / or extensive mechanical damage cause to individual trees and/or wooded areas.
Ice Storms	Naturally occurring risk exacerbated by climate change (i.e., increased frequency and intensity of ice storm events). Applies to forested features only.	FORESTS / HEDGEROWS - Severe and / or extensive mechanical damage cause to individual trees and/or wooded areas.
Drought	Naturally occurring risk exacerbated by both urbanization (i.e., changes in drainage and infiltration) and climate change (i.e., increased frequency and intensity of heat events) .	FORESTS / HEDGEROWS - Severe and / or extensive drying of substrates / soils resulting in extensive die-back and / or mortality; WETLANDS & OPEN WATER - reduced water levels and / or loss of habitats and related functions.
Extreme heat	Heat stress to vegetative communities caused by extreme and sustained or repeated heat events.	FORESTS / HEDGEROWS - Severe and / or extensive drying of substrates / soils resulting in extensive die-back and / or mortality; WETLANDS & OPEN WATER - reduced water levels and / or loss of habitats and related functions.
Overuse (within public natural areas)	Impacts resulting from excessive and overuse of publicly accessible natural assets causing negatively impacts.	FORESTS, WETLANDS, MEADOWS, BEACH / BAR / BLUFF - Widening of formal trails and / or off-trail activities, use of motorized vehicles such as ATVs, dogs off-leash, etc. causing compaction and vegetation loss, disturbing wildlife, etc.
Run-off (road, agricultural) impacts to terrestrial upland assets	Introduction of pollutants and/or chemicals to the asset that can seriously impair the function of or kill the asset.	ALL ASSETS - Metals and oils from urban road run-off, salt runoff and/or spray.
Run-off (road, agricultural) impacts to aquatic/lowland assets	Introduction of pollutants and/or chemicals to the asset that can seriously impair the function of or kill the asset.	ALL ASSETS - Metals and oils from urban road run-off, salt runoff and/or spray.
Chemical/pollutant spills - aquatic	Introduction of pollutants and/or chemicals to the asset that can seriously impair the function of or kill the asset.	ALL ASSETS - Spills or leaching of chemicals from current or former industrial uses or landfill.

2b. Rank the Impact of Each Hazard

The second task in the workshop was to assign an impact score to each hazard on a scale of 1 to 5, where 1 is a very low impact and 5 is very high impact. Table 15-3 contains impact rating criteria based on financial, socio-economic, and environmental impacts.

Table 15-3. Rating the impacts of hazards on natural assets.

Scale	Impact	Financial	Socio-economic	Environmental
5	Very High	Cost of remediation exceeds annual budget > 100 times	Permanent loss of related services	Potential to cause long term environmental damage to the condition of the natural assets.
4	High			
3	Moderate	Cost of remediation exceeds annual budget > 10 times	Temporary loss of related services.	Potential to cause short term repairable environmental damage to the condition of the natural asset over a large area.
2	Low			
1	Very low	Cost of remediation falls within annual budget	Little to no effect on related services	Potential to cause non-lasting damage to environmental assets.

Table 15-4 contains the impact ratings assigned to each hazard during the workshop. High impact ratings were assigned to invasive plants, pests and diseases and run off impacts to aquatic and lowland assets.

Table 15-4. Risk impact ratings for Markham's hazards.

Potential Hazards to Natural Assets	Risk Impact Rating
Invasive plants	4.5
Pests and diseases	4
During construction impacts	1.5
Unauthorized encroachments/disturbances	1.5
Flooding	2.5
Erosion and sedimentation	3
Extreme wind	3
Ice storms	3
Drought	3
Extreme Heat	2
Overuse (within public natural areas)	2.5
Run-off (road, agricultural) impacts to upland assets	2
Run-off (road, agricultural) impacts to aquatic & lowland assets	4
Chemical/pollutant spills to aquatic assets	3.5

2c. Rank the likelihood of Each Hazard

In addition to an impact score, for each hazard a likelihood score was then allocated on a scale of 1 to 5, where 1 is rare and 5 is almost certain. Table 15-5 provides a summary of the likelihood ratings that were used as a reference. In this context, the focus of the likelihood scoring was on how likely or how frequent each hazard's impacts are anticipated to occur.

Table 15-5. Likelihood ratings for hazards.

Scale	Likelihood	Description	Annual probability	Return period
1	Rare	Likely to occur once every 50 years or less	Less than or equal to 2%	1:50 or less
2	Unlikely	Likely to occur between once every 21 years and once every 50 years	2 to less than 5%	1:21 to 1:50
3	Possible	Likely to occur between once every 5 years and once every 20 years	5 to less than 20%	1:5 to 1:20
4	Likely	Likely to occur between once every 2 years and once every 5 years	20 to less than 50%	1:2 to 1:5
5	Almost certain	Likely to occur annually or several times per year	Greater than or equal to 50%	1:1 or more

Table 15-6 shows the results of the likelihood exercise. For each hazard, a likelihood rating was assigned.

Table 15-6. Likelihood scores for Markham's hazards.

Potential Hazards to Natural Assets	Risk Likelihood Rating
Invasive plants	5
Pests and diseases	4
During construction impacts	5
Unauthorized encroachments/disturbances	5
Flooding	3.5
Erosion and sedimentation	3
Extreme wind	4
Ice storms	3
Drought	3.5
Extreme Heat	3.5
Overuse (within public natural areas)	5
Run-off (road, agricultural) impacts to upland assets	5
Run-off (road, agricultural) impacts to aquatic & lowland assets	5
Chemical/pollutant spills to aquatic assets	2.5

2d. Calculate the Risk Score

Once each hazard was rated for impact and likelihood, an overall risk score for each hazard was generated by multiplying the impact score by the likelihood score. Table 15-7 demonstrates the derivation of the overall risk scores for the hazards identified for Markham.

Table 15-7. Risk scores for Markham's hazards.

Potential Hazards to Natural Assets	Risk Impact Rating	Risk Likelihood Rating	Risk Score
Invasive plants	4.5	5	22.5
Pests and diseases	4	4	16
During construction impacts	1.5	5	7.5
Unauthorized encroachments/disturbances	1.5	5	7.5
Flooding	2.5	3.5	8.75
Erosion and sedimentation	3	3	9
Extreme wind	3	4	12
Ice storms	3	3	9
Drought	3	3.5	10.5
Extreme Heat	2	3.5	7
Overuse (within public natural areas)	2.5	5	12.5
Run-off (road, agricultural) impacts to upland assets	2	5	10
Run-off (road, agricultural) impacts to aquatic & lowland assets	4	5	20
Chemical/pollutant spills to aquatic assets	3.5	2.5	8.75

Table 15-8 demonstrates how the impact and likelihood ratings translate into an overall risk score that can be ranked on a scale from very low to very high.

Table 15-8. Hazards risk rating framework.

		Impact				
		1 Very low	**2 Low**	**3 Moderate**	**4 High**	**5 Very high**
Likelihood	**5 Almost certain**	High 5	High 10	High 15	Very high 20	Very high 25
	5 Likely	Moderate 4	Moderate 8	Moderate 12	High 16	Very high 20
	3 Possible	Low 3	Low 6	Moderate 9	Moderate 12	High 15
	2 Unlikely	Very low 2	Low 4	Low 6	Moderate 8	High 10
	1 Rare	Very low 1	Very low 2	Low 3	Moderate 4	High 5

2d. Allocate Risk Scores to Natural Assets

With the risk scores established for each hazard, the next step was to determine which natural assets are most likely to be impacted by those hazards. This was done by first identifying the type of natural asset that will be subject to the particular risk and then identifying the specific assets (of that type) that the risks would apply to.

Table 15-9 provides a summary of the allocation criteria used for each hazard. The table links the risks with the relevant asset types and then within those asset types, the allocation assumptions that determine the specific assets that will be subject to the risks. For example, while a broad range of asset types have the potential to be subject to encroachment, those that are located within 20 metres of private properties will ultimately be subject to this risk.

Table 15-9. Assumptions used to allocate risk to individual assets.

Potential Hazards to Natural Assets*	Applicability by Natural Asset Class						Spatial Distribution Assumptions and Selection Criteria
	Woodlands	Wetlands	Meadow	Open Water	Beach / Bar / Bluff	Hedgerows	
Invasive species	Y	Y	Y	N	Y	Y	All relevant asset classes
Pests and disease	Y	N	N	N	N	Y	Woodlands and hedgerows only
During construction impacts	Y	Y	Y	Y	Y	Y	Any asset that intersects with the Official Plan and Zoning Application dataset
Unauthorized edge encroachments/disturbances	Y	Y	Y	Y	Y	N	All relevant assets directly abutting, or within 5 m of any residential land use
Flooding	Y	Y	Y	N	Y	Y	Assets within regulated flood zone
Erosion and sedimentation	Y	Y	Y	Y	Y	Y	Assets within erosion hazard mapping
Extreme wind - forest / woodlot	Y	N	N	N	N	Y	Woodlands and hedgerows only
Ice storms / freezing rain - forest / woodlot	Y	N	N	N	N	Y	Woodlands and hedgerows only
Drought	Y	Y	Y	Y	Y	Y	All asset classes
Extreme heat	Y	Y	Y	Y	Y	Y	All asset classes
Overuse (within public natural areas) caused by people (includes litter)	Y	Y	Y	N	Y	N	Relevant assets with formal trails, and/or adjacent to other public open space / parks
Run-off (road, agricultural) impacts to terrestrial upland assets	Y	N	Y	N	Y	Y	Relevant assets within 30m of major road or agricultural land
Run-off (road, agricultural) impacts to aquatic/lowland assets	N	Y	N	Y	N	N	Relevant assets within 30m of major road or agricultural land
Chemical/pollutant spills – aquatic only	N	N	N	Y	N	N	Open water only

*See Appendix 1 for descriptions and examples of each hazard

The allocation assumptions allow for the combined risk scores (Table 15-9) to be allocated to specific natural assets within the inventory. This resulted in the 14 hazards having a unique field in the asset inventory registering the associated risk score.

The final step in the hazards assessment process was to combine the risk scores (each on a scale of 1 to 25) into a single overall risk score for each asset. This is achieved by summing each of the individual hazard risk scores together. The following summarizes how the scores are combined:

- **Step 1:** Sum hazard risk scores to establish the maximum possible risk score any asset could have.
- **Step 2:** For each asset, sum all the hazard risk scores that have been allocated to the asset.
- **Step 3:** For each asset, divide the results of Step 2 by the results of Step 1, and then multiply by 100. This establishes a normalized hazard risk weighting on a scale of 0 to 100. The result is a relative risk score that captures the various hazard impact and likelihood scores as well as each individual assets exposure to the 14 priority hazards.
- **Step 4:** Each asset is then allocated a risk category as outlined in Table 15-10.

Table 15-10. Risk category assumptions.

Risk Category	Normalized Hazard Risk Score
Very Low	0 to <25
Low	25 to <40
Moderate	40 to <70
High	70 to <85
Very High	85 to 100

15.3 Establishing Probability and Consequence of Failure

To more closely parallel the approach to asset management used for built assets, it is useful to assign a PoF and CoF rating to a municipality's natural assets. The sub-sections below propose an approach for doing so.

