Canadian Ontario Agreement Mapping

A GIS based Approach to Green Infrastructure

Site Selection for the Application of Agricultural Best Management Practices

Proposed Methodology and Testing Results

Prepared by:

Chris Menary Hon. BA, TRCA

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1. INTRODUCTION

1.1 Project Overview

The intent of this project is the development of a mapping tool and/or a methodology for identifying potential sites for green infrastructure on agricultural lands, which will provide environmental and economic benefits by increasing resiliency, improving water quality and optimizing drainage infrastructure.

This project will examine potential sites across 3 different watersheds and aims to prescribe the appropriate best management practices (BMPs) to reduce nutrient loading by identifying lands for wetland creation, erosion control and tallgrass prairie plantings.

1.2 Objectives

The objectives for this project are as follows:

1. Conduct a literature review of studies and methodologies to determine the most current trends and practices in agricultural best practices.
2. Once complete, determine the most applicable studies/methodologies using the available data in the project study area.
3. Conduct a proof-of-concept test to determine the validity of the methodologies.
4. Select a test subwatershed and run the same methodologies to see whether they are scalable.
5. Analyze results of subwatershed test against original studies to determine if results are similar
6. Once complete, gain approval of selected methodology and process the remaining extend of the project study area.

1.3 Project Study Area

The project study area encompasses three Conservation Authorities (Kettle Creek/Catfish Creek/Long Point Region) covering 3900 km^2 along the north shore of Lake Erie in six municipalities (Figure 1). The area encompasses 28 major subwatersheds ranging in size from 6.8-749 km^2

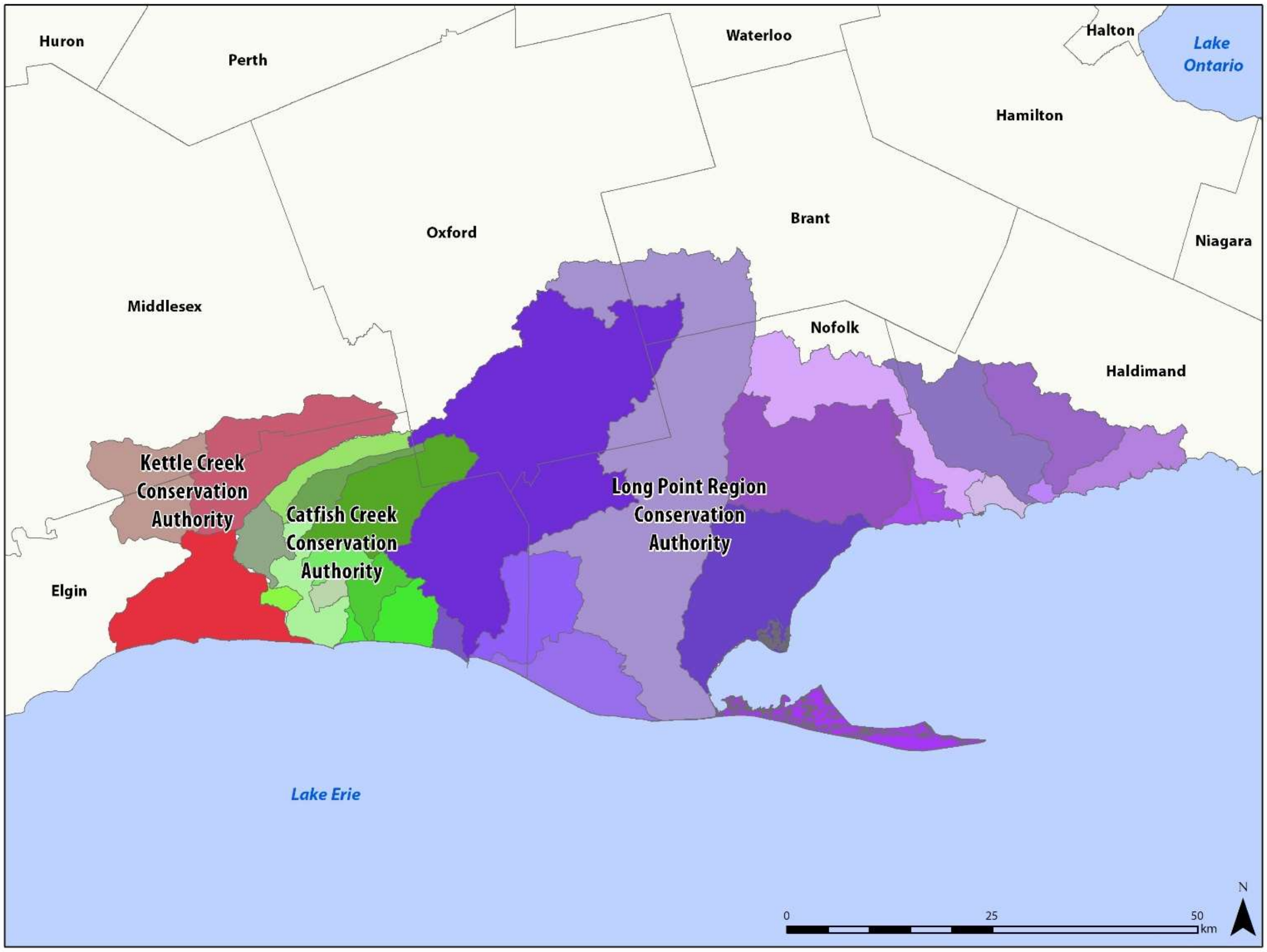

FIGURE 1: PROJECT STUDY AREA & SUBWATERSHEDS BY CONSERVATION AUTHORITY

2. LITERATURE REVIEW

2.1 Literature Review

In order to select which BMPs are best suited for this project, a number of case studies, project reports, and dissertations were reviewed. These represent the most recent work in the field and overall best practices. The following were reviewed:

Akturk, E., Post, C. & Mikhailova, E.A. Modeling and monitoring riparian buffer zones using LiDAR data in South Carolina. Environ Monit Assess 192, 350 (2020).

Rody Nigel, Karem Chokmani, Julio Novoa, Alain N. Rousseau & Anas El Alem (2014) An extended riparian buffer strip concept for soil conservation and stream protection in an agricultural riverine area of the La Chevrotière River watershed, Québec, Canada, using remote sensing and GIS techniques, Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 39:3, 285-301

Seidler, A., Atkinson, L., Durand, C. Brown Creek Riparian Study. St. Clair Conservation Authority.

Ghiyasvand, Mostafa. Developing a Mobile GIS Application for Facilitating Information Communications in Agri-Environmental Programs. Master of Science Thesis. University of Guelph, 2019

McPherson, T., Veliz, M. The use of GIS in the Gully Creek Watershed to Identify Suitable Locations for Agricultural Best Management Practices. Ausable Bayfield Conservatoin Authority, 2016.

Yang, W., Lio, Y., Shen, H. Evaluation of Multiple Best Management Practices in Fairchild Creek Watershed. University of Guelph, 2011.

Daggupati, Naga. GIS Methods to Implement Sediment Best Management Practices and Locate Ephemeral Gullies. Doctor of Philosophy dissertation abstract. Kansas State University, 2012.

Tomer, M., Porter, S., James, D., Boomer, K., Kostel, J., McLellan, E. Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. Journal of Soil and Water Conservation, Sept/Oct 2013. Vol 68, No. 5.

Galdin et al. Large-Scale Modeling of Soil Erosion with RUSLE for Conservationist Planning of Degraded Cultivated Brazilian Pastures. Land Degradation & Development, 2015.

RBZs are vegetation patches adjacent to watercourses which prevents sediment run-off from entering the water. This can also lead to a reduction of phosphorus and nitrogen deposition into Lake Erie. The intent would be to determine the current extent of RBZs, determine the type of habitat present, identify areas lacking in RBZs adjacent to agricultural fields, and suggest suitable locations for the creation of new RBZs.

2.2 Methodology Review

In addition to the review of literature, a technical review of methodology was conducted to ascertain the best techniques currently utilized for BMP GIS creation. This included numerous online articles, descriptions of GIS tools, and instructional videos on how to create the products to be used in the methodology. Several GIS tools identified in the review were downloaded for potential use. A selection is listed below:

- https://ncsu-geoforall-lab.github.io/erosion-modeling-tutorial/arcgis.html
- https://www.youtube.com/watch?v=ra-jG1agmO8
- https://www.arcgis.com/home/item.html?id=84e8f762b4d541b689c4f0eb9eca3156
- https://servirglobal.net/Portals/0/Downloads/Training%20Materials/Ex_3_Erosion_Flood_en_sm.pdf
- https://proceedings.esri.com/library/userconf/proc15/papers/85_746.pdf
- https://swat.tamu.edu/software/arcswat/
- https://www.sfei.org/projects/ripzet#tool
- http://downloads.esri.com/archydro/archydro/Setup/

3. IDENTIFICATION OF BEST MANAGEMENT PRACTICES

3.1 Riparian Buffer Zones

RBZs are vegetation patches adjacent to watercourses which prevents sediment run-off from entering the water. This can also lead to a reduction of phosphorus and nitrogen deposition into Lake Erie. The intent would be to determine the current extent of RBZs, determine the type of habitat present, identify areas lacking in RBZs adjacent to agricultural fields, and suggest suitable locations for the creation of new RBZs.

