Ontario Ring of Fire Surface Water Susceptibility Analysis

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Abstract

Since the discovery in the early 2000s of North America's first commercial chromite deposit in Northen Onatrio, dubbed the Ontario Ring of Fire (RoF), extensive mining development plans have been in progress. Chromite is used in the production of steel and is extracted using open pit mines that can leech toxic material and generate hazardous mining dust that contaminate soil and water. The proposed mining development is predicted to generate 32 million tons of waste rock in its 30 year lifespan, thus presenting a significant threat to the surrounding environment consisting of undeveloped boreal forest interspersed with swamps, marshes, fens and valuable peat land. This project seeks to determine the surface water susceptibility of the RoF region using GIS techniques developed by the University of Minnesota-Duluth Laboratory for Spatial analysis in the Geosciences, based on fact that areas that are more prone to runoff are capable of carrying suspended sediments, resulting in contamination of waterbodies. The analysis was conducted using four factors that contribute to overland flow: slope, distance to water, land cover and soil properties. The final combination of these factors showed that the region has low surface water susceptibility mainly due to the low slope percentage of the area and the majority of the landcover being open water, swamp, marsh and fen. The results indicate that contamination will not be rapidly transported away from the region through water bodies. Therefore, the areas immediately surrounding the mine may be at higher risk, as contamination will not be transported away and infiltrate the groundwater, contaminate aquatic life or be deposited in soils.

Introduction & Background

The Ontario Ring of Fire (RoF), located 500km North of Thunderbay in the Unorganized Kenora District, is the location of a large 220 million tonne deposit of chromite (Ontario Chamber of Commerce [OCC], 2014). This discovery presents a substantial economic opportunity for Ontario, boosting its export and manufacturing sector and predicted to generate $9.4 billion in GDP in the short-term alone (OCC, 2014). However, the RoF presents a unique challenge due to the fact that chromite has never been mined before in Canada in conjunction with the deposits location in a remote, untouched and inaccessible region of Ontario. As such there is large degree of uncertainty surrounding the potential risks and environmental impacts of developing the area, as well as conflicts with First Nations.

Currently, Noront Resources owns the claims to all the major discoveries in the RoF (Northern Life, 2015), including the largest chromite deposit, the Black Thor Deposit and the Eagle's Nest Mine, a high grade nickel, copper-platinum group element deposit (Noront, 2014). As Noront recently acquired the chromite deposit from Cliffs Resources no environmental assessment has been conducted. However, Noront has made a voluntary agreement to make the Eagle's Nest Mine subject to the requirements of the Environmental Assessment Act and are waiting for approval of their assessment by the Government of Ontario (Government of Ontario, 2014). Many NGOs, such as Ontario Nature (2013), are pushing back against the possibility of the assessment being fast tracked and are calling for a strategic environmental assessment to determine the cumulative impacts on the environment.

As the RoF is located in a mosaic of wetland and boreal forest, the saturated soil in the region present obstacles that limit development, which is further limited by the lack of available infrastructure due the delicate ecology in the area (OCC, 2014). Furthermore, transportation networks such as railways, road systems, transportation networks and transmission lines will need to be developed, which will increase the impact on the environment and animals (Ontario Nature, 2013). To reduce environmental impact Noront has proposed for the Eagle's Nest Mine, an underground mining and processing facility, an underground tailings storage and management and will recycle 100% of the process plant water to minimize effluent discharge, as well as treating waste water before releasing it (Noront 2013). However, whether or not the Black Thor mine will be suitable for underground mining has not been stated. A report by Golder Associates describes the previous proposal by Cliffs as slated to operate as two open pit mines for 10 to 15 years before transitioning to an underground operation, with a mining rate of 6,000 to 12,000 tonnes per day and generating 230 million tonnes of waste rock over its 30 year lifetime, with tailings management for this facility expected to be undergound as well (as cited in Bialy & Layfield, 2012). However, these estimates may change as further research is conducted.

Environmental Impacts

The greatest influencing factor on the degree of environmental impacts will be whether or not the chromite mine will require an open pit mine. Nevertheless, the main Environmenntal risks will include, but are nor limited to, acid mine drainage, heavy metal and hexavalent chromium contamination, tailings, and air polluition. The Ontario Ministry of Northern Development and Mines, reports aid mine drainage is a relatively low risk as only 20% of the rock tested in the Black Thor deposit show potential for acid generation (as cited in Bialy & Layfield, (2012). Heavy metal contamination may be more of an issue as open pit mining of chromite generates more waste rock than it does ore, creating higher odds of leaching to occur (Maponga & Ruzive, 2002). Hexavalent chromium is generated from chromite processing or from leaching of waste rock, and is a known carcinogen linked to numerous health conditions such as, skin rashes, ulcers, respiratory problems, lung cancer, weakened immune system, alteration of genetic material, kidney and liver damage (Kien et al. 2010; Das & Singh, 2011; Lenntech, 2011). As the tailings will be stored underground, the major risks will come from the possibility of accidents and mechanical or structural failures resulting in breakage of tailings storage and possibly catastrophic contamination. The Government of the Northwest Territories reported in 2011 that 92% of its hazardous waste spills were attributed to waste water spills, mostly sewage and mine tailings. While, the 2000s have seen a decrease in tailings failure events worldwide since the 1970s, there are still about 20 events per decade, which are mainly attributed to unusual rain and poor management (Azam & Li, 2010). As climate change continues to drive more unpredictable and severe weather this may prove problematic for the integrity of the tailings ponds in the Ring of Fire, especially as this may cause flooding in an already saturated environment with low runoff capacity. Air contamination will occur mainly through the creation of dust, which settles on soil and water, generated from excavation, dumping, loading and transporting activities, posing the highest risk for hexavalent chromium contamination to the environment and employees (Das & Singh, 2011).