3a. Establishing Probability of Failure (PoF)

In asset management, PoF rankings are typically allocated based on the condition of the asset. For instance, assets in very good condition are assumed to have a very low PoF and assets in very poor condition are assumed to have very high PoF. While this approach is commonly employed for built assets it is less applicable to natural assets, which are more resilient. In the case of natural assets, poor condition in and of itself does not necessarily mean a high PoF.

To reflect the relatively more resilient nature of natural assets we propose that PoF reflect not only the relative condition of the asset, but also the relative risk to those assets. Risk scores can be obtained through a hazards risk assessment (as described in the preceding section). Table 15-11 provides a proposed approach for combining risk and condition scores to generate a PoF score. As is shown in the table, assets with a very high-risk score that are also in low condition are going to have a relatively higher PoF.

Table 15-11. Combining condition and risk scores to estimate probability of failure.

Condition	Risk Score				
	Very Low	Low	Moderate	High	Very High
Very Good	PoF = 1 Rare	PoF = 1 Rare	PoF = 2 Unlikely	PoF = 3 Possible	PoF = 3 Possible
Good	PoF = 1 Rare	PoF = 2 Unlikely	PoF = 3 Possible	PoF = 3 Possible	PoF = 4 Likely
Fair	PoF = 1 Rare	PoF = 2 Unlikely	PoF = 3 Possible	PoF = 4 Likely	PoF = 5 Almost Certain
Poor	PoF = 2 Unlikely	PoF = 3 Possible	PoF = 3 Possible	PoF = 4 Likely	PoF = 5 Almost Certain
Very Poor	PoF = 3 Possible	PoF = 3 Possible	PoF = 4 Likely	PoF = 5 Almost Certain	PoF = 5 Almost Certain

Using the framework depicted above, each asset within the inventory can be assigned a PoF score.

3b. Establishing Consequence of Failure (CoF)

To assign CoF ratings, practitioners can consider the financial, socio-economic and environmental consequences of asset failure (Table 15-12).

Table 15-12. Rating natural assets for consequence of failure.

Scale	Impact	Financial	Socio-economic	Environmental
5	Very High	Cost of remediation exceeds annual budget > 100 times	Permanent loss of related services	Potential to cause long term environmental damage to the condition of the natural assets.
4	High			
3	Moderate	Cost of remediation exceeds annual budget > 10 times	Temporary loss of related services.	Potential to cause short term repairable environmental damage to the condition of the natural asset over a large area.
2	Low			
1	Very low	Cost of remediation falls within annual budget	Little to no effect on related services	Potential to cause non-lasting damage to environmental assets.

As an example of how CoF ratings could be assigned to Markham's natural assets, Table 15-13 presents CoF ratings by ELC class. In the table, the more "natural" ELC classes receive a higher CoF rating (based on the assumption that they would be more expensive to replace and could result in a greater loss of services). In contrast to this, the "cultural" classes, which tend to be previously disturbed sites in various states of succession, receive lower CoF ratings (these assets are assumed to be less expensive to replace and have relatively lower loss of services). The table also distinguishes between assets located within the greenway system, that are assumed to be more important (and thus have a high CoF) then those located outside the Greenway System.

Table 15-13. Summary of assumed consequence of failure ratings.

ELC Class	Assets Inside Greenway	Asset Outside Greenway
Open Beach / Bar	2	1
Shrub Beach / Bar	2	1
Open Bluff	2	1
Treed Bluff	3	2
Plantation	3	2
Cultural Savannah	2	1
Cultural Thicket	2	1
Cultural Woodland	3	2
Coniferous Forest	4	3
Deciduous Forest	4	3
Mixed Forest	4	3
Hedgerow	2	1
Cultural Meadow	2	1
Open Tallgrass Prairie	4	3
Open Aquatic	4	3
Floating-leaved Shallow Aquatic	4	3
Submerged Shallow Aquatic	4	3
Treed Fen	4	3
Meadow Marsh	4	3
Shallow Marsh	4	3
Coniferous Swamp	5	4
Deciduous Swamp	5	4
Mixed Swamp	5	4
Thicket Swamp	5	4

Taking this approach, each asset within the natural asset inventory can be assigned a CoF rating. While the assigned scores are most certainly an oversimplification, the results provide a starting point for assigning CoF scores to natural assets. The assessment could be improved by considering additional variables such as relative asset size, asset shape, and asset proximity to humans.

3c. Asset Risk Scoring

The Asset Risk score is the product of the PoF and CoF scores. This result can then be mapped and incorporated into the asset registry.

16 Appendix F: Levels of Service Business Drivers and Regulatory Context

The levels of service developed for Markham were derived with consideration for:

- The good practices outlined in the MNAI 2022 LOS guidance document
- The consulting team's experience in Ontario and elsewhere in Canada
- Alignment with the City`s strategic objectives and business drivers
- Applicable local, regional, provincial and federal legislation
- Relevant local and regional technical sources
- Internationally recognized performance indicators for natural assets
- Input from the City's Project Team; and
- Input from the project's Technical Advisory Group.

Specific sources of information that were considered in developing the LOS for Markham have been grouped into four categories and are cited below.

1) The applicability of categories of levels of service below in relation to natural assets and in conformity or alignment with the City's approved Asset Management Plan and O. Reg. 588/17:

- User Expectation (e.g., amenity, biodiversity, nature experience, shade/cooling)
- Regulatory Constraints
- Public Safety (e.g., management strategies to remove hazard trees or address erosion hazards)
- Operational Opportunities and Limitations
- Infrastructure Protection (e.g., erosion control, extending life cycle of assets)
- Sustainability (e.g., ecosystem service provision such as flood attenuation, air quality improvement through pollutant removal, contribution to local food systems through pollination)
- Other aspects or characteristics of a service such as capacity, quality, reliability, cost, accessibility, and responsiveness

2) Alignment with relevant local, regional and global strategic plans and documents:

City/Local Strategic Plans/Documents:

- City of Markham Greenprint Sustainability Plan (2011)
- City of Markham Official Plan (2014)[4]
- City of Markham Asset Management Plan (AMP) (2021)
- DRAFT Greenway System Restoration Framework for North Markham (TRCA 2020)
- Markham's Natural Heritage Inventory and Assessment Study (NHIAS) (NSEI and DA 2021)
- Natural Heritage Management Strategy (NHMS) (CBCL 2021, CBCL 2022, CBCL2024b)
- Markham Forest Study (TRCA 2022)
- Markham's Satisfaction Survey data (2022)

Regional Scale Strategic Plans/Documents:

- York Region Green Infrastructure Asset Management Plan (2022)
- York Regional Forest Climate Change Mitigation and Adaptation Plan (2023)

Global Scale Strategic Plans/Documents:

- World Council on City Data, ISO 3720 Series core and supporting indicators
- C40 Cities Urban Nature Declaration Performance Indicators

3) Consideration of LOS measures or performance indicators contained in:

- York Region Green Infrastructure Asset Management Plan (2022)
- York Regional Forest Climate Change Mitigation and Adaptation Plan (2023)
- City of Markham and Toronto Region Conservation Authority Greenway System Restoration Framework (2020)
- Developing Levels of Service for Natural Assets: A Guidebook for Local Governments, Municipal Natural Assets Initiative (2022)
- World Council on City Data, ISO 3720 Series core and supporting indicators
- C40 Cities Urban Nature Declaration Performance Indicators

4) Alignment with the following relevant provincial, regional and local legislative and policy requirements:

Legislation/Policy	Requirements
O. Reg. 588/17	Sets out requirements for municipal AMPs; Natural assets are considered non-core LOS measures are therefore discretionary
Greater Golden Horseshoe Growth Plan (2019)	Sets out requirements related to land use and development; guidance principle to protect and enhance natural heritage, hydrologic, land forms systems, features and functions
Greenbelt Plan (2017) & Oak Ridges Moraine Conservation Plan (2017)	Policies related to NHN protections, new development or site alternation in NH system, water resource system policies, defines key natural heritage features and key hydrologic features; parkland, public and open space and trail policies
Provincial Policy Statement 2020	Provides policy direction for natural assets that meet tests of significance as part of a natural heritage system.
Conservation Authorities Act (1990)	Requires measures for protection of persons and property from natural hazards
York Region Official Plan 2022	Sets out environmental protections and policies
City of Markham Official Plan 2014	Sets out environmental protections and policies
Endangered Species Act (2007)	Requires protection of regulated species and their critical habitats

The scope of the LOS measures for Markham is as follows:

- Measures focus on natural assets as a sub-set of green infrastructure.
- Measures focus on management of City-owned natural assets.
- Most LOS measures relate to management of the City's Natural Heritage Network (NHN).
- Some LOS measures consider the entire Greenway System, particularly with respect to City objectives around public land securement and naturalization of secured areas.
- Some LOS measures relate to non-infrastructure solutions[5] that support the City in achieving its desired LOS (e.g., community-wide land stewardship, stewardship partnerships).
- Measures do not include:
  - Naturalized stormwater ponds as they are addressed through the City`s stormwater services, or
  - Public access via trails that are addressed through the City's parks services.

The scope of the LOS measures is narrow in relation to the scope of the City's natural assets inventory, which includes all natural features and areas in the Greenway System as well as agricultural lands and City-owned enhanced natural assets (i.e., golf course greens and manicured park lands).

It is understood that sustaining and enhancing the overall ecological health of the NHN depends in large part on the protection and management of the entire Greenway System in Markham, as well as the broader regional Greenway System. Notably, this includes the Federal Rouge National Urban Park (RNUP) which accounts for about a third of Markham's Greenway System. For example, it would not make sense for the City to invest in the removal and management of invasive plants within a City-owned natural asset if a nearby natural area under private ownership was filled with the same invasive species and left unmanaged.

However, it is typical for municipal asset management plans to focus on municipally-owned assets as these are the assets over which the municipality has direct control and for which they are directly responsible. Therefore, for this project, the condition and risk assessments, as well as the LOS, are primarily focused on the City-owned natural assets.

Furthermore, although the priority of the City is to use the LOS identified through this project to guide operational management of City-owned natural assets, it is understood that these assets should generally be considered in the context of all natural assets in the city and potentially also in relation to other green infrastructure, such as storm water management ponds and trees outside of natural areas that form part of the overall urban forest. For example, tracking city-wide changes in total natural cover and total tree canopy over time can help inform life cycle management needs of natural assets.

17 Appendix G: Ecosystem Service Valuation Details

Figure 17-1 depicts numerous ecosystem services categorized by the common themes of provisioning, regulating, supporting and cultural. The ecosystems services summarized in Figure 17-1 align closely with the classification used by the Economics of Ecosystem and Biodiversity (TEEB).

Figure 17-1. Ecosystem services diagram (Source: WWF Living Planet Report 2016).