3.2 Agricultural Field Run-Off Assessment

Using a Revised Universal Soil Loss Equation (RUSLE), this methodology identifies agricultural fields that are susceptible to sheet and/or gully erosion for the purpose of mitigating soil loss. For this study, parts of the RUSLE analysis could be used as the methodology can be broken down into different pieces (slope analysis, rainfall, upland contributing areas) if not all data inputs are available. A secondary outcome of identifying these fields is to target cover crop planting.

3.3 Soil and Water Assessment Tool (SWAT)

The Soil & Water Assessment Tool is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change. SWAT is widely used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

These three were selected as they target sediment loss in agricultural lands and the capturing of run-off before it would enter Lake Erie. A combined methodology would include both examining fields for erosion risks (SWAT & Run-Off Assessment) and determining where riparian buffers could be located to prevent colluvium entering a watercourse (RBZs).

Most GIS data inputs to used create these three BMPs are available for the study area. Some datasets (such as yearly rainfall and soil conditions) may not be completely available, in which case the methodology may be altered.

4. DATA AVAILABILITY

All available data has been received from individual CAs or downloaded from the provincial GeoHub. The table below shows which data is available from whom and where.

	CCRA	KCCA	LPRCA	Province	
Watercourse	x	x	x	x	
Culverts	x	x			Elgin County coverage
Watreshed Boundary	x	x	x		
Subwatershed Boundary	x	x	x		
Imagery	x	x	x	x	SWOOP 2010/15
Engineered Floodway		x			
Lake Erie Flood Uprush		x			
Landcover	x	x	x	x	SOLRIS & LPRCA
Generic Regulation Limit	x				
Natural Heritage	x				
Tile Drainage Area	x			x	
Floodplain			x		
Agricultural Resource Inventory				x	Limited coverage
Lot Fabric				x	
Soils				x	
Constructed Drains				x	
Lidar DSM				x	
Lidar DTM				x	

Additionally, the quality of the data was evaluated to determine compatibility across all three Conservation Authorities. Metadata for this analysis was available for most of the data. The most crucial data for a riparian zone analysis was watercourses, and crucially a common dataset covering all CA's was available. Furthermore, it included the following fields which made further refinements possible:

1. **Watercourse Type**: 10 different classes, including constructed drain, culvert, ditch, and stream.

2. **Permanency**: Ephemeral/Intermittent/Permanent/Unknown.
3. **Name**: includes stream name, constructed drain name, and street name if roadside ditch

The one issue with the watercourse data was KKCA did not include virtual segments through waterbodies as with the other CAs. This was resolved by manually adding these segments through head-up digitizing utilizing the SWOOP 2015 data.

Aside from watercourses, the other data type which is present across all three CA's is Landcover. The provincial SOLRIS covered the entire project area and was created in 2011. Long Point Region has it's own Land Cover, created in 2017, which extents outside partially into Catfish Creek's jurisdiction.

The provincial data is present across all three CA's, except for Agricultural Resource Inventory. This is only available in a small number of townships unfortunately. As this data contains individual agricultural fields, the final methodologies chosen must therefore not rely on this data. This precluded any site-specific analysis and resulted in the methodologies adopted focusing on a subwatershed-wide scale.

5. TESTING THE METHODOLOGIES

5.1 Riparian Buffer Zone Analysis

Two methodologies were selected that could be used with the available data. The first was the *Brown Creek Riparian Study* by Seidler et al. This methodology is a vegetation analysis along a watercourse buffer, producing a polyline feature indicating the presence/absence of certain vegetation types along a watercourse. The main drawback with this methodology was the large amount of manual input required. The buffer was determined by the width of the watercourse, data that is not available and would have to be created by either measuring the distance or calculating bankfull width. Furthermore, the methodology states that if the watercourse width is greater than 4 m, both banks would need to be digitized instead of using the available centreline data. The riparian vegetation type along the watercourse buffer was also manually entered by viewing aerial imagery and making a subjective determination if it was meadow/thicket/woodland. The Brown Creek methodology could work well in a small area (the study area was only 155 km^2) where time could spent on a single subwatershed. As the study area for this project is over 3400 km^2 with 8739 km of watercourse, a manual approach would be too time consuming. Furthermore, this methodology does not create an actual riparian buffer zone. It merely identifies the vegetation along a watercourse. It suggests a buffer based on stream width, but the final product is a single line. When looking to create new buffers where vegetation is absent, it merely suggests the location, not the actual width required.

The Akturk et al *Modeling and Monitoring Riparian Buffer Zones using LiDAR data in South Carolina* methodology offers a similar result to Seidler et al but uses Lidar as an input and removes all manual digitization and classification. The methodology creates a riparian buffer zone based on the mean slope found within 30 m of a watercourse segment. This buffer consists of a primary zone of 12 m, plus a secondary zone determined by the mean slope. Steeper slopes contribute more sediment run-off, so a larger buffer zone is required in those areas.

Slope (%)	Width of RBZs on each side (m)		
	Primary	Secondary	Total
< 5%	12	0	**12**
5-20%	12	12	**24**
21-40%	12	24	**26**
> 40%	12	36	**48**

The riparian buffer zone is then used to clip an absolute height raster (Digital Surface Model – Digital Elevation Model) to determine the height of vegetation within the buffer. This methodology uses a vegetation classification of <0.5 m/0.5-5 m/> 5 m which gives a similar output to Seidler et al (meadow/thicket/woodland); Arturk et al call their classes “other/shrub/trees” but stipulates that these classes can be modified based on the required BMP. If this study were to attempt to distinguish between agricultural crops and low riparian vegetation along a watercourse, the classes could be adjusted accordingly. As the Lidar was flown in the spring, the only crops present are those left from the previous year. Corn stalks could be identified and were generally 30 cm high.

The Akturk et al study has the following advantages over Seidler et al:

1. No manual inputs required. The entire process is automated
2. Output is a riparian buffer zone determined by the surrounding slope of the watercourse segment
3. A vegetation analysis is performed based on actual height, not subjective interpretation of aerial imagery
4. Vegetation heights/types can be customized

One additional field in the Brown Creek Study is whether the watercourse is within 30 m of an agricultural field. A similar analysis can be conducted using the SOLRIS/LPRCA land cover data. The province’s Agricultural Resource Inventory has very limited coverage in the project area so these two datasets are used in lieu of actual fields.

Furthermore, using the newly created riparian buffer zones, the actual land use *within* the buffer can be added as a field using one of the two Land Cover datasets. In this way the data can be queried to determine which RBZs have no vegetation cover and are within agricultural fields.

Veg Class	Watercourse	Permanency	Land Cover	Shape Area	Watercourse within 30m of Tile Drained Field	Veg Type
0.5-5m	Bridge	Ephemeral	Built-Up Area - Impervious	Area is m2	Yes	Other
<0.5m	Constructed Drain	Intermittent	Built-Up Area - Previous		No	Shrubs
>5m	Culvert	Permanent	Deciduous Forest			Trees
	Ditch	Unknown	Forest			
	Stream		Hedge Rows			
	Virtual Canopy Cover		Marsh			
			Open Water			
			Planations - Tree Cultivated			
			Thicket Swamp			
			Tilled			
			Transportation			
			Treed Swamp			
			Undifferentiated			

The final fields for this analysis area:

1. Vegetation Class: height of vegetation (used three classes but can be customized)
2. Vegetation Type: name of height classes from study
3. Watercourse: types from CA watercourse data
4. Permanency: types of CA watercourse data
5. Land Cover: from SOLRIS/LPRCA landcover
6. Shape Area: area in meters squared
7. Watercourse within 30m of Tile Drained Field: use provincial tile drainage to determine proximity

5.2 Agricultural Field Run-Off Assessment

The methodology selected as most applicable is *The Use of GIS in the Gully Creek Watershed to Identify Suitable Locations for Agricultural Best Management Practices* by McPherson et al. The study identifies two separate types of run-off, sheet & gully erosion, and provides a methodology for identifying each.

Potential for Sheet Erosion

To determine the potential for sheet erosion, a modified Revised Universal Soil Loss Equation is used:

$$PSE = K*LS*R$$

K represents the soil erodibility factor. In McPerson et al, the value was determined by soil samples. As this is impossible for such a large study area, the “KFactor1” field in the provincial soil data was used.

LS represents the length of slope value and can calculated using a slope in percent rise and flow accumulation raster. Both datasets are created from the provincial Lidar digital elevation model.

R represents the terrain roughness factor, which is derived from a land use/cover layer. Two land cover datasets are available for the project area, SOLRIS and LPRCA's, with differing classes. SOLRIS has complete coverage but dates to 2011, whereas the LPRCA only covers that Conservation Authorities boundaries with a small buffer into Catfish Creek but dates to 2017. Both are raster datasets with a gridcode representing a land cover type.