This is not an exhaustive list of risks, and there will be many other potential impacts on the environment. Disturbance of endangered species, such as the woodland caribou, from habitat destruction and development activities will also occur, as well as the damaging of valuable peatland in the region that acts as a carbon sink (Simpson & Dyczko, 2012).

Methodology

The Surface Water Susceptibility Analysis (SWSA) is based on the analysis of 4 factors contributing to overland flow: slope, distance to water, land cover and soil properties (UMD, 2003). Each of these factors was weighted according to their potential to generate runoff and then combined to estimate the surface water susceptibility for the study area. The results were then classified to indicate low, medium or high potential to generate surface-water runoff. All data was acquired online from government databases and the international research organization CGIAR-CSI (Table 1). The WGS 84 datum was used to reduce the need for numerous datum transformations and to ensure easier integration of data with satellite acquired DEM data. UTM Zone 16N was used as the common projection for all data layers to ensure measurements were made in meters. All data layers were then clipped to the study area boundary.

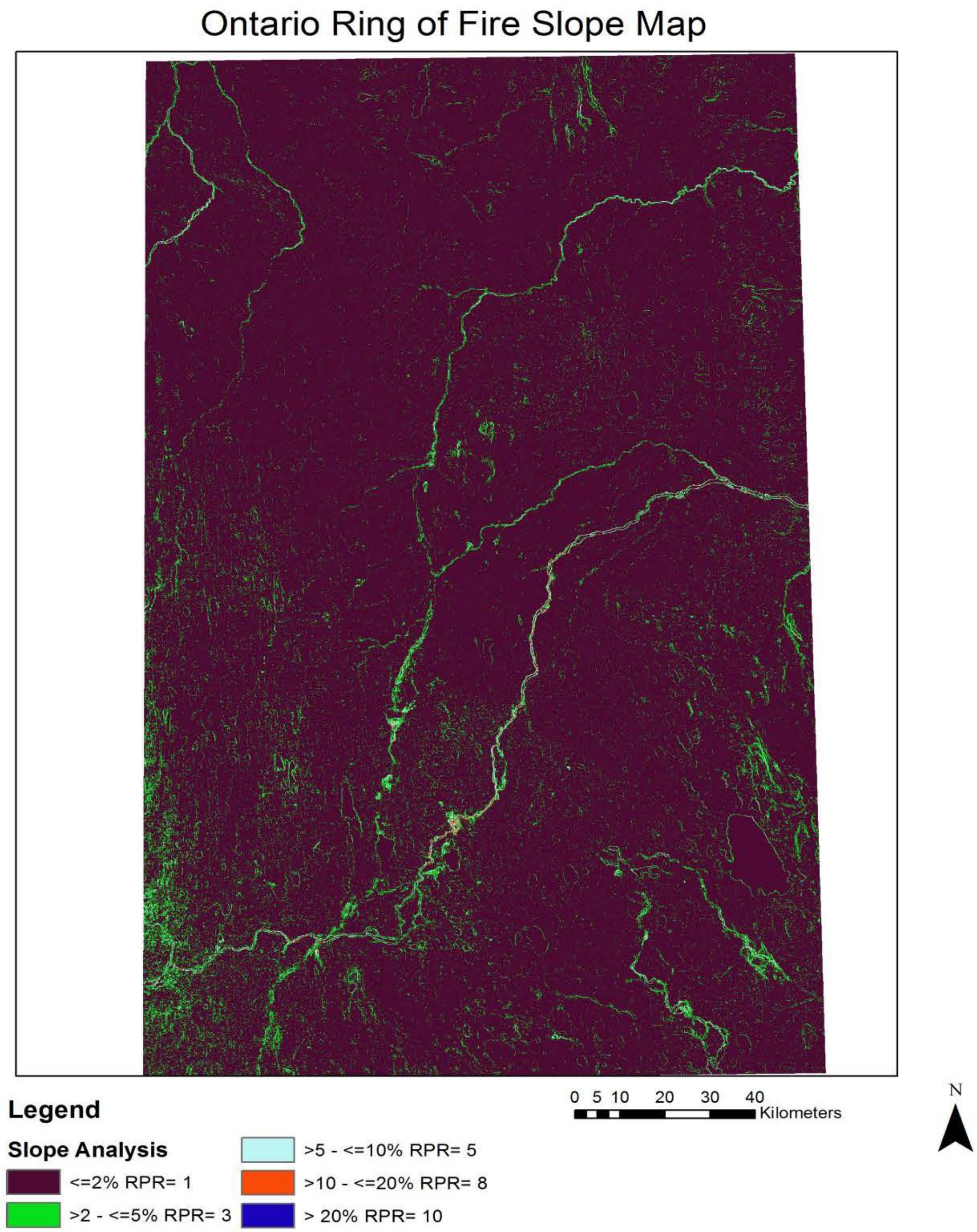
Slope Map

The slope map was created using a 90m DEM of the study area downloaded from the CGIAR Consortium for Spatial Information (CGIAR-CSI) website. Using the ArcMap slope tool a slope percentage was created and classified into five categories from low to high lope. Surface water susceptibility is highest when infiltration is low and runoff is high (UMD, 2003). Therefore, runoff potential ratings (RPR) were assigned to each category so that areas of low slope received low ratings and areas of high slope received higher ratings (Table 2). The RPR was multiplied by a weighting factor (WF) of three to create the SWSA total for each category of slope.