The first step in the ecosystem valuation was to identify the specific services that would be valued for the City of Markham. To that end, the project team presented a list of commonly valued services to Markham for consideration. In consultation with the City, the following services were identified for valuation: the provision of recreational opportunities, carbon sequestration, air quality regulation, stormwater regulation, habitat preservation, regulation of extreme heat, aesthetic appreciation and contribution to crop productivity.

Once the priority ecosystem services were identified, the value of those services could be established. The approaches employed varied by service type but at a high-level were based on existing norms and standards. In this regard, the valuation of the ecosystem services focused on the value of the *final* services provided to those who *benefit* from the services. This concept is demonstrated in the Cascade Model (Figure 17-2). As can be seen in the figure, natural assets have biophysical structures that provide functions which result in final services and benefits. Humans benefit from these biologically-driven services, and these can be valued.

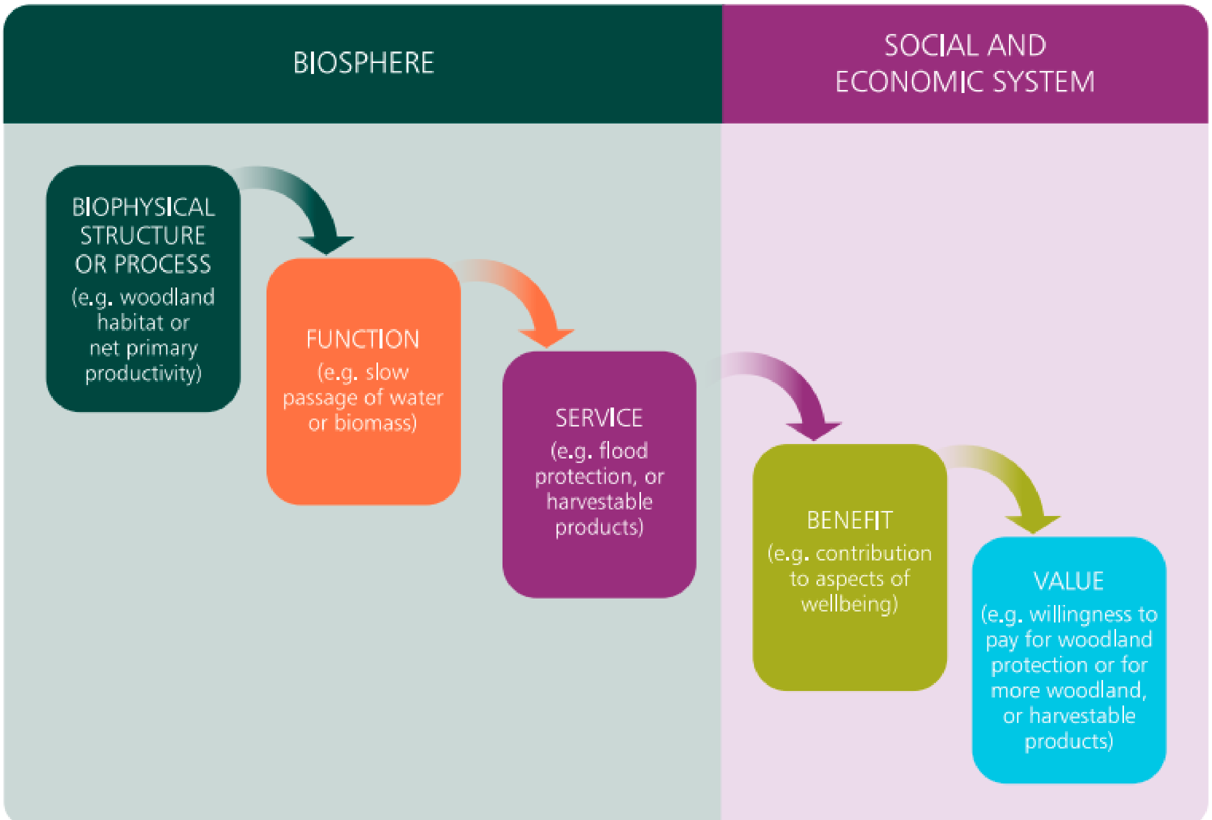

Figure 17-2. The cascade model depicts the framework used to value services from natural assets.

Willingness to pay (WTP) is the common convention used to establish values for ecosystem services. To establish WTP, economists employ stated preference, revealed preference, or benefits transfer approaches. For this analysis, the benefits transfer approach that was applied varied depending on the service provided. The simplest approach is to apply a dollar per hectare transfer from one location to another. In the case of valuing recreation, a dollar per unit approach is more appropriate. For example, the value of recreation can be estimated by applying a dollar per recreation user to the number of recreation users for a given set or sub-set of natural assets. More sophisticated still, benefits functions can be used for services like the value of air quality regulation where the distance between natural assets and population can be considered. For the current project, the most advanced approaches were employed taking into account the availability of relevant data and the budget constraints of the project.

The approaches employed to value the services along with valuation results are presented in the sections that follow.

17.1 Provision of Recreational Activities

Determining the value of recreational activities provided by natural assets within the City of Markham relied on an estimate of expenditures associated with trail use. A Canadian Nature Survey report, from 2014, determined an average value for nature-based recreation per day of $18 ($2012 dollars). After adjusting for inflation,[9] this value ($23 per user day) was used as the value applied to the number of people recreating on the City of Markham's trail network.

Within the geographic boundary of the City of Markham, there are an estimated 194 kilometers of trails. However, the majority of these are outside the boundaries of the natural assets. The trail network within Markham's natural assets is estimated to be 51.7 kilometres.

Trail user statistics were not available for the trails within the City of Markham. Data provided by the TRCA reported an estimated 99,325 users per year on 41.8 kilometers of trails comparable to the trails within the City of Markham.[10] This data was used to estimate the number of users per kilometre of trail per year within the City of Markham.[11] In order to discern the users per kilometer of trail, 99,325 was divided by 41.8 km, resulting in a user rate of 2,376 per kilometer of trail. Applying this user-rate, 2,376 users per kilometer, to the 51.7 kilometres of trail associated with the natural assets within Markham resulted in an estimated 122,849 users per year (51.7 * 2,376 = 122,849). To value this use, the Nature Survey's $23 (after correcting for inflation) per person per use rate was applied. The result was an estimated value of recreation for Markham's natural assets of $2.9 M per year.[12]

To establish the portion of this expenditure that is attributable to city-owned natural assets, the kilometers of trails within the Markham boundary were scoped to only those that intersect city-owned natural assets. This resulted in an estimate of 26.7 kilometres of trails. Using the usage rates per year, as described above, resulted in an estimated 63,444 users per year, which translates into a value of $1.5 M per year for recreation activities in city-owned assets.

For comparison, the value of recreational activities in the City of Markham's natural assets was also valued using an estimate of the average value per hectare by asset type. This method was based on the work done by Voigt et al. (2013) to map the off-site benefits from "protected areas ecosystem services." Their work focused on value-transfer. Table 17-1 displays the information used to establish a value for recreation using this approach.

Table 17-1. Land classes, their area in hectares, their value per hectare per year and the total value per year in the City of Markham.

Voigt et al (2013) Class	Hectares	$ / Hectare / Year	Total Value ($ / Year)
Open water: urban/suburban lake	632.9	$16,717	$7,689,272
Fresh wetland: urban/suburban	1689.5	$12,150	$4,019,421
Forest: suburban	196.3	$2,379	$3,282,155
Grassland / Pasture	1472.4	$91	$133,995
Total	**3,991**	**N/A**	**15,124,843**

[9] In order to calculate the 2023 dollar value, Table: 18-10-0004-01 (formerly CANSIM 326-0020) was used. Yearly averages for geographic boundary Ontario were chosen. The yearly CPI average for 2012 was found as 121.75 and the yearly CPI average for 2023 was 158.6. To convert the $18 dollars in 2012 to a value in 2023, the calculation used was: (158.6/121.75) x $18 = $23. Source: Statistics Canada. Table 18-10-0004-01 Consumer Price Index, monthly, not seasonally adjusted, https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810000401

[10] Personal communication, Joanna Klees van Bommel, Toronto and Region Conservation Authority, February 2024

[11] (99,325 (users / year) / 41.8 kilometers = 2,376 users / kilometer / year)

[12] 122,849 x $23 = $2,9 M

By applying specific values per hectare to the assets within the City of Markham, this approach estimated an annual value of about $15 M.

Table 17-2 provides a detailed breakdown of recreational values by ELC class mapped to Voigt at al. (2013) classes.

Table 17-2. Voigt et al. (2013) values mapped to ELC classes.

ELC Value	Voigt et al (2013) Class	Value per hectare	Hectares	Value per year
Thicket Swamp	Fresh wetland: urban/suburban	$24,300	57.5	$699,015
Shallow Marsh	Fresh wetland: urban/suburban	$24,300	69.7	$847,227
Deciduous Swamp	Fresh wetland: urban/suburban	$24,300	163.7	$1,989,552
Meadow Marsh	Fresh wetland: urban/suburban	$24,300	260.3	$3,162,558
Open Aquatic	Open water: urban/suburban lake	$16,717	196.3	$3,282,155
Treed Fen	Fresh wetland: urban/suburban	$12,150	0.2	$2,272
Coniferous Swamp	Fresh wetland: urban/suburban	$12,150	18.8	$228,699
Submerged Shallow Aquatic	Fresh wetland: urban/suburban	$12,150	4.9	$58,928
Floating-leaved Shallow Aquatic	Fresh wetland: urban/suburban	$12,150	0.7	$8,474
Mixed Swamp	Fresh wetland: urban/suburban	$12,150	57.0	$692,546
Coniferous Forest	Forest: suburban	$4,758	93.5	$222,331
Plantation	Forest: suburban	$4,758	160.2	$381,105
Mixed Forest	Forest: suburban	$4,758	254.2	$604,631
Deciduous Forest	Forest: suburban	$4,758	669.1	$1,591,791
Cultural Woodland	Forest: suburban	$4,758	293.2	$697,613
Cultural Thicket	Forest: suburban	$4,758	83.9	$199,519
Cultural Savannah	Forest: suburban	$4,758	135.2	$321,617
Treed Bluff	Forest: suburban	$2,379	0.3	$814
Open Tallgrass Prairie	Grassland / Pasture	$91	0.3	$30
Cultural Meadow	Grassland / Pasture	$91	1472.1	$133,966
Hedgerow	N/A	$0	70.8	$0
Open Beach / Bar	N/A	$0	1.2	$0
Open Bluff	N/A	$0	0.7	$0
Shrub Beach / Bar	N/A	$0	0.0	$0
Total	**N/A**		**4064.0**	**$15,124,843**

17.2 The Value of Carbon Sequestration

Depending on the type of natural assets, two approaches were used to estimate a total value for carbon (C) sequestration; one for forested assets and another for non-forested assets.

To attribute C sequestration values to forested assets in the City of Markham, the Carbon Budget Model of the Canadian Forest Service, v3 (CBM-CFS3) was used.[13] This model requires inputs for forested asset in terms of growth rates, ages, and species compositions. Forest characteristics embedded in the natural asset inventory were used to fulfill these data requirements. Specifically, the inventory of forested assets categorizes some forests as "Pioneer, Mature, Young, and Mid-age" trees. Table 17-3 identifies the specific ages that were assigned to the categorized forest assets.