McPerson et al provides an R value for their Land Use type, which was then matched to the SOLRIS/LPRCA grid code according to the following:

R_Factor	Land use	SOLRIS Gridcode
0.36	Agricultural crops	193 Tilled
0.10	Woodlands	90,91,92,93,191,192 (FO,FOC, FOM, FOD, CUP, CUH)
0.03	Farmsteads	250 Undifferentiated
0.042	Rough lands (i.e., pastures, meadows, ditches, grassed waterways)	131,135,160 (SWC, SWM, SWD, SWT, MA)
0	Water, roads	170,201,202,203,204

R_Factor	Land use	LPRCA Landcover Gridcode
0.36	Agricultural crops	1,2 (crop lands, bare soil)
0.10	Woodlands	4,5,6 (forests)
0.03	Farmsteads	
0.042	Rough lands (i.e., pastures, meadows, ditches, grassed waterways)	3,7,10,14 (grasslands, spare treed, barren, settlement open areas)
0	Water, roads	8,9,12,13,15

The LPRCA landcover dataset is superior to SOLRIS in terms of temporal date and quality of capture. Therefore the input for the potential sheet erosion calculation will be a combination of both with SOLRIS clipped to the missing extent of the project area that LPRCA landcover does not encompass (Figure 2).

Once all three inputs are created, they are multiplied together per the formula using the Raster Calculator to create the raster dataset. The final raster uses the largest cell size of the available data, which is SOLRIS at a 15 m resolution.

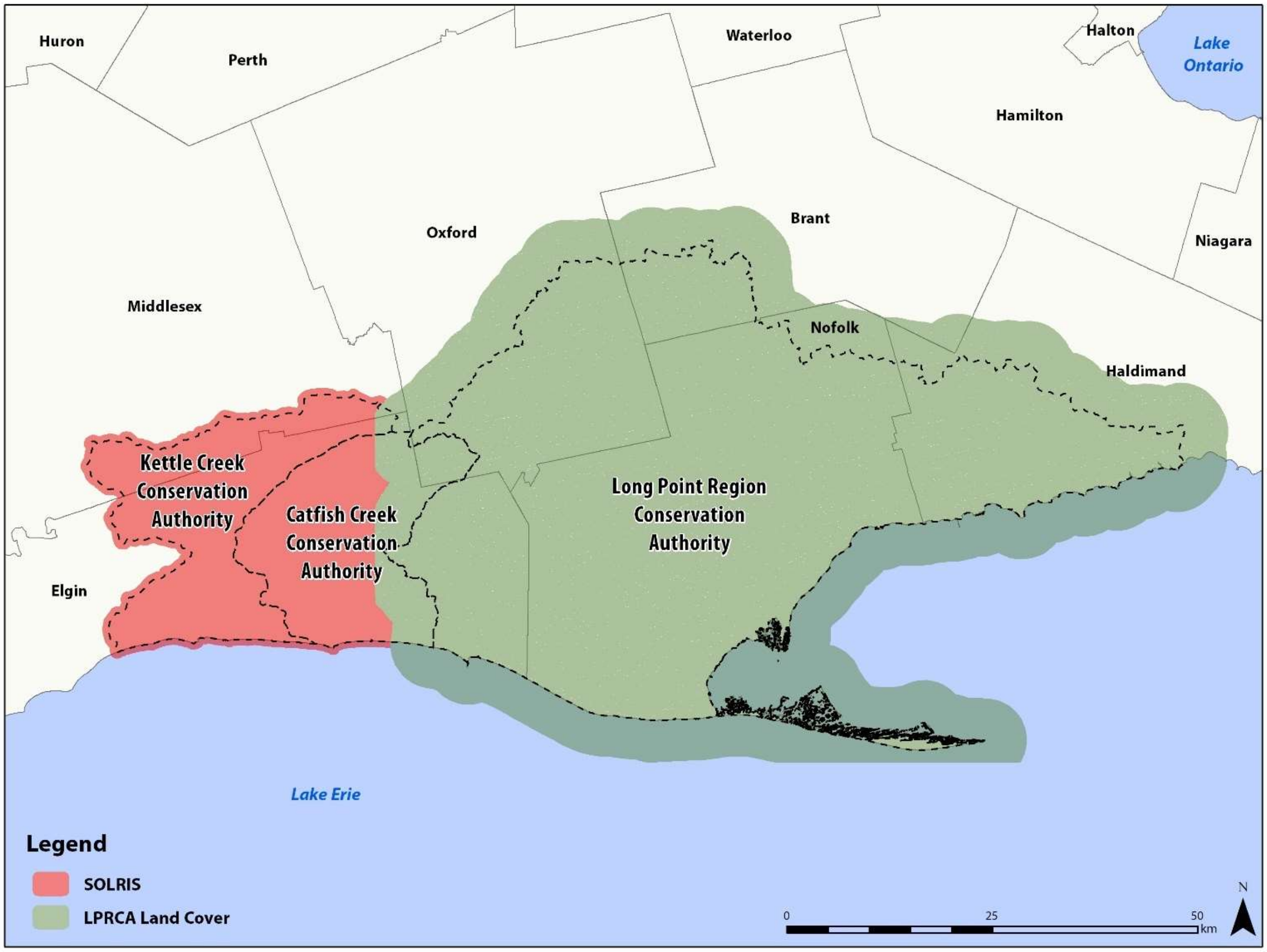

FIGURE 2: LAND COVER DATASET COVERAGE

Potential for Gully Erosion

The potential for gully erosion is calculated through a formula that creates a ***Stream Power Index***. This modeling determines which areas have higher and faster flow and are more likely to create scours in the landscape. This method utilizes a Lidar-derives Slope and Flow Accumulation grid, and is calculated via the following:

SPI= ln(flow_accumulation_dem+0.001)(slope_dem/100)+0.001)*

The two inputs, a flow accumulation and slope raster, are created with the provincial Lidar DEM.

Linking Results with Individual Agricultural Fields

Both the Ootential Sheet and Gully Raster results are a raster that covers the entirety of the subwatershed. This is impracticable to use as a screening layer at a subwatershed level, so in order to more easily determine which individual fields are at risk and to rank them zonal statistics are used to add quantitative measurements to agricultural fields.

The Gully Creek study used the provincial Agricultural Resources Inventory. This dataset is lacking data in most of the Project Area so cannot be used. An option considered was using the land use data (SOLRIS/LPRCA Land Cover) and extracting all agricultural polygons. This was determined to be impracticable as the data was a general land use and all agricultural areas were merged into large polygons with no individual fields present. The tile-drained field data was considered as well, but only contained fields with this drainage feature and not all fields.

The solution was to use the provincial lot fabric as a substitute for individual fields. The rational was:

1. These were the original land grants and many fields still follow this grid
2. They exclude road allowances (modern roads notwithstanding)
3. They are consistently a uniform size (roughly 100 acres)
4. The underlying input criteria includes all features within the lot (forest, wetland, urban areas) so these are reflected in the output
5. They are easy to view at a subwatershed scale
6. If there are any questionable results, the input criteria can be further investigated to understand the output

The PSE and PGE rasters were clipped to the subwatercourse boundary (or a buffer if the watercourses therein extend past the boundary) so the lots can either be clipped to the boundary or selected and exported. Some lots will be bisected by subwatershed boundaries, so there will be instances where two halves of a lot may have differing values.

Using Zonal Statistics, the mean PSE and PGE values within each lot are added to the lot polygon. This data can then be used to rank lots according to their susceptibility to gully and sheet erosion with a high/medium/low classification based on standard deviation. McPherson et al combined the PSE and PGE values into a final ranking, using the matrix below:

	Potential for Sheet Erosion (PSE) (K*LS*R)		
Stream Power Index (Rank value)	Highest (3) (> 0.5 SD. above the mean)	Moderate (2) (0.5 SD. above to -0.5 SD below the mean)	Low/flat (1) Low (< -0.5 SD below the mean)
Highest (3) (> 0.5 SD dev. above the mean)	High (6) Combined	High (5) Combined	Moderate (4) Combined

Moderate (2) (0.5 SD dev. above to -0.5 below the mean	High (5) Combined	Moderate (4) Combined	Moderate (3) Combined
Low (1) (< -0.5 below the mean)	Moderate (4) Combined	Moderate (3) Combined	Low (2) Combined

5.3 Soil and Water Assessment Tool (SWAT)

This methodology was not tested as it is very site specific, whereas the other two can be run at a subwatershed scale. There is also specialized software to run a SWAT analysis and it requires data inputs not available such as crop cover.

Once the RBZ and Erosion Potentiality Analyses have been run, the results can be used to determine individual fields at risk. A SWAT analysis could then be undertaken, with site visits, soil samples, and meetings with the landowner to learn of crop management.

6. DODD CREEK WATERSHED

To initially test the selected methodologies, two small creeks with direct Lake Erie drainage were processed. After receiving satisfactory results, the Dodd Creek subwatershed was selected for further testing as this would determine if the methodologies were practical for use on a large-scale area. The subwatershed is representative of the project area, with a mix of rural agricultural, forested areas, valleylands, and urban.