Table 2, Slope Factor Classification and Rating

Slope Value (Percent)	Runoff Potential Rating (RPR)	Weighting Factor (WF)	SWSA Total (RPR * WF)
<=2	1	3	3
>2-<=5	3	3	9
>5-<=10	5	3	15
>10-<=20	8	3	24
>20	10	3	30

Figure 2, Slope Map



Distance to Water

The distance to water map was derived from surface-water, water body polygon coverage retrieved from the Ontario Ministry of Natural Resources using the Scholars Geoportal web tool. Distance to water was calculated by generating buffers around lakes and rivers in the area. The UMD provided 5 buffer distances to be used in feet, which were converted to meters before creation in ArcMap using the buffer tool. Both ArcMap and QGIS were unable to buffer and dissolve in the same function due to the size of the data set. As such the buffer and dissolve functions were done separately. The polygon curves were converted to vertices connected by lines using the densify tool in ArcMap in order for the dissolve function to process the data. **Figure 3** displays the workflow used. The final polygon outputs were put through the erase tool to ensure no buffers overlapped adjacent waterbodies. Classification was completed by assigning high RPRs to distances closer to waterbodies and low RPRs to further distance **(Table 3)**. All buffer layers were then overlayed into one layer using the union tool and rasterized to the extent of the slope map using the SWSA Total assigned to each buffer polygon as the cell values **(Figure 4)**.

Figure 3, Distance to Water Workflow

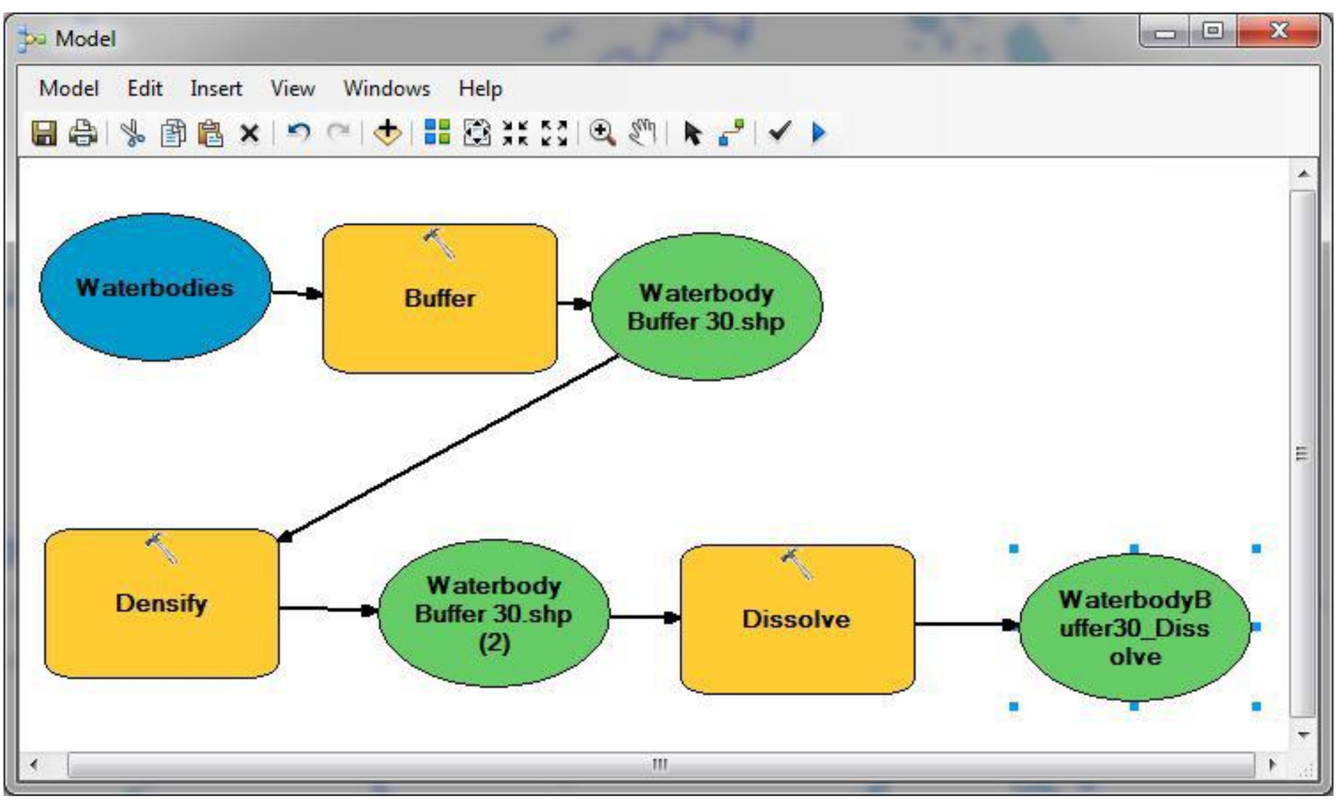


Table 3, Distance to Water Factor Classification and Rating

Distance to Water (Meters)	Runoff Potential Rating (RPR)	Weighting Factor (WF)	SWSA Total (RPR * WF)
>480	1	3	3
>240 - <= 480	3	3	9
>120 - <= 240	5	3	15
>60 - <= 120	7	3	21
>30 - <= 60	9	3	27
<=30	10	3	30