Table 17-3. Age assumptions used in the modelling of forested assets in Markham.

Label	Age
Young	25
Mid-age	50
Mature	100
Pioneer	125

The vast majority of forest assets, however, did not contain age information. Forested assets with no age information were assigned an age of 75 years. This was based on a review of satellite imagery that showed the ageless assets to be mature forests. Age assumptions, along with assumptions for species and growth rates derived from the ELC data were combined in the CBM-CFS3 model to estimate tonnes of C per hectare per year sequestration rates as well as tonnes of C per hectare for each forested asset.

For non-forested asset classes, the project team drew from experience and a literature review to assign sequestration rates. Non-Forested asset types were cross-referenced with a database of average sequestration rates by land cover type. Over 30 peer-reviewed papers informed the employed C sequestration rates. Using this approach, each non-forested natural asset class gets its own estimated C sequestration rate. Table 17-4 demonstrates the carbon sequestration rates employed for natural assets. Note that the ELC Values in green represent the mean values of all the assets in these classes as derived from the CBM-CFS3.

[13] https://natural-resources.canada.ca/climate-change/climate-change-impacts-forests/carbon-accounting/carbon-budget-model/13107

Table 17-4. Carbon sequestration rates used to estimate annual sequestration by natural assets.

ELC Value	Average tonnes CO_2e per hectare
Coniferous Swamp	17.34
Deciduous Swamp	17.34
Mixed Swamp	17.34
Floating-leaved Shallow Aquatic	7.85
Thicket Swamp	7.41
Treed Fen	7.41
Deciduous Forest	**6.49**
Plantation	**6.49**
Meadow Marsh	5.83
Shallow Marsh	5.83
Submerged Shallow Aquatic	5.83
Cultural Woodland	**4.44**
Coniferous Forest	**4.36**
Mixed Forest	**4.33**
Treed Bluff	3.96
Cultural Savannah	**3.96**
Cultural Thicket	**3.92**
Hedgerow	**2.68**
Cultural Meadow	1.76
Open Tallgrass Prairie	1.76
Open Aquatic	0
Open Beach / Bar	0
Open Bluff	0
Shrub Beach / Bar	0

The sequestration rates for forested and non-forested assets were then valued by applying the Canadian social cost of carbon (SCC) (upper bound) and the "Minimum National Carbon Pollution Price" (lower bound) to the sequestration rates. The SCC is a term used to describe an estimate of the monetary value in a given year of worldwide damage that will occur over the coming decades and centuries from emitting one additional tonne of carbon dioxide (CO2) emissions. Specifically, the SCC represents the marginal damage of an additional tonne of CO2 emitted into the atmosphere in a given year, expressed in dollars, based on an assumed global CO2 emissions path. Each natural asset had a specific sequestration rate measured in tonnes CO_2e per hectare which was multiplied by the SCC and the minimum national carbon pollution price. Table 17-5 presents the SCC published by Environment and Climate Change Canada. In order to estimate the current value of the SCC, the 2021 dollar value of $261 / t CO_2e for 2023 was converted to a 2023 dollar value using the Consumer Price Index of Canada's values for 2021 and 2023 respectively. This changed the value of the SCC to $291 /t CO_2e[14] in 2023 dollars and was used for determining the value of C sequestration within this analysis.

[14] 1 tonne of carbon is equivalent to 44/12 (3.66667) tonnes of CO_2e.

Table 17-5. Annual social cost of carbon (C$2021/tonne SC-$CO_2$), this value is converted to a $2023 value of 291 scc/sc-co_2.

Year	SCC/SC-CO_2
2020	$247
2021	$252
2022	$256
2023	$261
2024	$266

Table 17-6 presents the minimum carbon price used in the analysis. Specifically, the 2023 value of $65 /t CO_2e.[15]

Table 17-6. Minimum National Carbon Pollution Price Schedule (2023$CAD/tonnes CO_2e).

Year	2023	2024	2025	2026	2027	2028	2029	2030
Minimum Carbon Pollution Price ($ CAD/tonne CO_2e)	$65	$80	$95	$110	$125	$140	$155	$170

As seen in Figure 17-3, all the assets within the City of Markham generated carbon value. The most valuable assets in terms of carbon sequestration in the City of Markham were the woodlands, the wetlands, and the meadows. The total value C sequestration of the assets within the City of Markham were between $1.1 M and $4.9 M depending on the assumption of C priced used (minimum price versus the SCC). The City-owned assets, shown as the bordered assets in Figure 17-3 were estimated to provide between $291,644 and $1.3 M depending again on the price of C assigned.

[15] Note the analysis does not consider CH_4 or N_2O in this case, only tonnes CO_2.

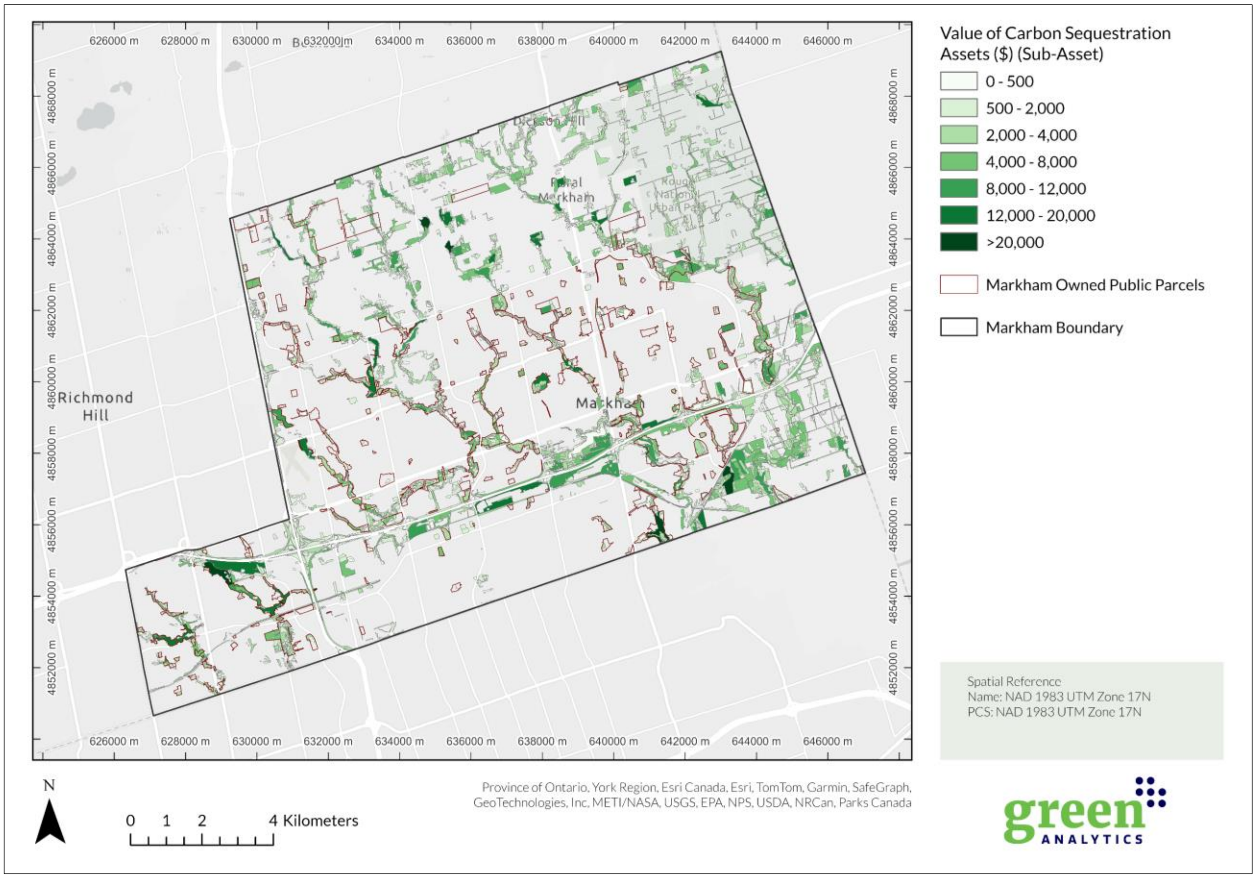

Figure 17-3. Carbon sequestration asset values within the City of Markham.

17.3 The Value of Air Quality Regulation

The value of air quality regulation is based on an estimate of the avoided health care costs associated with exposure to air pollutants (NO_2, O_3, $PM_{2.5}$, and SO_2). To establish a City of Markham specific value, a value function transfer (Nowak et al. 2014) was used. The value function transfer accounts for population density to scale the avoided health care costs according to the number of people exposed to surrounding air quality. Pollution removal rates per area of tree cover and wetlands, were used to estimate the avoided air pollution provided by Markham's natural assets (this analysis is limited to natural assets and does not include street trees or privately owned trees). Table 17-7 summarizes the key results from Nowak et al. (2014) used for these estimates.

Table 17-7. Nowak et al. (2014) equations and assumptions used in the current analysis.

Pollutant	Kg removed per ha of tree cover	Value function (y = dollars per tonne, x = people per $km^{2)}$
NO_2	5.5	y = 0.7298 + 0.6264x (r2 = 0.91)
O_3	54.9	y = 9.4667 + 3.5089x (r2 = 0.86)
PM2.5	2.7	y = 428.0011 + 121.7864x (r2 = 0.83)
SO_2	3.5	y = 0.1442 + 0.1493x (r2 = 0.86)

The results were based on tree cover, wetland area, and population density determined at the census subdivision level capturing the spatial variation in population densities and tree cover.

The total value of air quality regulation by the 2,061 hectares of natural assets in the City of Markham in 2023 dollars was $2.7 M per year. The City-owned assets were 667 hectares and were valued at $0.8 M per year. Table 17-8 displays the value of air quality regulation in the City of Markham.

Table 17-8. Value of air quality regulation from natural assets.

Area	Forest/Hedge Area (ha)	Pop Density (people / km²)[16]	Total Value ($2023)
City of Markham	2393	1,605	$2.7M
City-owned assets	667	1,605	$0.8M

The geographic distribution of the value of the assets is shown in Figure 17-4, below.