Dodd Creek is a tributary of Kettle Creek, situated north and west of St. Thomas. The watershed covers 130 km^2 and contains 277 km of watercourses. Most of the land cover is cropland interspersed with forest blocks. The watershed is bisected by Highway 401, contains the outskirts of St Thomas, and is located in both Elgin and Middlesex Counties (Figure 3).

The watercourse data extended past the watershed boundary in several places; this necessitated creating a 250m buffer from the watershed boundary which was used in all subsequent operations. This will have to be done in all instances where the watercourses extend beyond the boundary.

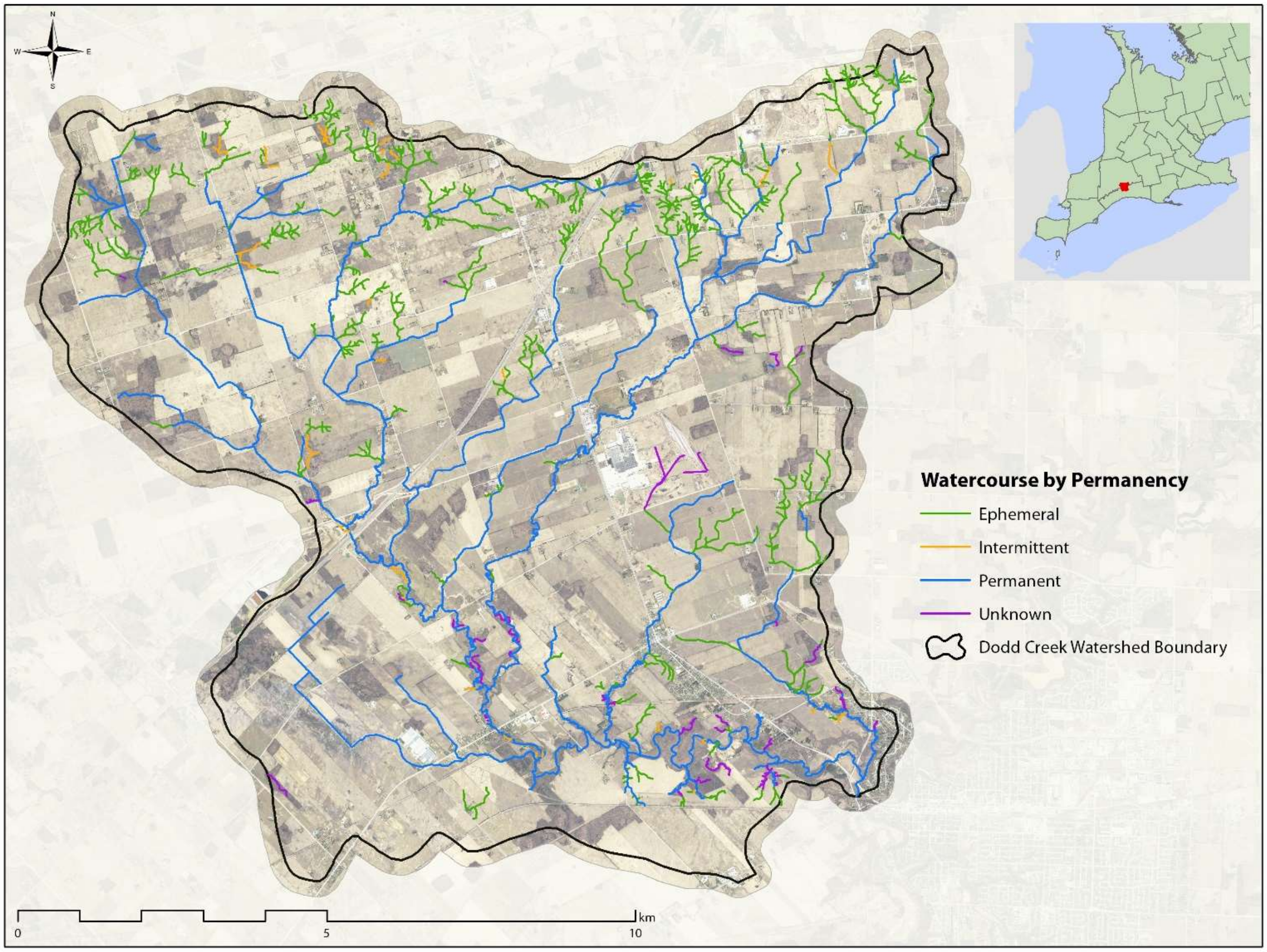

FIGURE 3: DODD CREEK WATERSHED

6.1 Dodd Creek Riparian Buffer Zone Analysis

The methodology outlined by Akturk et al was performed, and the results can be seen in Figure 4. From the subwatershed level, it is easy to see which watercourses have either low or high vegetation present. When zoomed in (see inset in Figure 4) individual trees and shrubs become apparent. Another level of analysis not pictured is the ability to combine watercourse type and permanency with the vegetation type. If one is interested in all intermittent watercourses that are adjacent to low vegetation, this can be determined via a simple query and displayed with differing symbology. The addition of land cover to the riparian buffer zones (Figure 5) adds more depth and the ability to further query the data.

As a screening tool, this analysis can identify where there is a permanent watercourse running through agricultural fields with low vegetation. It can further determine the extent of the riparian buffer zone needed based on the slope surrounding the watercourse. This information can then be used in the site selection process and provides quantitative evidence for funding applications and landowner meetings.

On a subwatershed level, this analysis can also provide metrics on the overall riparian habitat present. The total riparian buffer zone for Dodd Creek is 1276 Ha, which can be broken down as followed:

Vegetation Class	Ha	%
<0.5m	899	70.45%
0.5-5	68	5.33%
>5m	309	24.22%
Total	1276	100.00%

Less than 30% of the riparian zones in Dodd Creek are forested, a metric that can be included in watershed reporting. This also sets a benchmark that can be used in the future to track overall riparian changes.