Land Cover

A Far North Land Cover map was downloaded from the Ontario Ministry of Natural Resources in raster format using Scholars GeoPortal. The data came classified from Landsat data and based on previous provincial land cover classification schemes. Each of the land cover classed were assigned an RPR based on its rational runoff coefficient, which reflects the fraction of rainfall that becomes runoff for a particular land cover class (USDA, 1986). The values were obtained from recommended runoff coefficients published by the Knox County Tennesse Stormwater Management Manual (2013), as shown in **Table 4**. The coefficients differ depending on soil class as defined by the Natural Resources Conservation Service (NRCS, 2013) and by slope. As discussed in further detail below, the study area was dominated by soil class D with very high runoff potential and soil class C, with high runoff potential. The land cover classification was separated into two layers based on whether they were located in class C or D and assigned Runoff coefficients accordingly, assuming a constant slope of less than 2%, as the majority of the study area was below a 2% slope. The coefficients were then multiplied by ten to determine the RPR and multiplied by a weighting factor of four, resulting in the the final SWSA values **(Table 5 & 6)** and two land cover layers classified by soil group **(Figure 5 & 6)**. For ease of classification the SWSA was rounded to the nearest whole number. Bedrock was assigned the highest possible runoff coefficient of one, as it is an impervious surface. The two land cover classes were then merged back together to create the final raster output with the SWSA total as the cell value **(Figure 6)**.