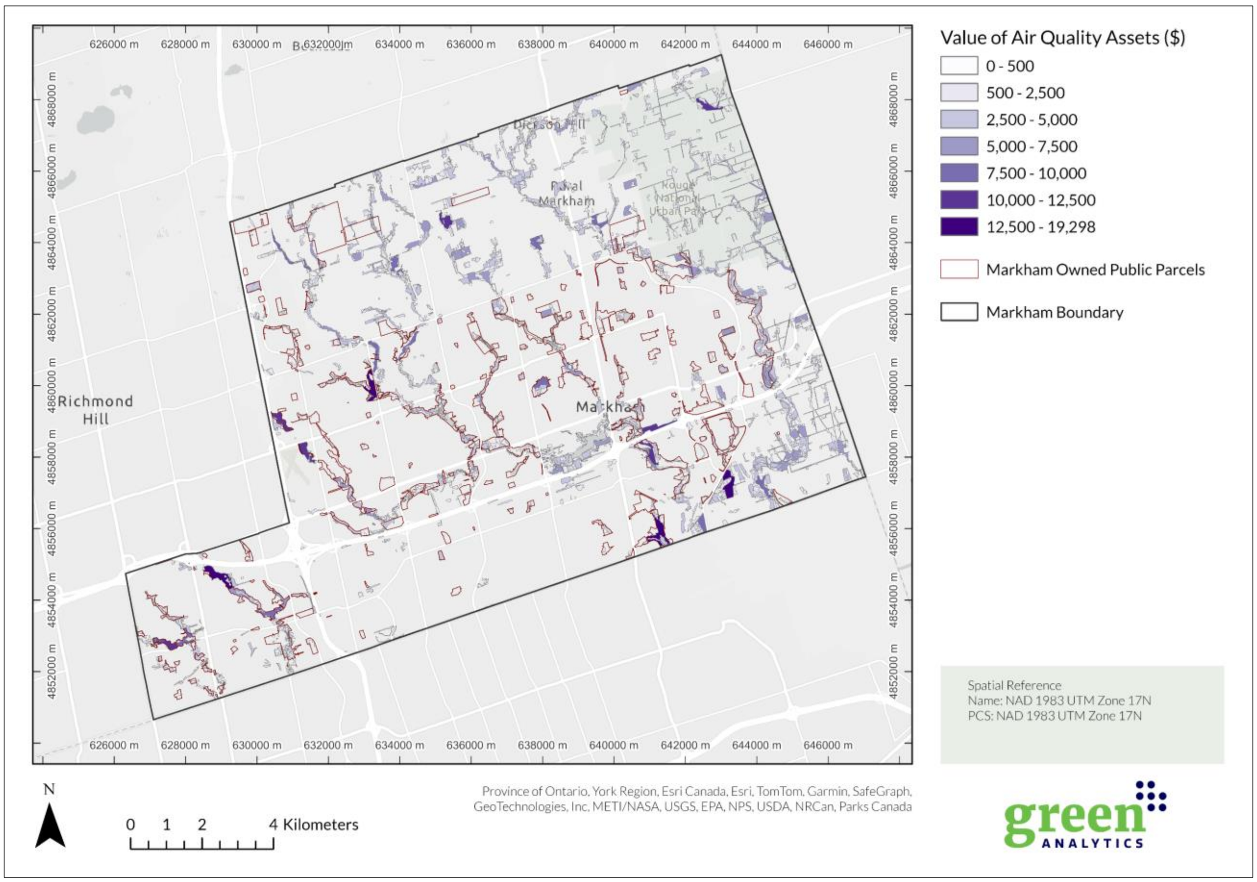

Figure 17-4. The spatial distribution of the value of air quality regulation.

[16] The population density was assumed the same for both all natural assets and the City-owned natural assets.

17.4 The Value of Stormwater Regulation

Stormwater regulation is ideally assessed through detailed hydrologic modelling to measure the value natural assets provide in terms of flood and erosion control and water quality. Such modelling was outside the scope of the current project. Instead, a replacement cost approach was employed to provide an estimate of the ability of natural assets to control and absorb water during low frequency heavy rain events. Specifically, the value of stormwater regulation was based on the Saini *et al.*, (2018) results which provide monetary estimates ($/ha) of stormwater regulation by asset type (including forests, grasslands and wetlands). That study included a preliminary assessment of stormwater performance of sample natural asset sites, scaled to other natural assets in Peel Region[17]. The study included calibration of modelled stormwater performance considering the sample sites' local soil and groundwater conditions in the Credit River Watershed. This approach differs somewhat from that used for the other services in that in this case the focus is not on the value that humans derive from stormwater regulation, but the value of the ecosystem functions (water filtration and storage, erosion control) provided by natural areas, which is taken as a proxy for the benefit to humans.

Trees and forests reduce stormwater runoff by capturing and storing rainfall in the canopy and releasing water into the atmosphere through evapotranspiration. Additionally, tree roots and leaf litter create soil conditions that promote the infiltration of rainwater into the soil. This helps to replenish the groundwater supply and maintain stream flow during dry periods, particularly where local groundwater conditions are conducive to recharge aquifers that sustain baseflows. The presence of trees also helps to slow down and temporarily store runoff, which further promotes infiltration, and decreases flooding and erosion downstream (Saini et al. 2018).

"Open green spaces" are spaces partly or completely covered with grass, trees, shrubs, or other vegetation. They can include parks, community gardens, and open fields. Such spaces provide pervious surfaces in otherwise urbanized catchments and stormwater draining to these spaces has a chance to be filtered and infiltrated before reaching receiving streams (Saini et al. 2018). In Markham, pre-1990 developments can have a high proportion of impervious surfaces directly connected to the storm sewer system, based on extensive surveys completed as part of downspout disconnection surveys. In those areas, stormwater drains directly to the City's storm sewer network and watercourse systems.

Wetlands receive stormwater from upland sources and hold large volumes of water in situ before slowly releasing it to streams, lakes, and rivers. They act as an important buffer system to stormwater regulation. Saini et al. (2018) identified different performance for different types of wetlands including palustrine, isolated and riverine wetlands. Isolated wetlands were estimated to have over 16 times the stormwater storage capacity of riverine wetlands.

Table 17-9 shows the value of stormwater regulation within the City of Markham. The table is divided into all assets within the City of Markham and the City-owned assets. Wetlands types within Markham were assumed to be riverine. This preliminary analysis assumes that sample site characteristics in Peel Region can be scaled to Markham natural assets, and that stormwater services monetized in the Peel/Credit Valley subwatersheds are equivalent to services required in Markham subwatersheds.

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[17] The Peel pilot study notes: "The major assumption for the current study results is the scaling approach applied at the subwatershed scale. This approach assumes value of natural assets in any category being proportionate to surface area of the assets in that category. The subwatershed scale valuation results presented in the current study should therefore be used with caution." (Saini et al., 2018)

Table 17-9. Estimated value of stormwater regulation within the City of Markham.

Asset Type	$ Hectare / Year	Total Hectares of Assets	$ / Year	City-owned Hectares of Assets	$ / Year
Forests and Hedgerows	$2,062	1,760	$3,629,120	553	$1,140,286
Open Green Spaces	$740	1,472	$1,089,280	226	$167,240
Wetlands	$129	633	$81,791	114	$14,706
Total Value			**$ 4,801,453**		**$ 1,322,232**

Some limitations in the analysis approach for stormwater regulation are listed below:

i) Different Local Stormwater Requirements: Markham staff noted that TRCA's 2012 water quantity control criteria that apply to the City's largest subwatersheds in the Rouge River watershed do not have flood flow requirements (e.g., no flood storage required on the Main Rouge downstream of Major Mackenzie Drive or on the Little Rouge downstream of Elgin Mills Road). In contrast, the Peel Region pilot study assumed that storage for the 100-year design storm would be required in all areas that have natural asset storage.

ii) Existing Local Stormwater Services: The Peel pilot study author noted[18] limitations in the modeling analysis including that 'benefit of upstream features to downstream is not assessed' and 'existing built stormwater infrastructure not included in the model'.

While an assessment of downstream benefits for Markham assets is beyond the scope of the current study, the stormwater values in the City of Markham in Table 17-9 could be considered as theoretical upper values. This is given that a significant proportion of Markham does not require quantity controls (i.e., downstream portion of Rouge River subwatersheds), and that stormwater services are already provided in newer subdivisions with advanced infrastructure controls (i.e., upstream portion of Rouge River subwatersheds) 17-5.

[18] CVC-led Natural Asset Valuation Studies, Saini et al. (https://www.glc.org/wp-content/uploads/1.NAvaluation_GLC_Workshop_201906242.pdf)

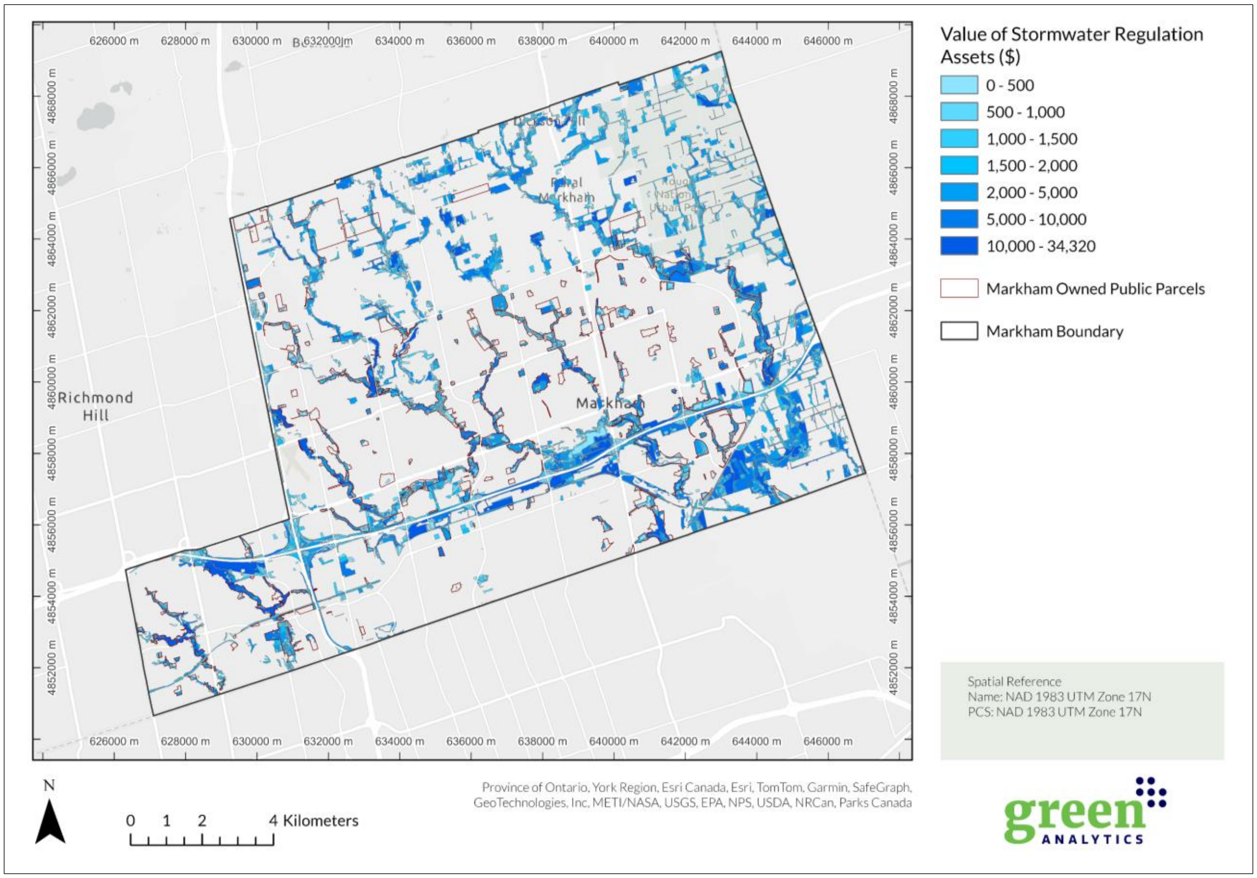

Figure 17-5. Value of stormwater protection. City-owned assets are bordered in black.