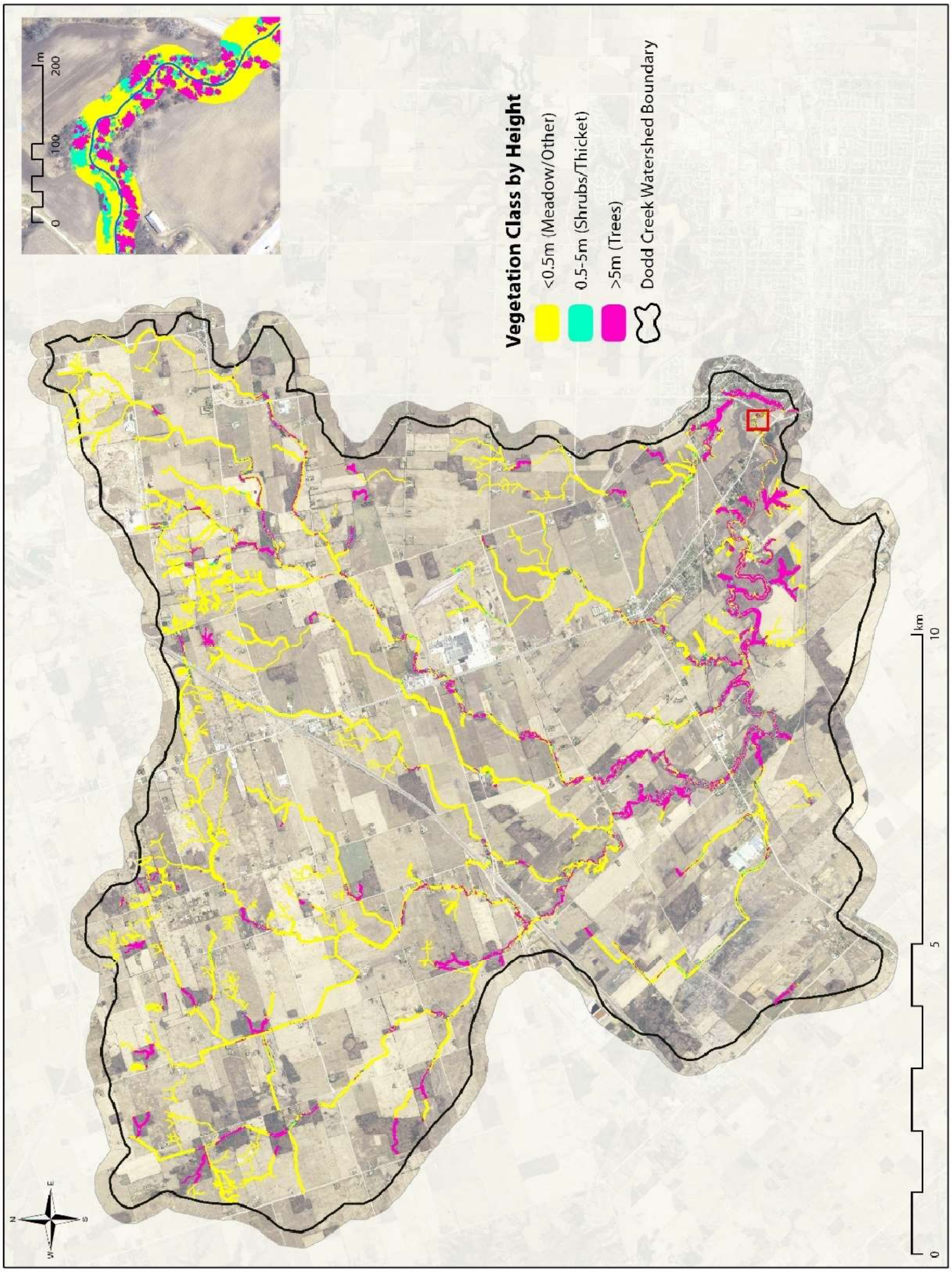

Figure 4: Riparian Buffer Zones by Vegetation Class

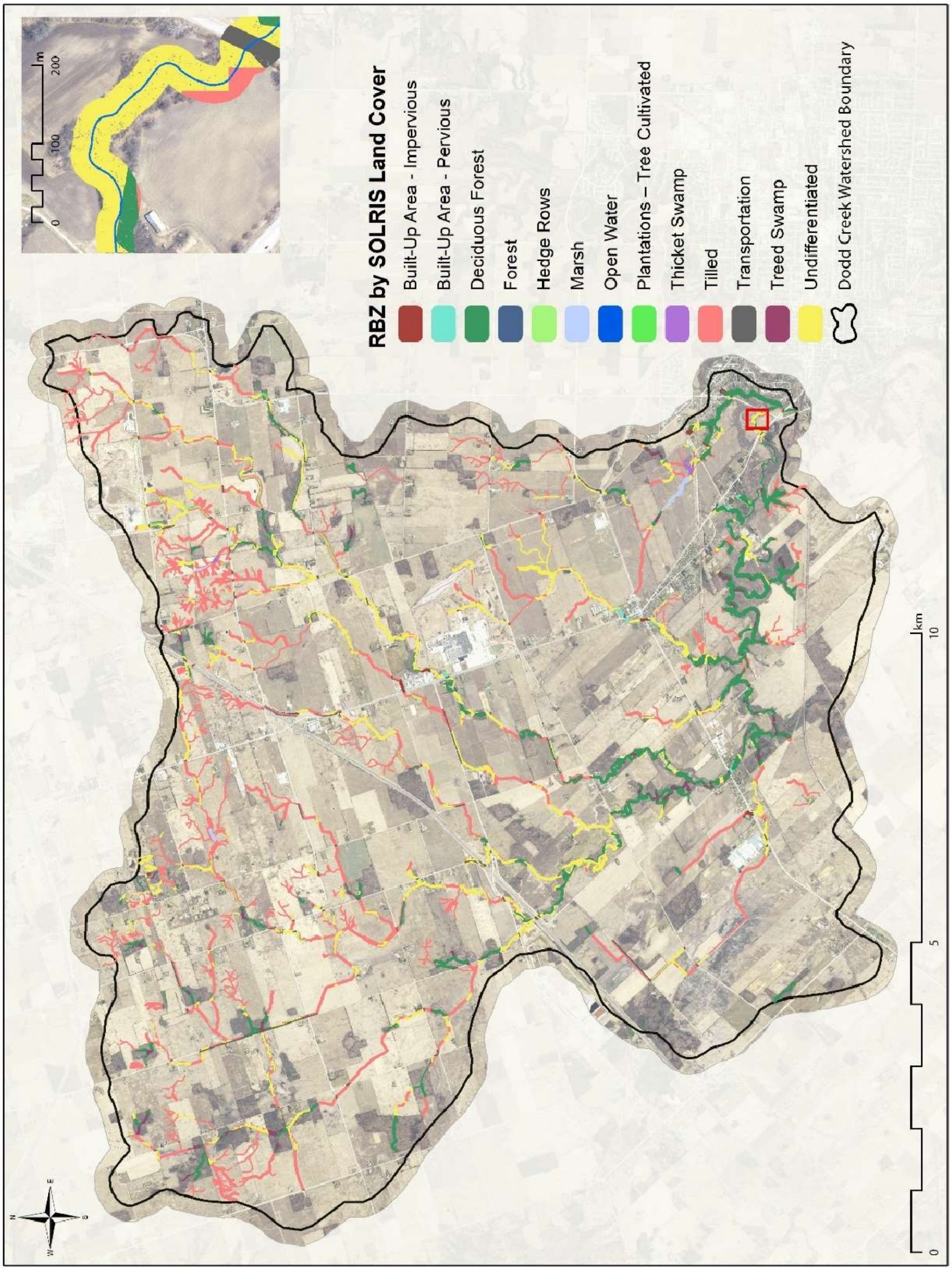

FIGURE 5: RIPARIAN BUFFER ZONES BY LAND COVER

6.2 Dodd Creek Erosion Potential Analysis

Potential for Sheet Erosion

When creating the criteria inputs for this analysis, an issue arose with the soils data. In urban areas and bottom lands, the K value was -9 where for every other soil type the value ranged between 0-1. If this value of -9 was included, it would skew the results and so was removed from the soils criteria input. These areas are not susceptible to agricultural erosion, and the two other criteria (R and LS) are still present so the resulting output does not contain any gaps.

The result of the PSE analysis was a 15 m raster, the cell size of which was based on the size of the largest input criteria (SOLRIS). The lot fabric was used and the mean PSE results in each were added. A map of low/medium/high susceptibility was produced like the Gully Creek Study based on standard deviation (Figure 6).

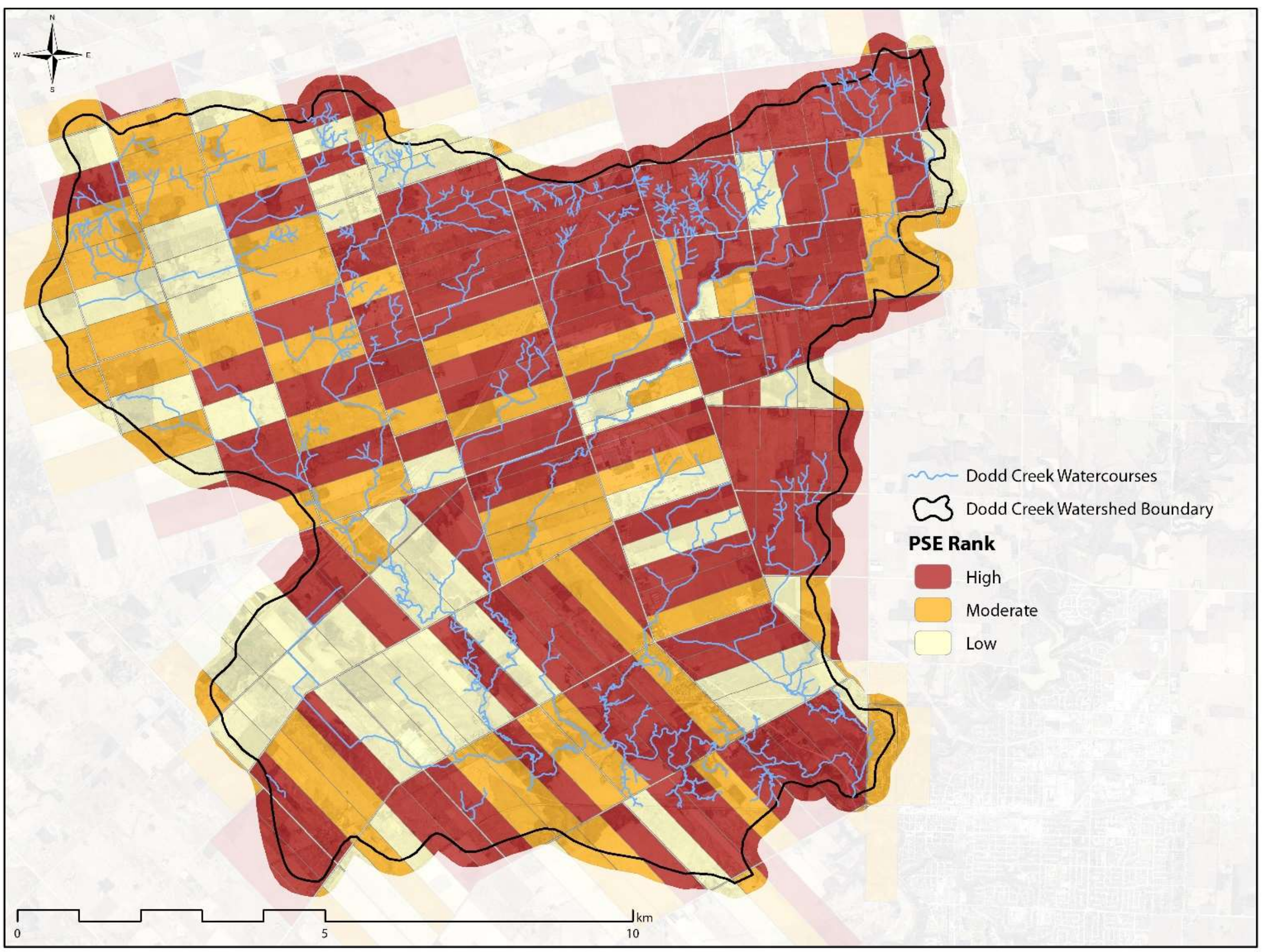

FIGURE 6: POTENTIAL FOR SHEET EROSION

If there are any questions of why one lot is high while the adjacent field is low, the criteria layers can be examined. When doing so, there was usually one criteria that was effecting the scoring. The soils data was compiled from maps made in the 1950s and a small change in the K value of one area versus another can change the results. The SOLRIS land use was created 10 years ago at a 15 m resolution and includes an “undifferentiated” Category that includes farmsteads, fallow fields, and other rural areas that were not forested.