Figure 4, Distance to Water Map

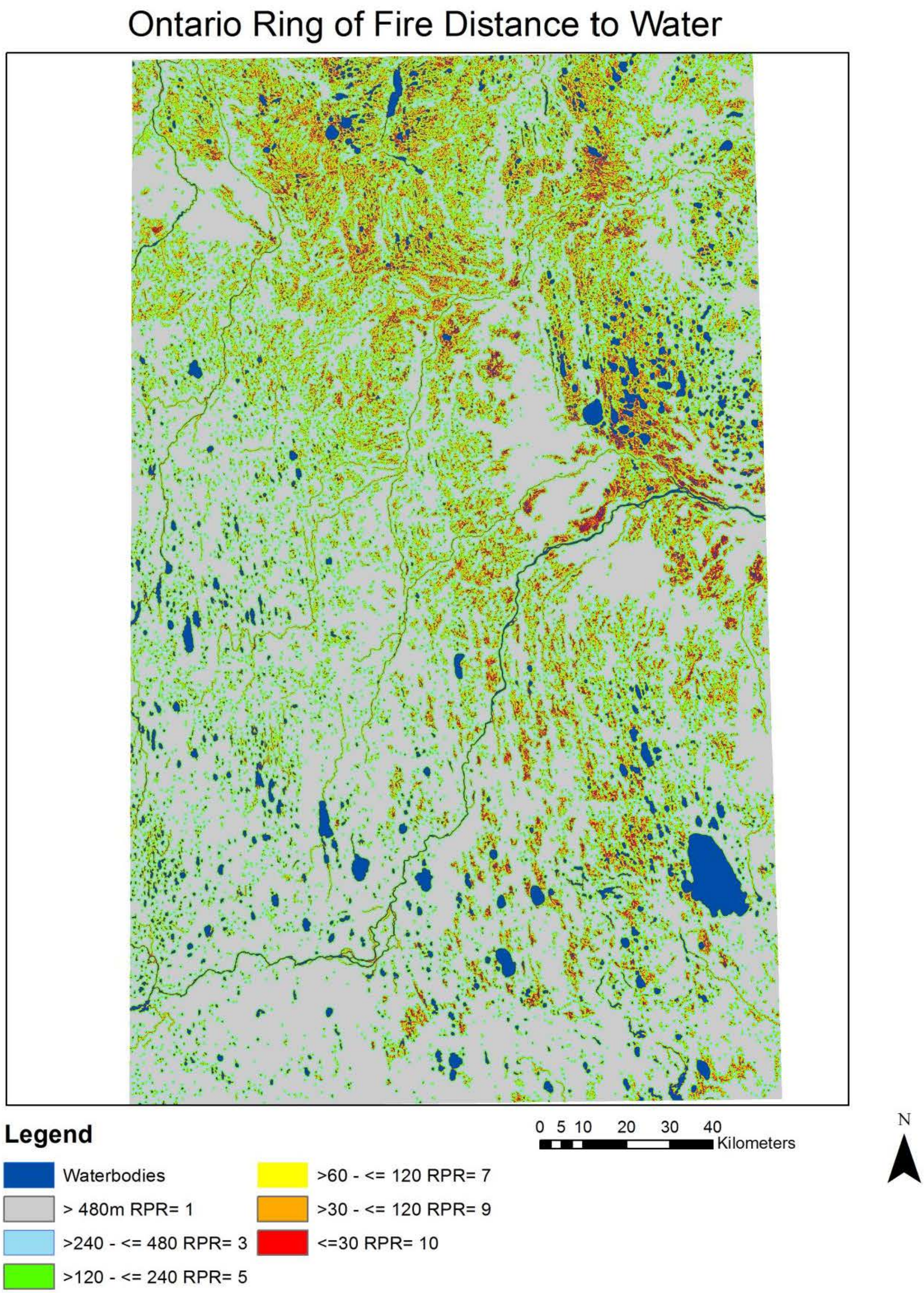


Table 4, Rational Runoff Coefficients

	Runoff Coefficient, C					
	Soil Group C			Soil Group D		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.12	0.16	0.20	0.15	0.20	0.25
Meadow	0.26	0.35	0.44	0.30	0.40	0.50
Pasture	0.30	0.42	0.52	0.37	0.50	0.62
Farmland	0.20	0.25	0.34	0.24	0.29	0.41
Res. 1 acre	0.28	0.32	0.40	0.31	0.35	0.46
Res. 1/2 acre	0.31	0.35	0.42	0.34	0.38	0.46
Res. 1/3 acre	0.33	0.38	0.45	0.36	0.40	0.50
Res. 1/4 acre	0.36	0.40	0.47	0.38	0.42	0.52
Res. 1/8 acre	0.38	0.42	0.49	0.41	0.45	0.54
Industrial	0.86	0.86	0.87	0.86	0.86	0.88
Commercial	0.89	0.89	0.90	0.89	0.89	0.90
Streets: ROW	0.84	0.85	0.89	0.89	0.91	0.95
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.68	0.70	0.72	0.69	0.72	0.75

Rational Method Runoff Coefficients - Part II

Table 5, Landcover Factor Classification and Rating Soil Group C

Land cover	**Rational Runoff Coefficients Soil Group C**	**(X)**	**Runoff Potential Rating (RPR)**	**Weighting Factor (WF)**	**SWSA Total (RPR * WF)**
Open Water/Wetlands-Bogs, Fens, Marshes and Swamps	0	10	0	4	0
Forest	0.12	10	1.2	4	4.8
Disturbance	0.68	10	6.8	4	27.2
Bedrock	1	10	10	4	40

Table 6, Landcover Factor Classification and Rating Soil Group D

Land cover	**Rational Runoff Coefficients Soil Group D**	**(X)**	**Runoff Potential Rating (RPR)**	**Weighting Factor (WF)**	**SWSA Total (RPR * WF)**
Open Water/Wetlands-Bogs, Fens, Marshes and Swamps	0	10	0	4	0
Forest	0.15	10	1.5	4	6
Disturbance	0.69	10	6.9	4	27.6
Bedrock	1	10	10	4	40