17.5 Regulation of Extreme Heat Events

The value associated with the regulation of extreme summertime heat events was estimated as the reduction in mortality in natural asset adjacent residential neighbourhoods stemming from the anticipated reduction in maximum daily air temperatures attributed to assets. A with-without approach was used to estimate mortality due to extreme heat given the current distribution of natural assets and the anticipated change in this mortality after removing the natural assets' influence on air cooling. The economic value of the resulting estimated change in mortality serves as the value of the regulation of extreme heat events associated with the parks.

In general, the approach relied on data from Kroeger et al. (2018) to estimate the cooling influence of natural assets in °C on the summer air temperature of park adjacent residential neighbourhoods (summer corresponds with the months of June, July, and August).[19] Changes in air temperatures were linked to changes in population mortality in the City of Markham using a relationship from Chen et al. (2016). Finally, the estimated change in mortality was valued using the value of a statistical life. Details are outlined in the following steps:

[19] Kroeger et al. (2018) focus their analysis on treed areas but the data they sourced to estimate the relationship between tree cover and temperature was gathered from studies assessing the influence of multiple cover types on air temperatures. Their approach and relationships were applied, therefore, to non-treed assets.

1. The cooling influence of natural assets depends on their size, with larger assets cooling the air more than smaller assets. Following Kroeger et al. (2018) we used GIS to first group contiguous assets together to create larger asset conglomerations. The resulting asset areas were then divided into four size classes depending on their park width distance (PWD), which is measured as the square root of their area (Table 17-10). Each size class yields a different level of maximum daily air temperature reduction within and beyond the asset area which Kroeger et al. (2018) refers to as the park cooling intensity (PCI). The intensity of a park's influence on reducing air temperatures is highest within its boundaries and declines with distance from its edge (Figure 17-6).

Table 17-10. Asset Size Classes and Associated Air Cooling Intensity Within and Beyond the Asset.

Size Class	PWD (m)	PCI (°C)	Level of Cooling Intensity Beyond Asset Edge (m)		
			High	Medium	Low
1	<30	1.055	0 to 30	None	None
2	30 to <90	2.143	0 to 30	30< to 40	40< to 50
3	90 to <270	2.445	0 to 50	50< to 80	80< to 160
4	>=270	3.283	0 to 150	150< to 250	250< to 500

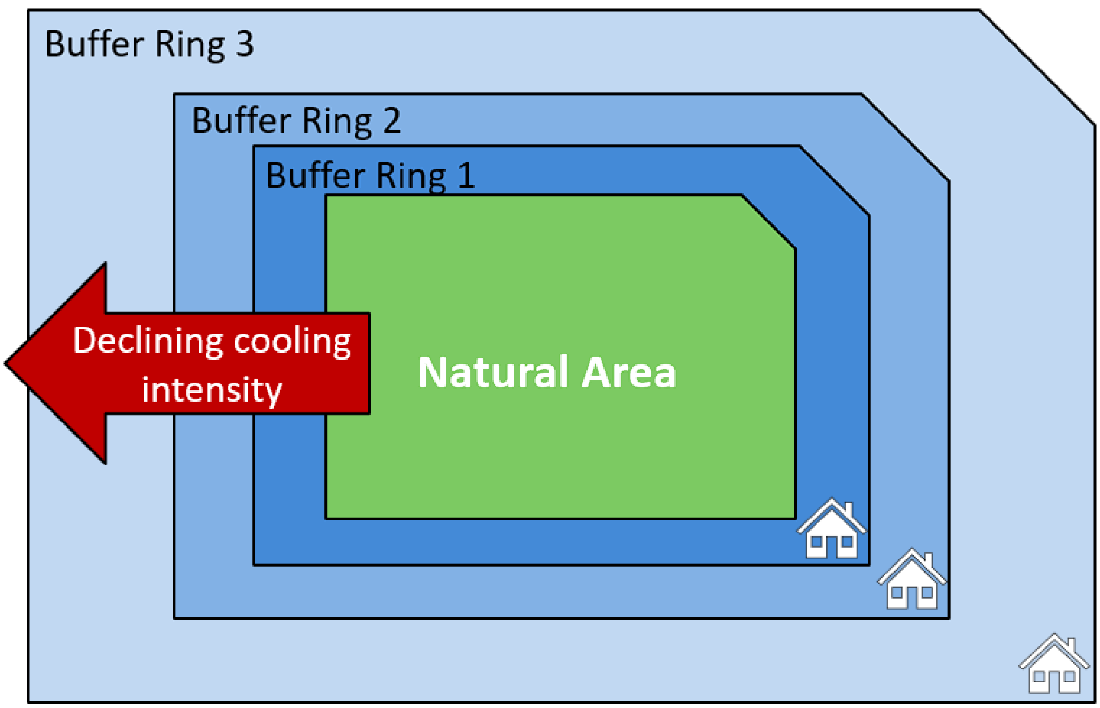

Figure 17-6. Air Cooling in Natural Assets and Asset-Adjacent Areas.

2. The air cooling that extends beyond the edge of the natural assets is most important for this analysis as this area intersects with neighbourhoods where people live. The distance beyond the asset's edge as well as the intensity of this cooling — which Kroeger et al. (2018) categorize as high, medium, or low — both depend on the asset's area (Table 17-11 and Figure 17-6). As such, using GIS, the contiguous groups of assets were buffered with three rings of varying widths and distance from the asset edges to represent the areas experiencing the different levels of air cooling. Cooling from the

smallest assets (size class 1) is only experienced in the high intensity buffer and does not extend beyond 30 m from the asset's edge. Kroeger et al. (2018) estimate the reduction in maximum daily air temperatures experienced beyond the edge as the percentage of the PCI remaining in each buffer which can be converted to degrees Celsius (Table 17-11).

Table 17-11. Air Cooling Intensity Experienced in Each Buffer Beyond the Asset's Edge.

Size Class	Remaining PCI in Percent			Remaining PCI in °C		
	High	Medium	Low	High	Medium	Low
1	39%	None	None	0.411	None	None
2	49%	27%	20%	1.050	0.579	0.429
3	59%	40%	26%	1.443	0.978	0.636
4	59%	40%	26%	1.937	1.313	0.854

3. The next step involved estimating the population of residential areas overlapping with each asset's buffer rings. To do so GIS was used to intersect each buffer ring with 2021 Census of Population dissemination areas (DA) to determine the area of overlap between the buffer rings and DAs. The area of these DAs was first clipped of non-residential features such as parks and cemeteries such that they better represent where people actually live in the City of Markham. The population density for each clipped DA was then calculated and applied to the area of each buffer ring intersecting with the clipped DAs to estimate the population residing in each asset's buffer ring (and thus the residents experiencing the different levels of summertime air temperature cooling). The total population forecast to experience some park-related air cooling at their place of residence is 237,161.

4. It was then necessary to estimate the influence of the park-related air temperature cooling on mortality in these neighbouring residential populations. The first step was estimating the current annual non-accidental mortality in park adjacent residential populations. This involved multiplying the estimated population in the buffer rings by the average annual mortality rate from non-accidental causes for the years 2013 to 2022 in Ontario, which was 689.9 per 100,000 people (Statistics Canada 2023a).[20] This yields total annual estimated non-accidental mortality for the population of all three buffers of all natural assets of 1,636.2 per year. However, since this analysis is focused on summertime air temperatures, Statistics Canada (2023b) data on the monthly distribution of deaths from all causes for Ontario averaged from 2013 to 2022 to estimate mortality for the months of June, July, and August (the assumption is that this distribution reflects that of non-accidental deaths) was used. On average, 23.2% of deaths occurred during these months yielding an estimate of total summertime mortality of 379.8.

   It is assumed that this mortality already incorporates the influence of the existing park assets on air cooling and thus deaths related to extreme heat. Therefore, the project team estimated how removing the influence of the park assets on air cooling calculated in the prior steps might increase non-accidental mortality in the adjacent residential populations using data from Chen et al. (2016). They related maximum daily summertime (June, July, and August) air temperature in °C to percent change in non-accidental mortality for residents of Ontario, finding that with every 5 °C increase in

[20] Causes thought less likely to be linked to air temperatures including homicides, suicides, deaths due to medical or surgical care, and those from unknown causes were not included when estimating the non-accidental mortality rate. Non-accidental deaths included in the analysis account for 93% of deaths that comprise the average annual mortality rate.

maximum temperatures this mortality increased by 2.2 percent daily (or 0.44 % for every °C). This relationship was used to estimate the increase in non-accidental mortality in the residential populations of each of the assets' buffers associated with removing the park-related air cooling measured earlier. To that end, it was forecasted that removing this cooling yields an increase in non-accidental mortality of 2.1 individuals per year, which is the reduction in mortality attributable to the network of assets.

It is likely that many residents influenced by the cooling of natural assets live in homes with air conditioning and can take refuge from high air temperatures inside their houses. The estimated population can therefore be adjusted to account for air conditioning penetration. Statistics Canada (2023c) estimates that 87% and 84% of homes in the Toronto Census Metropolitan Area and Ontario, respectively, had some form of air conditioning in 2021 (the latest year available). While estimates could be adjusted using these penetration rates this would likely result in too large a change. Since Chen et al. (2016) used population mortality data it is likely that their findings already incorporate the influence of some level of air conditioning on summertime temperature-related mortality in Ontario; this level increased between 1996 and 2010 the time during which their mortality data was collected (Statistics Canada 2023c). It is possible that heat related deaths have declined as a result, making some adjustment necessary, although at the same time any reduction in heat-related deaths is potentially already incorporated into to the contemporary non-accidental death rate for Ontario offsetting the need for adjustment.

Within this context attempts are made to adjust for differences in air conditioning. Determining the proper adjustment to apply to the analysis is difficult given that the available data for Ontario only covers the years 2003, 2007, and 2009 of Chen et al.'s (2016) period of study (Natural Resources Canada Office of Energy Efficiency 2006, 2010; Sawicz 2011).[21] Thus, American data on air conditioner penetration from the Middle Atlantic (Northeast) and East North Central (Midwest) census sub-regions, bordering Ontario, from the years 1997, 2001, and 2005 was used to estimate air conditioner use in Ontario for these years (USEIA, n.d.). These estimates were used, in combination with the aforementioned data for Ontario, to estimate an average household penetration rate during the 1996 to 2010 period. It was estimated that the average annual air conditioner penetration rate over this period was 70% which is only 0.83 times the penetration rate for Ontario in 2021 (84%) — the estimated mortality of 2.1 was adjusted downward by multiplying by 0.83 yielding a reduction in mortality of 1.8 deaths per year.