Based on the inputs, this methodology has some caveats. As is it is done on a subwatershed level, the results can be viewed as coarse which is acceptable for a general screening layer. For more specific details on erosion, a SWAT model that utilizes soil samples, local precipitation, and site visits should be utilized. Nonetheless the PSE results can form the initial process of determining which fields to focus on with a SWAT analysis.

Potential for Gully Erosion

The Stream Power Index created for the subwatershed is based on 2019 Lidar data, so the potential for gully erosion can be viewed as higher-quality than the potential for sheet erosion. Unlike the PSE results which use a 15 m cell size, the PGE results use a 0.5 m cell size based on the Lidar inputs.

By linking it with the lot data, however, it does dilute its effectiveness to a subwatershed level. It serves well as a screening layer, and the underlying raster can be used with smaller polygons of individual fields to further refine areas of potential gully erosion if required.

The results can be seen in Figure 7.

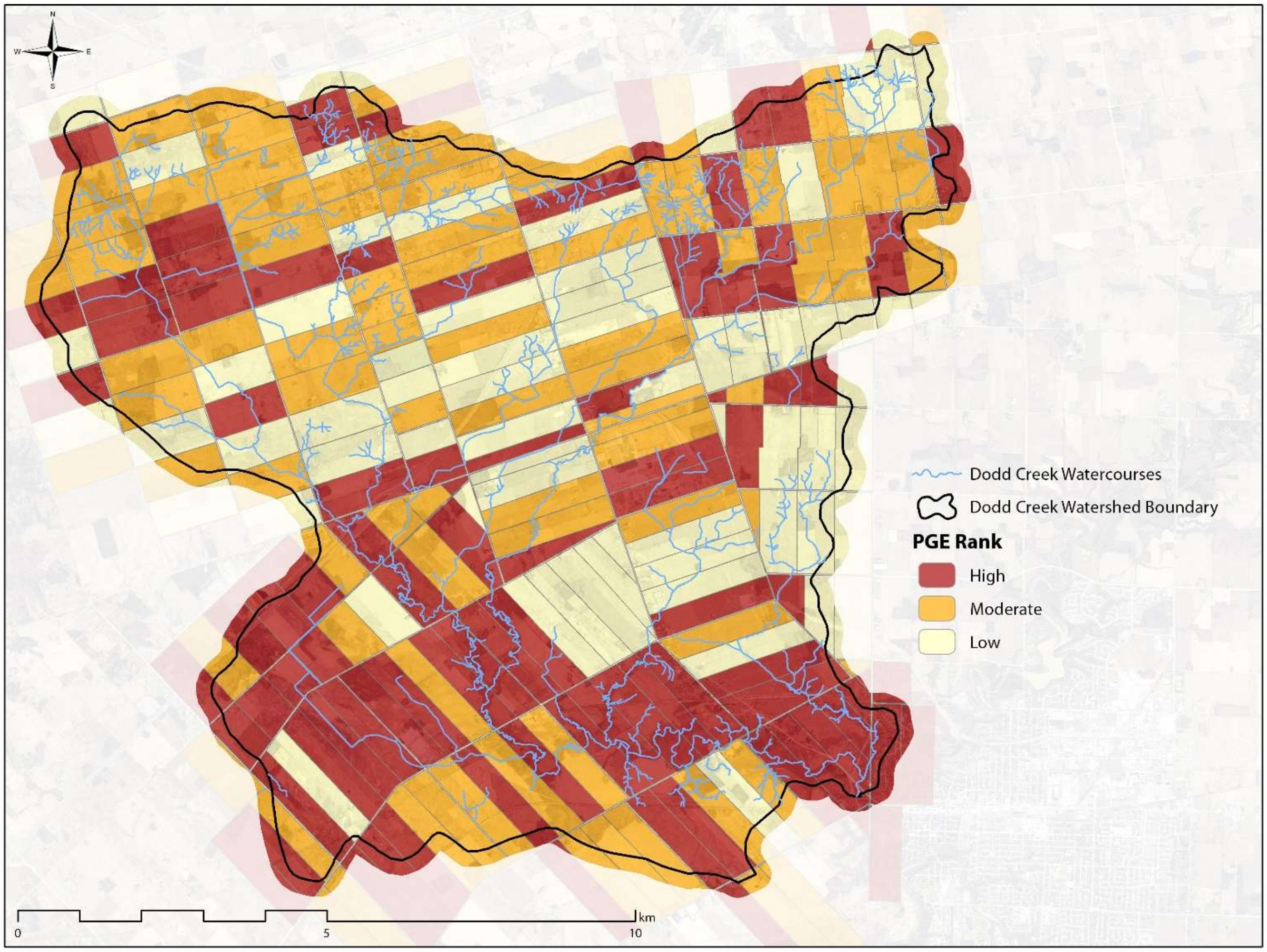

FIGURE 7: POTENTIAL FOR GULLY EROSION (SPI)

Combined Ranking

The final step was to combine the PSE and PGE rankings to create an overall rank for combined erosion on each lot. This was accomplished using the matrix in Section 5.2. The results can be seen in Figure 8

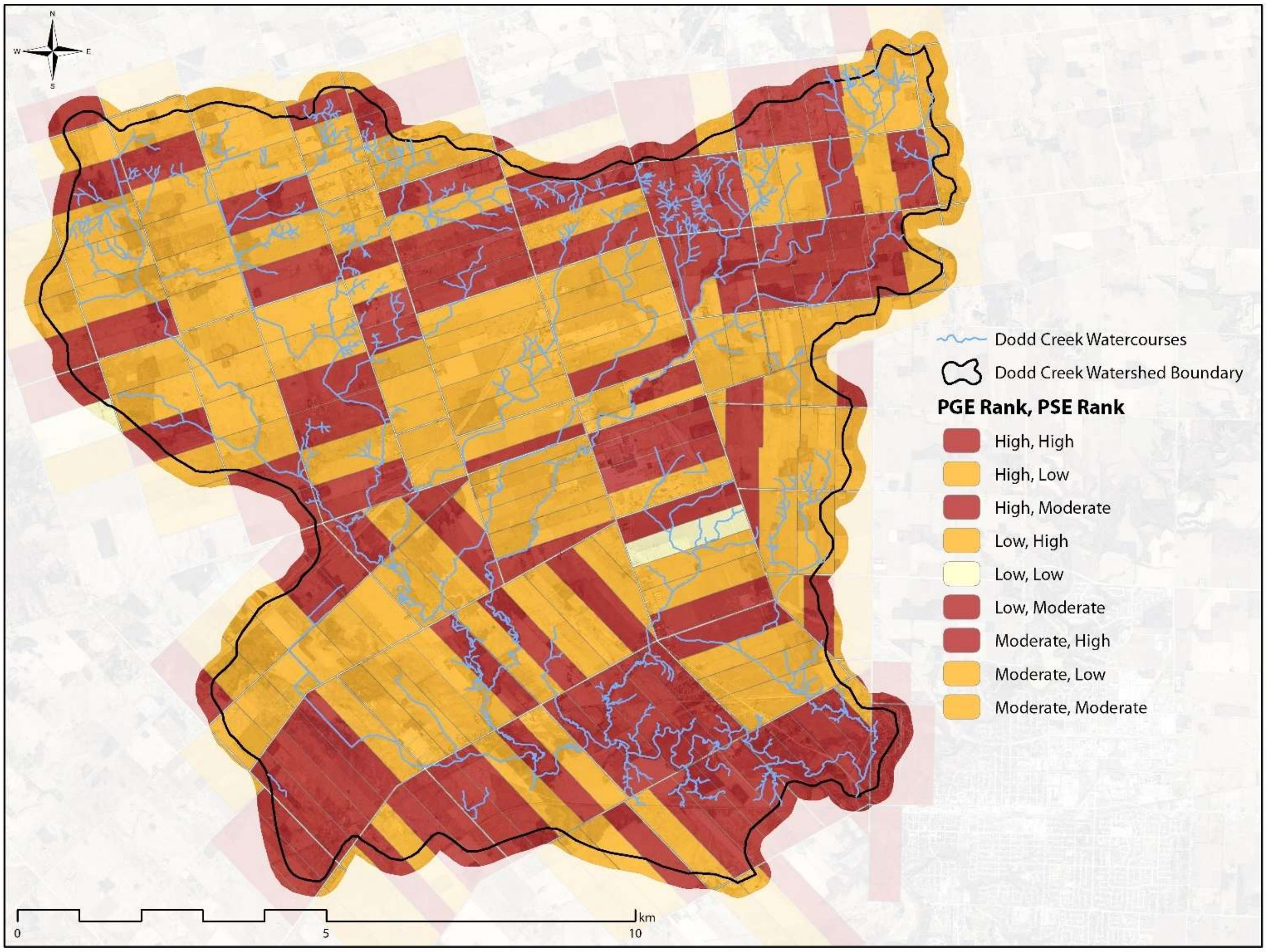

FIGURE 8: COMBINED PSE & PGE

7. METHODOLOGIES TO FURTHER REFINE RESULTS

7.1 SWAT Analysis

As previously mentioned, a SWAT was not one of the methodologies selected due the lack of site-specific data. Nonetheless, a SWAT analysis of an individual field would be a next step after the RBZ and Erosion analysis.