Figure 5, Land Cover Classification by Soil Group C Rational Coefficents

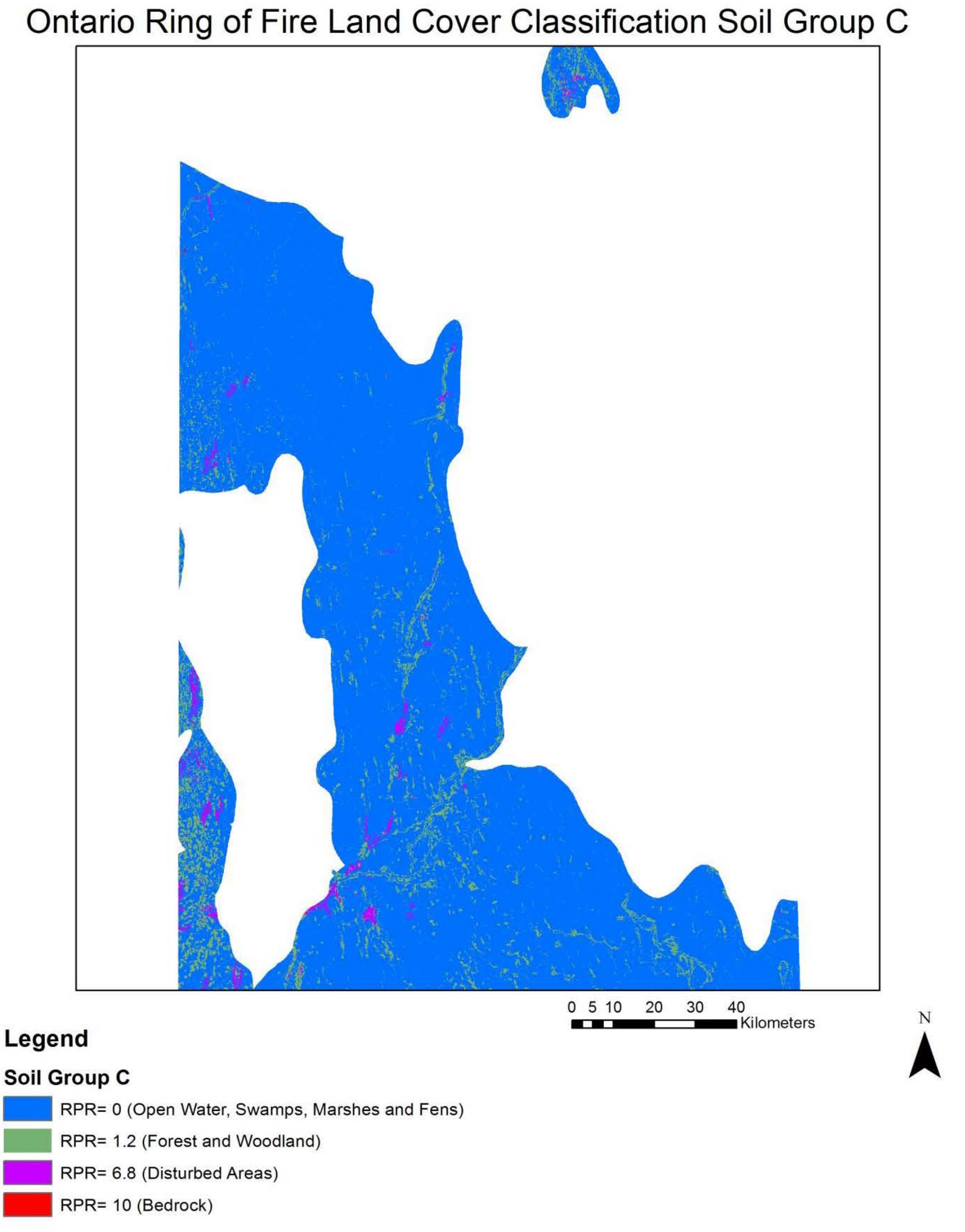