5. The final step was to assign a monetary value to the estimated changes in mortality. To do this the value of a statistical life of $6.5 million (2007 CAD [$9.31 M 2023 CAD]) per deceased individual from the Treasury Board Secretariat of Canada's (2022) Cost-Benefit Analysis Guide for Regulatory Proposals was employed.

Assuming no adjustment for air conditioning, the total value of extreme heat reduction associated with the City of Markham's network of natural assets was estimated at $20 M per year with City-owned assets valued at $10 M per year. Adjusting for air conditioning yields a total of $16.7 M per year with City-owned assets valued at $8.35 M per year. The distribution of values across the City's network of natural assets is displayed in Figure 17-7 for estimates not adjusted for air conditioning use and in Figure

[21] There are other instances of the Survey of Household Energy Use in the 1990s but this data is mostly not accessible and the summary report for the 1997 survey does not clearly break out air conditioner use for Ontario (Natural Resources Canada Office of Energy Efficiency 2000).

17-8 for estimates that are adjusted for their use (note that the distribution of the adjusted and unadjusted estimates is similar, although the adjusted values are lower).

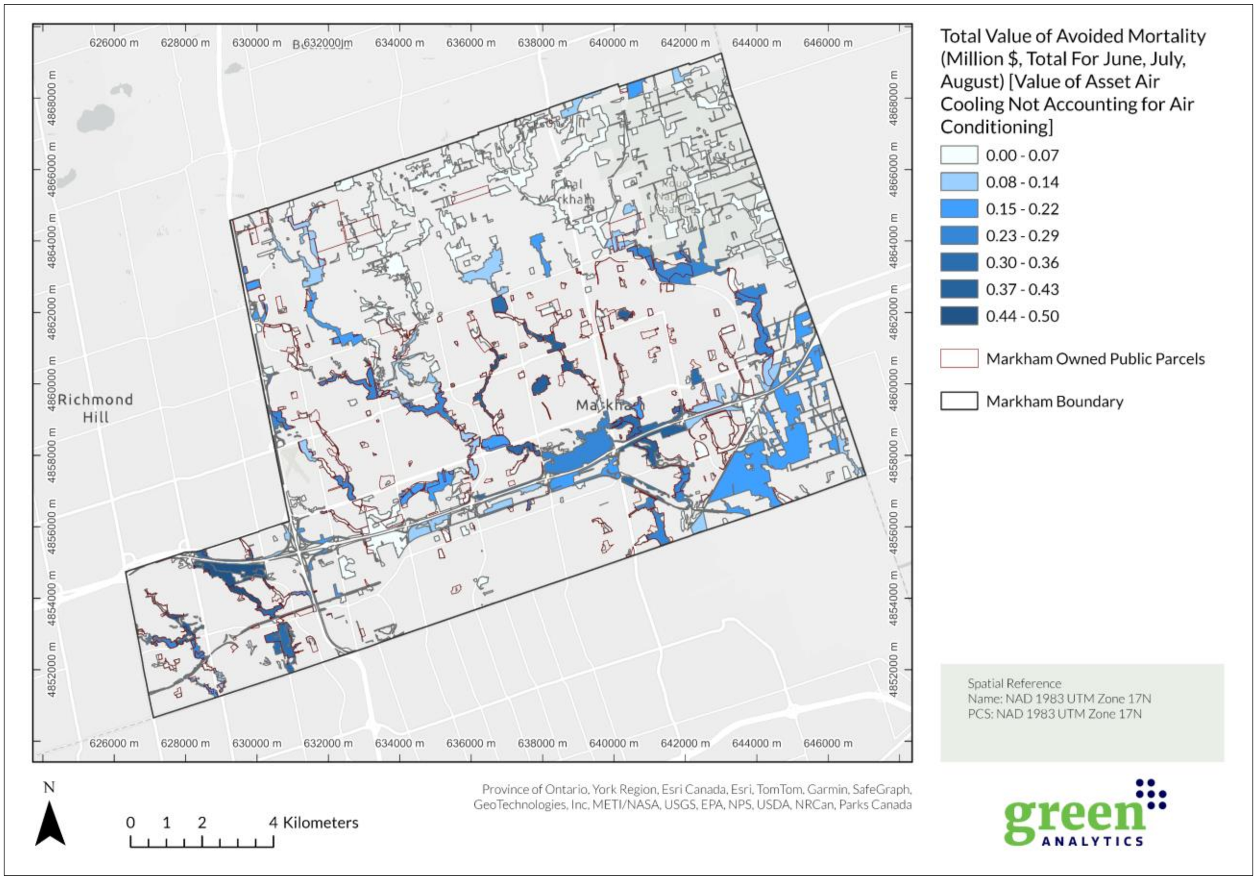

Figure 17-7. Value of summertime air temperature regulation (not accounting for changes in air conditioning.)

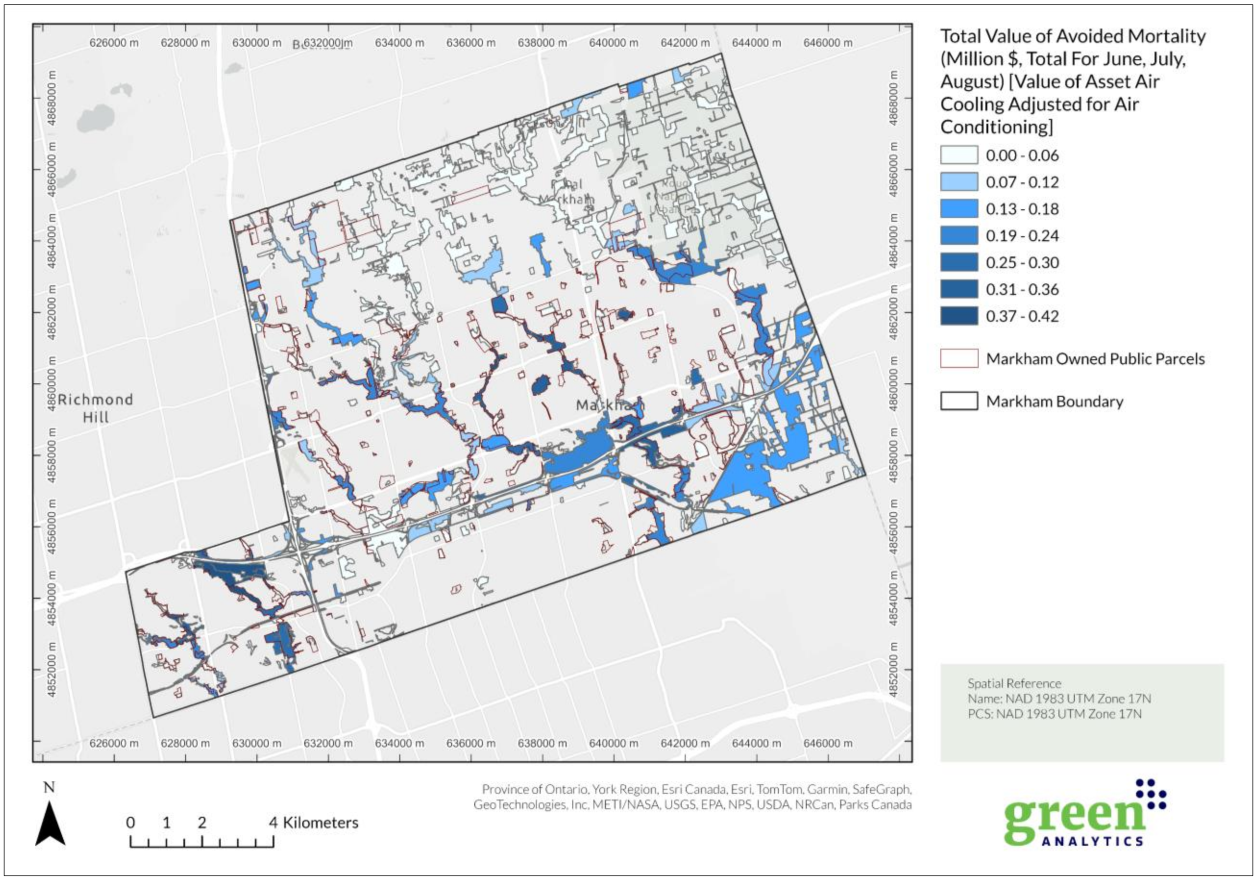

Figure 17-8. Value of summertime air temperature regulation (accounting for changes in air conditioning).

17.5 The Value of Habitat Preservation

A review of the literature identified a study that estimated the value people place on urban open spaces. The study by Luke Brander and Mark Koetse defined urban open spaces as urban parks, forests, green spaces, undeveloped lands and agriculture lands.[22] The authors use regression analysis to articulate a mathematical function that can be used to estimate the value of open spaces in other jurisdictions. They note that the results of their analyses can be used to estimate the value of the area of open space by substituting information on the parameter values for a specific site. It was within this context that the regression equation was applied to the natural assets with the City of Markham. The key independent variables that feed into the equation are area of open spaces, gross domestic product per capita and population density. To apply the regression equation to City of Markham's natural assets, these variables were populated with specific data to the supplied datasets. The result is an estimate of the value of open spaces measured in dollars per hectare, which can be applied to the hectares of open space within the City of Markham.

There were a total of 4,064 hectares of natural assets within the City of Markham of which 3,074 hectares were within the Greenway system and 986 hectares owned by the City of Markham. This results in an

[22] Brander, Luke and Mark Koetse. (2011). The value of urban open space: Meta-analyses of contingent valuation and hedonic pricing results. Journal of Environmental Management, 92, 2763-2773.

estimated value of $25 M per year for the value of preservation by the Greenway Systems natural assets and a value of $8 M per year for City-owned assets.

> **Value of Volunteering**
>
> In 2019, the City of Markham witnessed a significant demonstration of community engagement in the preservation and enhancement of its natural assets, as evidenced by the substantial volunteer involvement in various environmental initiatives. The data reveals that 2,850 individuals devoted their time to tree planting events, cumulatively contributing approximately 9,975 hours. Additionally, stewardship events saw the participation of 864 volunteers, who collectively dedicated around 2,160 hours. This commitment resulted in over 12,000 hours of volunteer time directed toward nurturing and safeguarding natural assets.
>
> The economic value of this volunteer effort is noteworthy. By applying the average hourly wage rate of $35 to the total hours volunteered, the monetary equivalent of this community contribution is estimated to be around $425,000. This figure not only underscores the substantial financial impact of volunteer work but also reflects the community's deep-rooted appreciation and commitment to the conservation and management of natural assets. Such community involvement is invaluable and plays a pivotal role in the effective stewardship of natural resources, aligning with broader environmental sustainability goal.

17.6 The Value of Aesthetic Appreciation

Estimating the value of aesthetic appreciation in the City of Markham was based on a study by Mazzotta et al. (2014) who assessed the value of low impact development practices in residential areas; the objective of their study was to assign a monetary value to aesthetic benefits of this open space. As part of their analysis they evaluated the influence of open space, such as grassed or forested areas, wetlands, or riparian buffers, on the sale prices of nearby houses in residential areas using a hedonic function estimated from a meta-analysis review of the literature.[23] Specifically, the function relates the percent change in home sales prices to the percentage of 0 to 250 meter and 250 to 500 meter buffers surrounding each house that is covered in open space, in addition to other variables accounting for characteristics of the open space and neighbourhood. This function was used to assign a monetary value to the aesthetic benefits stemming from Markham's network of natural assets.