7.2 RBZ Depressions

Using hydrological tools, it is possible to located depressions in the landscape with the Lidar DTM. Depressions adjacent to watercourses within an RBZ are prime locations for the construction of wetlands (Figure 9).

This analysis uses already-processed data, so can be run after the RBZs have been delineated, and only in those areas. Depressions for Dodd Creek were run and can be used as an additional screening tool when determining implementing BMPs.

FIGURE 9: DEPRESSIONS WITHIN THE RBZ

7.3 Run-Off Risk Assessment

The Gully Creek Study undertook a Run-off risk assessment on individual fields. This involved calculating the steepness of slope and proximity to a watercourse, and then identifying the overlap between convergent foot slopes and relative saturation of the field. This is a very processing-heavy application, and best suited to small areas rather than a subwatershed.

Furthermore, as individual field data is lacking for the project, this methodology is best suited for further refinement of the PSE and PGE analysis. One of the inputs, the Compound Topographic Index which indicates relative saturation (Figure 10), was run for Dodd Creek as a test. While not part of an analysis, this product could be created for each subwatershed for further use.

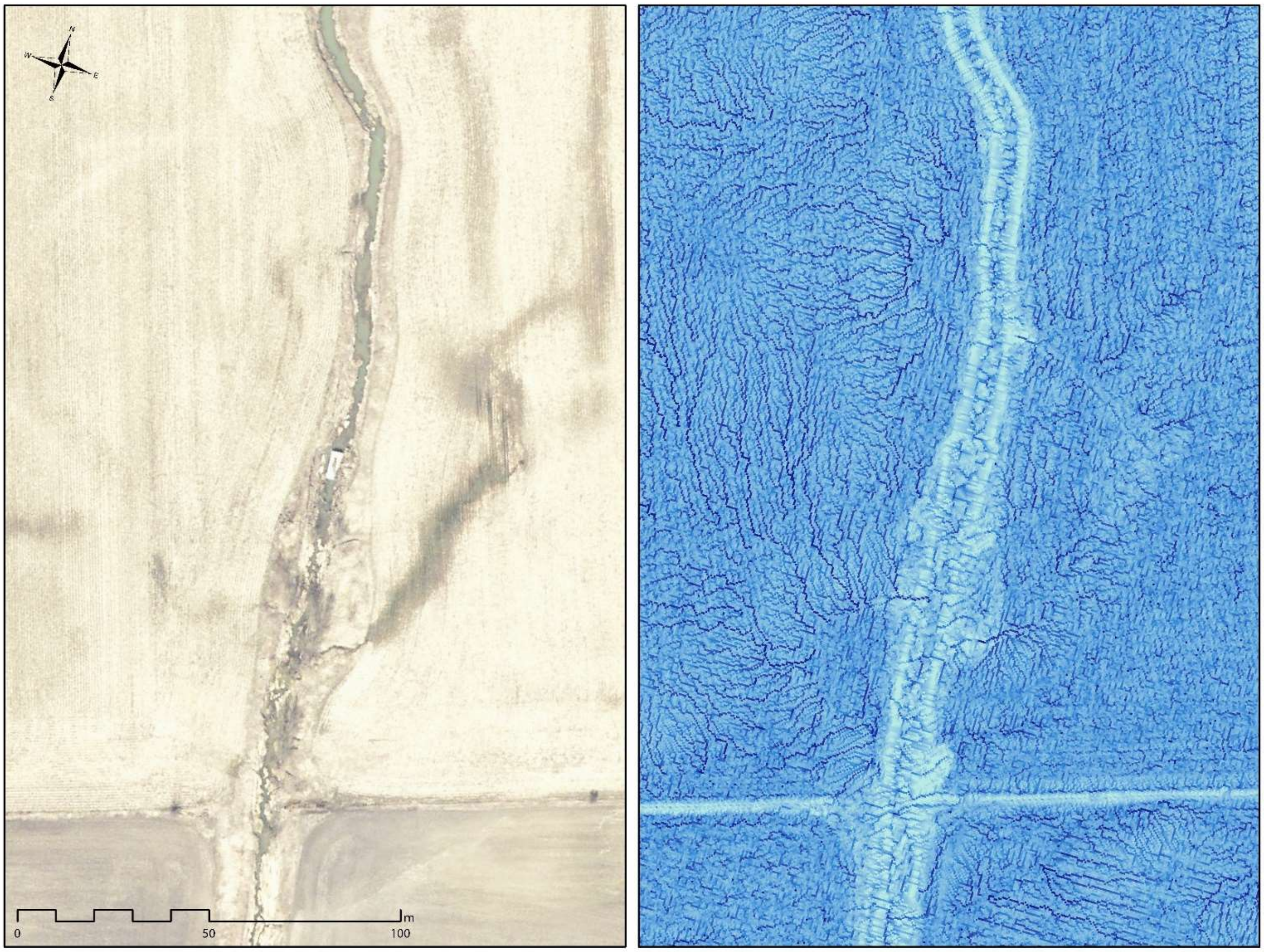

FIGURE 10: SWOOP 2015 AND CTI

7. CONCLUSION

The two methodologies selected for the COA Project are a Riparian Buffer Zone analysis, and an erosion potential model. Both look at the problem of sediment flow into Lake Erie if different ways. The RBZ analysis attempts to create a mechanism to capture sediment from agricultural fields before it enters a watercourse.

The erosion potentiality model seeks to identify which field are most susceptible to sheet and gully erosion. Working together, both of these methodologies can identify risk and provide mitigation. They also function as a subwatershed-level screening tool, which allows for the selection of areas at highest risk for prioritization.

Once these areas have been identified, further analysis can be undertaken using a SWAT model or using the PGE and PSE inputs to see where on a site the greatest risk areas are.

The results can be used to create a web application where staff from all thee CA's can view and query the data.

APPENDIX 1: DETAILED METHODOLOGY

RBZ Analysis

1. Create new folder in "Production" in the correct CA for the watershed to be run
2. Use Subwatershed layer to select all watercourses in F:\COA Mapping\Data\KCCA\watercourses\watercourses_kcca_ccca_lprca.shp
3. If some watercourses extend beyond boundary, manually select them. This process relies on watercourse extent, not subwatershed boundary. Export the watercourse layer into "SubwatershedName_watercourse"
4. Buffer watercourses by 30m. This step is to determine the slope surrounding the watercourse and to determine the width of the buffer zone. Call it "WatercourseXX_Buffer_30m"
5. Bring in the "DTM_Mosaic"
6. Use Raster Function on the mosaic to create a Slope by Percent Rise grid
7. Use Zonal Statistics as Table tool using the 30m buffer and the slope grid. Need the mean of slope within the buffer. Use the object ID of both when running tool.
8. Once the tool has run, join the zonal statistics table to "SubwatershedName_watercourse" layer. Create two new fields called "Mean_Slope" and "BufferWidth". Both are Double.
9. Copy mean slope from the table into Mean_Slope field.
10. The mean slope determine the buffer applied to the watercourse for the Riparian Buffer Zone.
11. For the BufferWidth Field, add the values below based on the Mean_Slope field:
    - Slope <5% = **12**
    - Slope 5-20% = **24**
    - Slope 21-40% = **36**
    - Slope >40% = **48**
12. Use **Create Buffers** tool and use BufferWidth field as input in the Buffer Type area. Dissolve the buffer by the fields "watercourse" and "permanency".
13. New layer of buffered watercourses "SubwatershedName_watercourse_RBZ" is created. Bigger buffer = more slope around hence greater chance of colluvium entering watercourse.