Figure 6, Land Cover Classification by Soil Group D

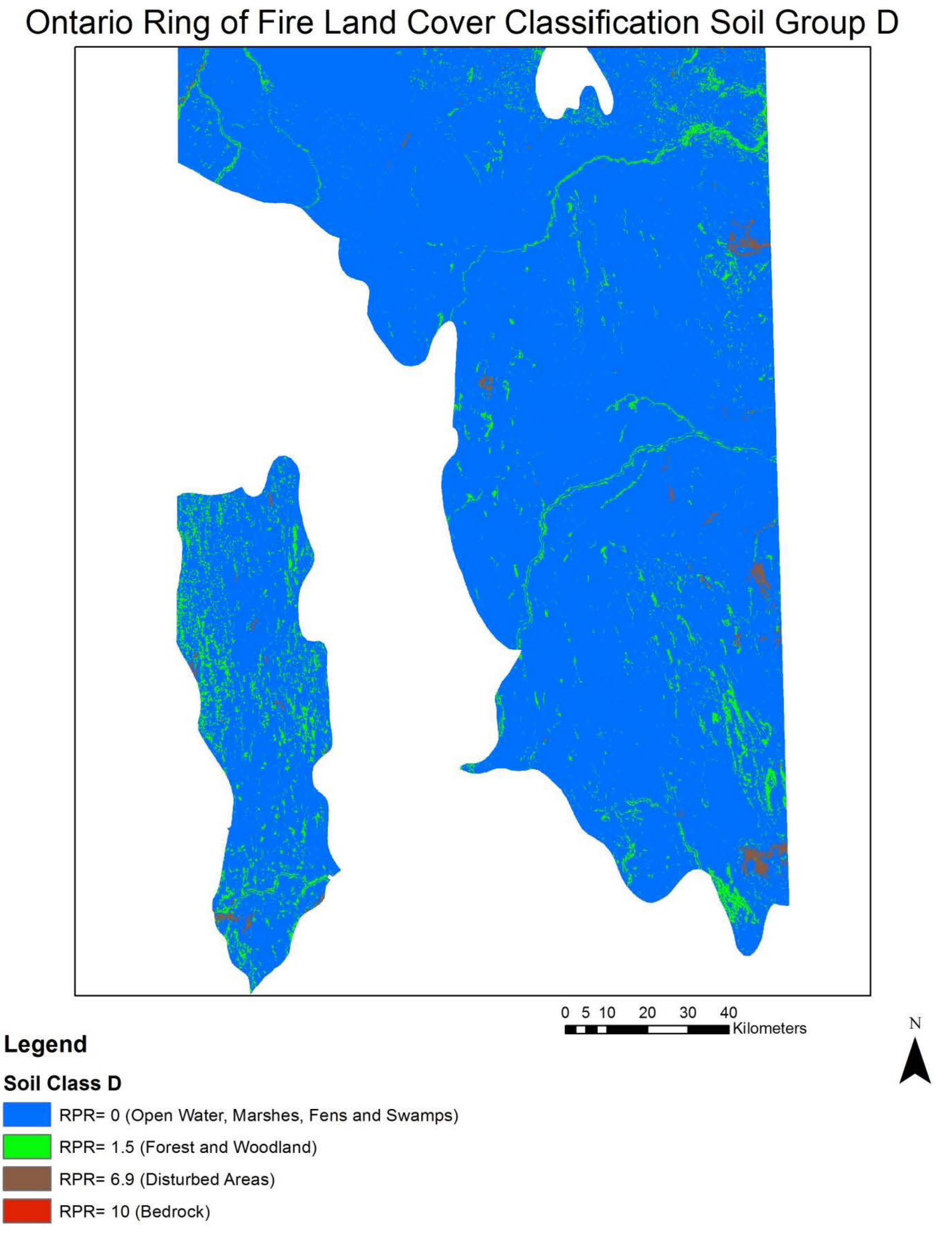
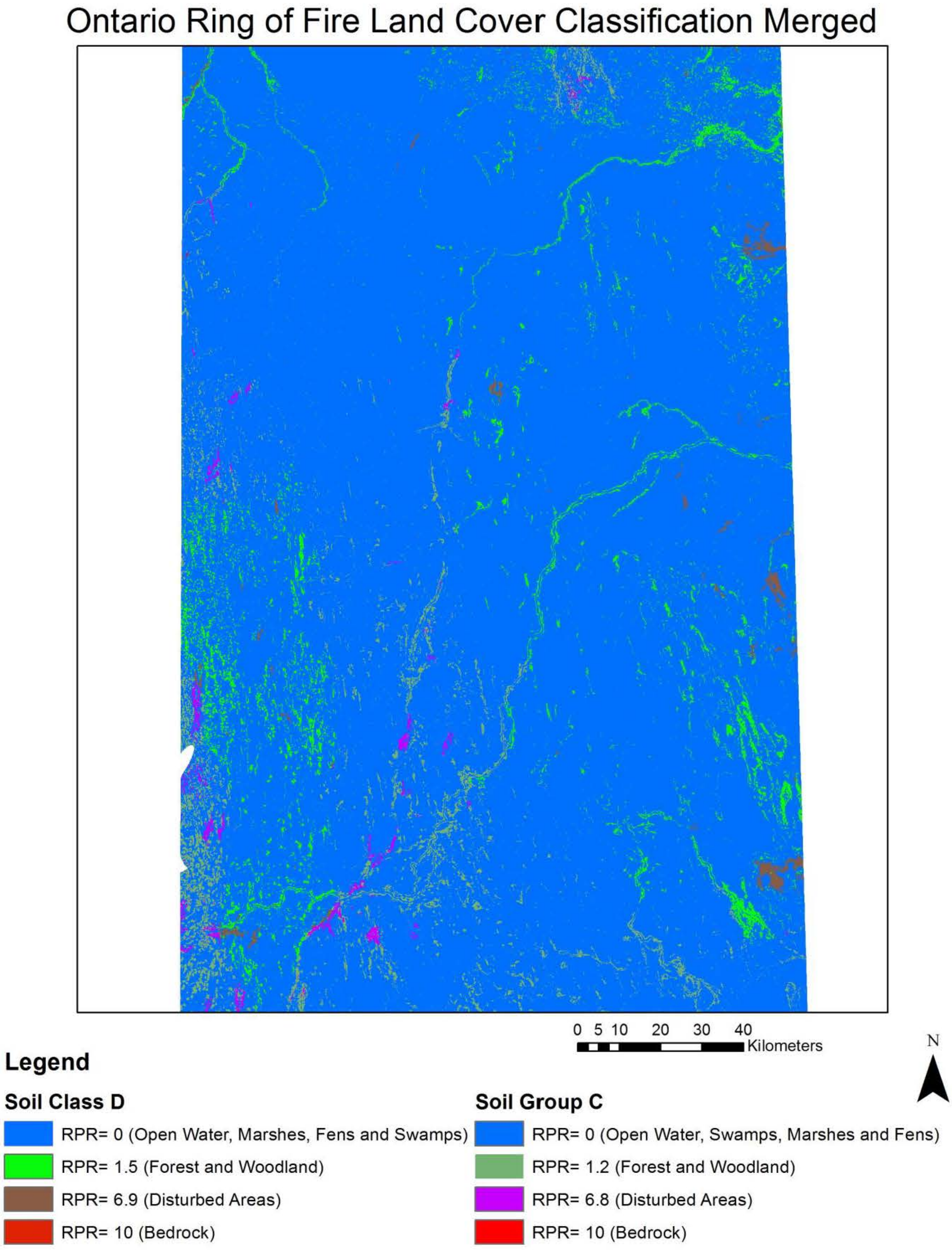