The approach involved first using GIS to build a dataset of residential building footprints, focusing on single-family dwellings to align with Mazzotta et al. (2014), which were each then buffered with 0m to 250m and 250m to 500m buffer rings. The area of natural assets within these buffers was then calculated enabling an estimation of the percentage of each buffer covered with natural assets (Figure 17-9). The value of homes in Markham was then estimated by averaging historical sales prices and then applying coefficients from Mazzotta et al.'s (2014) meta-function to estimate how natural asset coverage in the two buffer rings influences home values. Since this process yielded a onetime value for each home — and not an annual value — the annual rental-equivalent following Mazzotta et al. (2014) was subsequently calculated. Detailed steps follow.

[23] Mazzotta et al. (2014) omitted certain types of hedonic studies from their meta-analysis such as those focused on agricultural lands, golf courses, water features, and very large parks or forests.

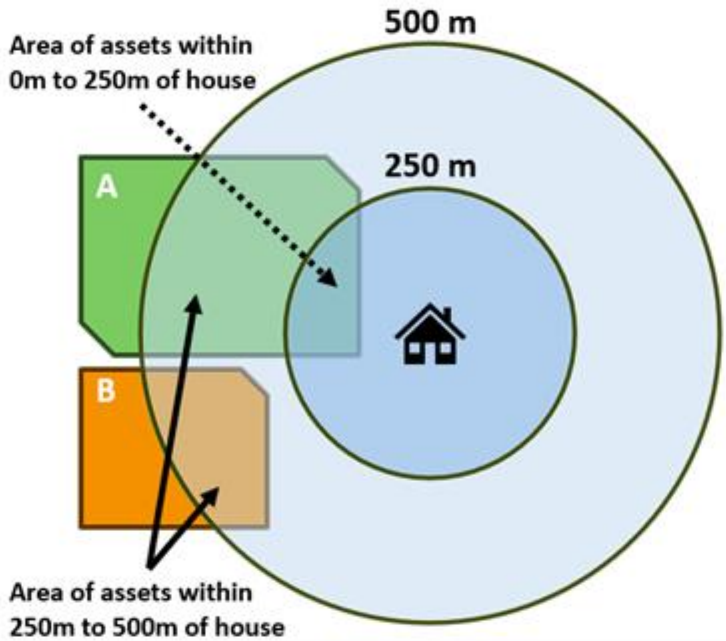

Figure 17-9. Visual description of the determination of natural assets within 0, 250 and 500 meters of houses within the city of Markham.

1. To estimate the extent of natural assets surrounding Markham's houses a GIS dataset representing residential building footprints was developed. Since the focus was detached single-family residential dwellings, to best align with Mazzotta et al. (2014), footprints in lower density neighbourhoods represented by Markham's 'Residential Low Rise' and 'Residential Estate' zoning were selected. The Official Plan 2014 Mapping Data was used to remove footprints in these areas identified as multi-unit buildings or non-residential. In addition, the original building footprint data included separate footprints for outbuildings, such as garages or sheds, associated with a home. As such a sample of outbuilding footprints were selected by scanning satellite imagery from which a distribution of outbuilding areas was used to inform a cutoff value for classifying footprints as actual homes or related outbuildings (footprints with an area below this cutoff were considered to be outbuildings); all suspected outbuildings were deleted from the footprint data. Despite these efforts, it is likely that the data contains footprints for other types of homes, such as townhomes.

Each footprint in the assembled spatial residential building data was then buffered with 0m to 250m and 250m to 500m buffer rings using GIS. These buffers were then intersected with the spatial natural asset data to estimate the area of each buffer covered with natural assets from which the percentage of each buffer ring covered in assets was calculated.

2. The value of low-density residential homes in Markham was estimated using historical data on home sales from January 2013 to October 2023 obtained from Listings.ca for the city. The sales prices for single-family detached homes was used as well as townhouses since the spatial dataset likely includes both types of dwellings. The resulting average home price used in the analysis was $1.2 million (2023 CAD); note that single-family detached home prices are not too different at $1.36 million (2023 CAD).

3. The influence of the extent of natural assets on home values was then estimated using coefficients from Mazzotta et al.'s (2014) meta-function. These coefficients measure the percent change in property values given the percentage of the buffer rings covered in natural assets. Mazzotta et al. (2014)

estimated separate coefficients for the two buffers which were apply to the percentage natural asset cover calculated for the 0m to 250m and 250m to 500m buffer rings around each home. The estimated percent change in home prices was then multiplied by the average home prices estimated earlier yielding the onetime estimate of the value for each home footprint. These were then summed across all homes yielding onetime estimates of: $1 billion for assets in the 0m to 250m buffer; $954 million in the 250m to 500m buffer; and $2 billion across both buffers (2023 CAD).

4. These onetime estimates were changed into annualized rental-equivalent values following Mazzotta et al. (2014) by multiplying them by the discount rate (assumed to be 3%, matching the social discount rate recommended by the Treasury Board Secretariat of Canada (2022)).

The total value of aesthetic appreciation in the City of Markham was $59 million per year and the value of City-owned assets was $39 M per year (2023 CAD). The physical distribution of the value is displayed in Figure 17-10, below.

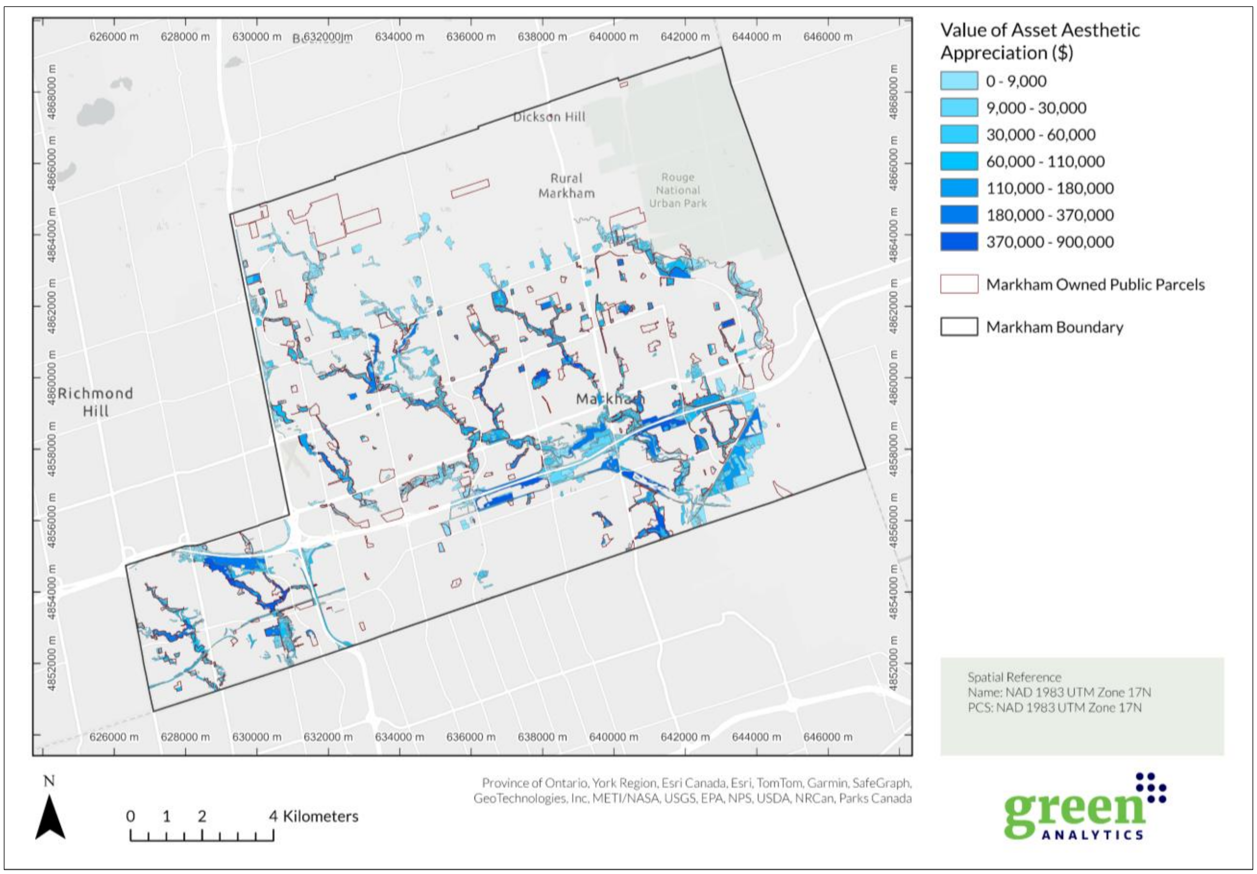

Figure 17-10. Value of aesthetic appreciation.

17.7 The Value of Natural Assets Contribution to Crop Productivity

To estimate the contribution of the natural assets with the City of Markham to crop productivity, each asset within the City of Markham was buffered by the assumed pollinator foraging range of 1,500m (AAFC 2014). The area of crop types within the pollinator foraging range of each asset was then established. The crops were scoped to those that are dependent on insect pollination and allocated an animal pollination impact rating based on Aizen et al. (2019) and Klein et al. (2007).

The crop types dependent on wild pollination[24] in the City of Markham were Soybeans and "Other Vegetables.[25]" Their dependence assumptions, and yield impact percentages, are shown in Table 17-12.

Table 17-12. City of Markham crops and assumed dependence to pollinators.

Crop Type	Pollinator Dependence Level	Upper Yield Impact	Lower Yield Impact	Mid-point Yield Impact
Soybeans	Modest	40%	10%	25%
Other vegetables	Little	10%	0%	5%

Agriculture statistics were then used to establish average Ontario crop production values and prices per unit of production.[26] Average production values ($/ha) for soybeans and other vegetables[27] were established based on a 5-year average from 2017 to 2021. Total crop values were approximated by multiplying the average production value by the area of each crop within the wild pollinator foraging radius to establish a total crop value influenced by pollinators. Finally, the pollination yield impacts mid-point factor % (Table 17-12) was applied to each crop's production value to establish the contribution to crop productivity provided by wild pollinators. For example, if the factor was 25%, then 25% of the value of crops were assumed to be lost without the presence of wild pollinator habitat. Taking average yields and prices for soybeans, and the other vegetables, the value of the assets which provided contributions to crop productivity within the City of Markham was $1.0M per year and the City-owned assets was $0.3M per year.

[24] The assumption here is that pollination for other crops is facilitated due to other factors such as wind.
[25] "Other Vegetables" were assumed to be onions, peppers, beans, and cabbages.
[26] https://www.ontario.ca/page/horticultural-crop-statistics
[27] "Other Vegetables" were assumed to be peppers, beans and cabbages. The average yield and price per bushel for beans, cabbages and peppers was applied to the area of agricultural land producing "other vegetables"