14. Use “SubwatershedName_watercourse_RBZ” to clip the DSM and DTM mosaics.
15. Subtract the clipped DTM from the DSM using the Raster Calculator to create an Absolute_Height raster. “SubwatershedName_DSM_clip” – “SubwatershedName_DTM_clip” = “SubwatershedName_AbHeight”
16. Symbolize “SubwatershedName_AbHeight”into /0-0.15 m/0.15-1 m/1-5m/>5 m or use the Absolute Height.lyrx
17. Use **Reclassify** to remove <0 m class and convert the other three into integer from floating point. Call it “SubwatershedName_AbHeight_reclassify”
    a. 0-0.15m – **1**
    b. 0.15m-1m – **2**
    c. 1-5m – **3**
    d. >5m – **4**
    e. **There may be additional values if there are hydro lines present. These can be removed like the <0m class. There may be additional gridcodes in the negative range. These are from aggregate pits or other deep depressions. They can be deleted when the layer is dissolbed**
18. Using the **Raster to Polygon** tool, convert “SubwatershedName_AbHeight_reclassify” into a polygon called “SubwatershedName_AbHeight_export”. Simplify the polygon part.
19. Dissolve the exported polygon class by grid code and call it “SubwatershedName_AbHeight_export_dissolve”
20. Add a new string fields called “Veg_Class” (use alias Vegetation Class) and “Veg_Type” (use alias Vegetation Type) to “SubwatershedName_AbHeight_export_dissolve”
21. Select each gridcode in turn, and add the following text in the Vegetation Class and Vegetation Type fields:
    a. Gridcode 1 = 0-**0.15m = None**
    b. Gridcode 2 = **0.15-1m = Low**
    c. **Gridcode 3 = 1-5m = Thicket**
    d. Gridcode 4 = **>5m = Trees**
22. The next step involves combining the RBZ vegetation data with landuse and watercourse data. Using the **Pairwise Intersect** tool, combine “SubwatershedName_AbHeight_export_dissolve” and “SubwatershedName_watercourse_RBZ”. Call it SubwatershedName_Vegetation_RBZ
23. Combine “SubwatershedName_Vegeation_RBZ” with “SubwatershedName_Landcover” with the same Pairwise intersect tool.
24. Call the output “WatershedName_Vegetation_RBZ_LandCover”
25. The final step is to determine if the RBZ contains a depression or municipal drain. Add two text fields “Municipal_Drain” (alias Municipal Drain) and “Depression_in_RBZ” (alias Depression in RBZ)

26. Use the **Select by Location** tool. Select all the polygons that intersect a municipal drain or depression. Those will be “yes” in the two fields. Switch the selection and make the rest “no”.

Modified RUSLE Analysis

Potential for Sheet Erosion (PSE)

PSE = K*LS*R

R= vegetation/land use

- For this input the provincial SOLRIS data and LPRCA Land Cover data was used
- The R values to be used come from McPherson & Veliz, 2016 and are five broad categories:

Value	Land use	Source or rationale
0.36	Agricultural crops	OMAFRA example (grain corn, spring plow)
0.10	Woodlands	Wall et al. 2002
0.03	Farmsteads	Assumed that had lawns and trees. NOAA 2008
0.042	Rough lands (i.e., pastures, meadows, ditches, grassed waterways)	Institute of Water Research 2002 – Continuous Low Residue Grass
0	Water, roads	

- The SOLRIS and LPRCA data has a much more detailed typology:

Value	Name
11	Open Beach/Bar
21	Open Sand Dune
23	Treed Sand Dune
41	Open Cliff and Talus
43	Treed Cliff and Talus
51	Open Alvar
52	Shrub Alvar
53	Treed Alvar
81	Open Tallgrass Prairie
82	Tallgrass Savannah
83	Tallgrass Woodland
90	Forest
91	Coniferous Forest
92	Mixed Forest
93	Deciduous Forest
131	Treed Swamp

135	Thicket Swamp
140	Fen
150	Bog
160	Marsh
170	Open Water
191	Plantations – Tree Cultivated
192	Hedge Rows
192	Tilled
201	Transportation
202	Built-Up Area - Pervious
203	Built-Up Area - Impervious
204	Extraction - Aggregate
205	Extraction – Peat/Topsoil
250	Undifferentiated

- It is also an integer raster, and the R vales are floating point
- Convert the SOLIR/LPRCA Land Cover raster to a polygon using the **Raster to Polygon** tool
- Call the output “KC_CC_SOLRIS”/”LPRCA_Landcover”
- Dissolve each by Gridcode
- Add a new field (double) to each called R_Factor
- For each gridcode, assign the value in the tables below

R_Factor	**Land use**	**SOLRIS Gridcode**
0.36	Agricultural crops	193
0.10	Woodlands	90,91,92,93,191,192
0.03	Farmsteads	250
0.042	Rough lands (i.e., pastures, meadows, ditches, grassed waterways)	131,135,160
0	Water, roads	170,201,202,203,204

R_Factor	**Land use**	**LPRCA Landcover Gridcode**
0.36	Agricultural crops	193
0.10	Woodlands	90,91,92,93,191,192
0.03	Farmsteads	250
0.042	Rough lands (i.e., pastures, meadows, ditches, grassed waterways)	131,135,160
0	Water, roads	170,201,202,203,204

- Use the Polygon to Raster tool to convert back to a raster. For the Value use R_Factor, and for cell size use 15 m2 as this was the original raster size.

K= soil erodibility factor

- Provincial Soils data (“Soil_Survey_Complex”)contains a field for K value (K Factor1)

- Clip the "Soil_Survey_Complex" by the Subwatershed Boundary. If on the edge of the CA boundary, see how far any watercourses extend past this. Then use this distance to buffer the Subwatershed boundary before clipping. Call it "SubwatersheName_Soils"
- The K value for urban areas or some valley lands is -9. As the expected K value is between 0-1 this will effect the analysis, so remove those areas from "SubwatersheName_Soils"
- Use the **Polygon to Raster** tool. The Value field is K Factor 1. Cell size is 15m

LS=Slope Steepness and Length of Slope

- LS = [0.065 + 0.0456 (slope) + 0.006541 (slope)^2](slope length ÷ constant)^{NN}
- **https://www.youtube.com/watch?v=-ISuKwQj830**
- Ls=(("fac"*30/22.1)^0.5)*(0.065+0.045*"slopprcent"+0.0065*("slopprcent"* "slopprcent"))
- Clip DTM_Mosaic with Subwatershed boundary
- Create Slope grib by percent rise
- Run Fill on clipped DRM
- Flow Direction
- Flow Accumulation
- Raster Calculator for the formula

Potential for Gully Erosion (Stream Power Index)

- ***SPI*= Ln(flow_accumulation_dem+0.001)*(slope_dem/100)+0.001)**
- Use the already created Flow Accumulation and % Slope rasters
- Call the output *SubwatershedName_PGE*

Determining Sheet and Gully Erosion potentiality for Individual Fields

- Run Zonal Statistics as Tool to generate Mean for each field
- Input is the lots, raster is the PGE/SPI raster
- Use OBJECTID as the common link
- In lots, add new double fields PGE_VALUE and PSE_VALUE. Add new text fields PGE_RANK and PSE_RANK
- Join the Zonal Stats table with the lots data
- Copy the Mean data from PGE/PSE into the resulting tables
- For the rank, determine the mean and standard deviation of the _VALUE field
- For the Rank field Low <0.5 SD/ Moderate between -0.5SD and +0.5 SD/High >0.5 SD
- Determine ½ SD, subtract from the mean value, select all values that are <0.5 SD for "Low" in %_RANK
- Determine ½ SD, add to the mean value, select all values that are >0.5 SD for "High" %_RANK

- Select all remaining values (%_VALUE IS NULL) and add “Moderate” for these in %_RANK

Locating Depressional Areas within the RBZ

- Using the DTM clipped to the final RBZ buffer (SubwatershedName_Clip), run the **Fill** tool and call the output *SubwatershedName_Clip_Fill*
- This fill in any areas in the DTM that water does not flow out of
- Using the **Raster Calculator**: “SubwatershedName_Clip_Fill - SubwatershedName_Clip”
- Call the results *SubwatershedName_Depressions*
- Use the Set Null tool to remove all areas that are 0
- Use SubwatershedName_Depressions for both the “Input conditional raster” and “input false raster or constant value” input fields
- In “Expression (optional)” enter “VALUE = 0”
- For the “Output raster” enter *SubwatershedName_Depressions_SetNull*
- This eliminates all areas without depressions, but there are still many areas where the depth may be only 1 mm. It’s best to set a minimum depth before exporting to a polygon.
- Classify the raster into two classes. For a minimum depth use at least 2 cm, so the classes would be 0.000001-2cm, and 2-XX cm
- To convert to a polygon, the raster needs to be converted from a floating point to an integer. The class under 2 cm also needs to be removed. Both of these can be performed with one tool
- Use the **Reclassify** tool. For the class under 2cm, reclass it to NoData. Change the second class (2>cm) to a 1. Call the output *SubwatershedName_Depressions_Reclassify*
- Use **Raster to Polygon** to export the new output to a polygon feature class. Call it *SubwatershedName_Depressions_Export*
- This new feature class will have several tens of thousands of polygons. To clean it up and make it more manageable, delete all entries that have a shape area of <1.0 m.

Toronto and Region Conservation Authority