Figure 7, Land Cover Classification by Soil Group C & D



Soil

Soil Landscape maps were retrieved from the Government of Canada Agriculture and Agri-Food National Soil Database website. The data gave polygon coverage of different soil types, as well as databases that could be linked to the polygons that included information such as soil type, name and drainage class. For this analysis the drainage class of the soil was used to map the polygons. Three drainage classes were present in the study area medium, poor and very poor. RPRs were assigned to these drainage classes based on the four hydrological soil groups as defined by the NRCS **(Table 6)**. Soil group D has very low infiltration, which is associated with the very poor drainage class, as water is removed very slowly from the soil impeding transmittance surface-water through the soil to the watertable (Canadian Soil Information Service, 2013; USDA, 1986). The well-drained class of the soil landscapes data was assigned the RPR associated with soil group D. The poor drainage class was associated with soil group C and the very poor drainage class was associated with soil group B. The RPR of each class was multiplied by a WF of four to obtain the SWSA total **(Table 7)**. The polygon coverage was then rasterized to the extent of the slope map, with the SWSA total as the cell values **(Figure 8)**.

Table 6, Hydrological Soil Groups

Hydrological Soil Group	**Description**	**Infiltration Capacity/Permeability**	**Leaching Potential**	**Runoff Potential**
Soil Group A	Deep, well-drained sands and gravels	High	High	Low
Soil Group B	Moderately deep to deep, moderately drained, moderately fine to moderately coarse texture	Moderate	Moderate	Moderate
Soil Group C	Impeding layer, or moderately fine to fine texture	Low	Low	High
Soil Group D	Clay soils, soils with high water table, shallow soils over impervious layer	Very low	Very low	Very high

Table 7, Soil Factor Classification and Rating

Soil Drainage Class and Hydrological Soil Group	Runoff Potential Rating (RPR)	Weighting Factor (WF)	SWSA Total (RPR * WF)
Well-Drained (Soil Group A)	1	4	4
Poor Drainage (Soil Group B)	4	4	16
Very Poor Drainage (Soil Group C)	8	4	32

Results

The final surface water susceptibility map was created adding all the weighted raster layers together using the raster calculator tool **(Figure 9).** The raster data was then converted back to polygon coverage to calculate the total area covered by each SWSA class **(Figure 10)**. The results show that 50% of the area is classified as low risk of surface water susceptibility, 32% as medium low, 17% as lowest and 1% as medium high (**Figure 11)**. Due to rounding, the high and highest classes appear as 0%, however the raw data shows that they constitute 0.12% and 0.006%, respectively of the study area. While the region is at low to medium risk of generating runoff and contaminating surface water, a large portion of the mine is situated over an area consisting largely of medium low risk areas, in addition to a few hot-spot areas of high risk **(Figure 12)**. These areas are therefore more vulnerable and capable of transporting contamination to other areas of low risk. However, since the area generally does not generate high runoff this may indicate that areas immediately surrounding the mine will be impacted heavily by contaminates and hazardous materials produced by the mine. As water is removed slowly from the soils in this region, low runoff rates may allow the time necessary for contaminates to infiltrate to the groundwater. Further analysis, possibly using the DRASTIC method, is suggested to determine the groundwater susceptibility to contamination. However, finding sufficient data sources in remote regions such as this may hinder the analysis.

Figure 8, Soil Group Classification

Figure 9, Final Surface Water Susceptibility Map

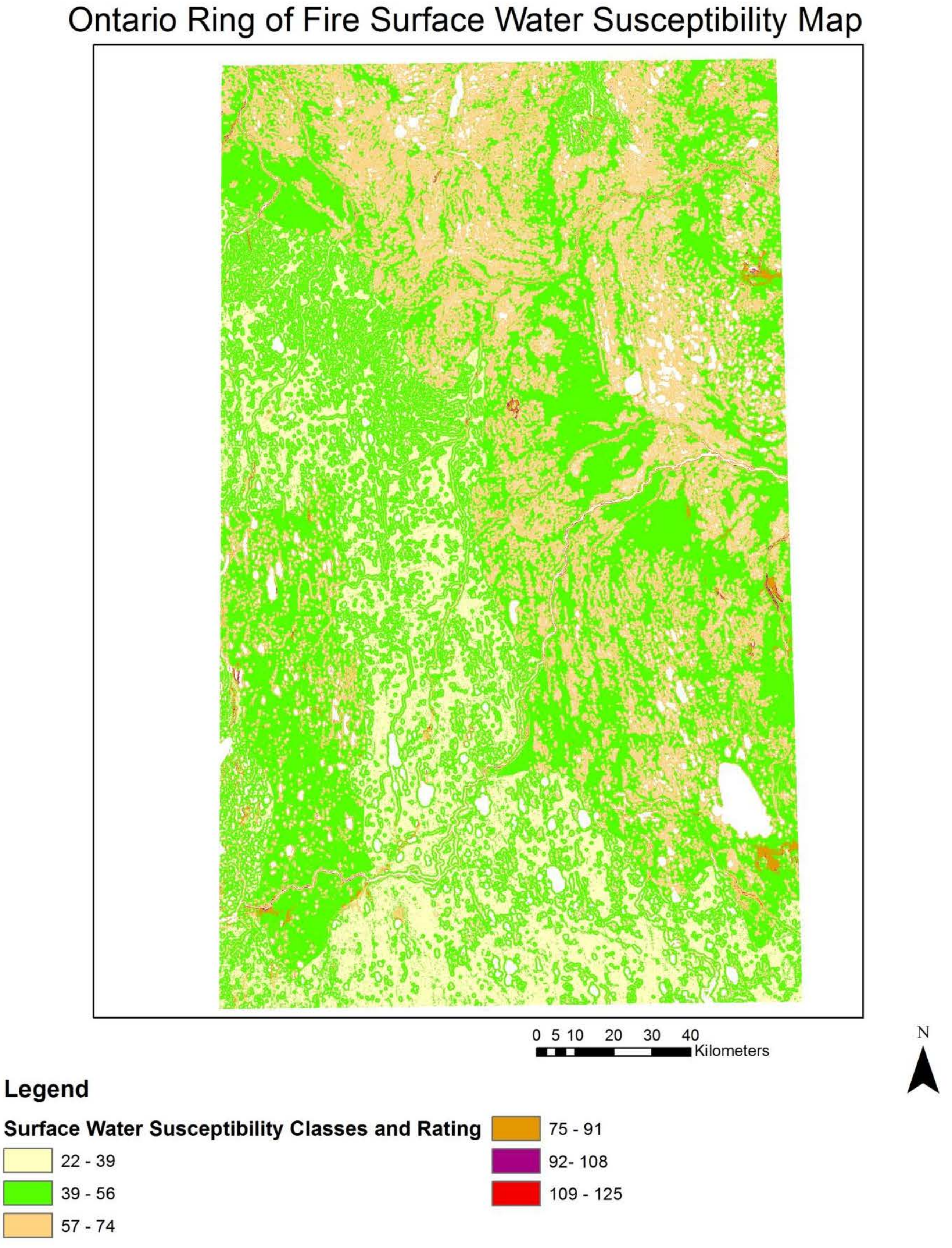


Figure 10, Total area coverage of each SWSA class

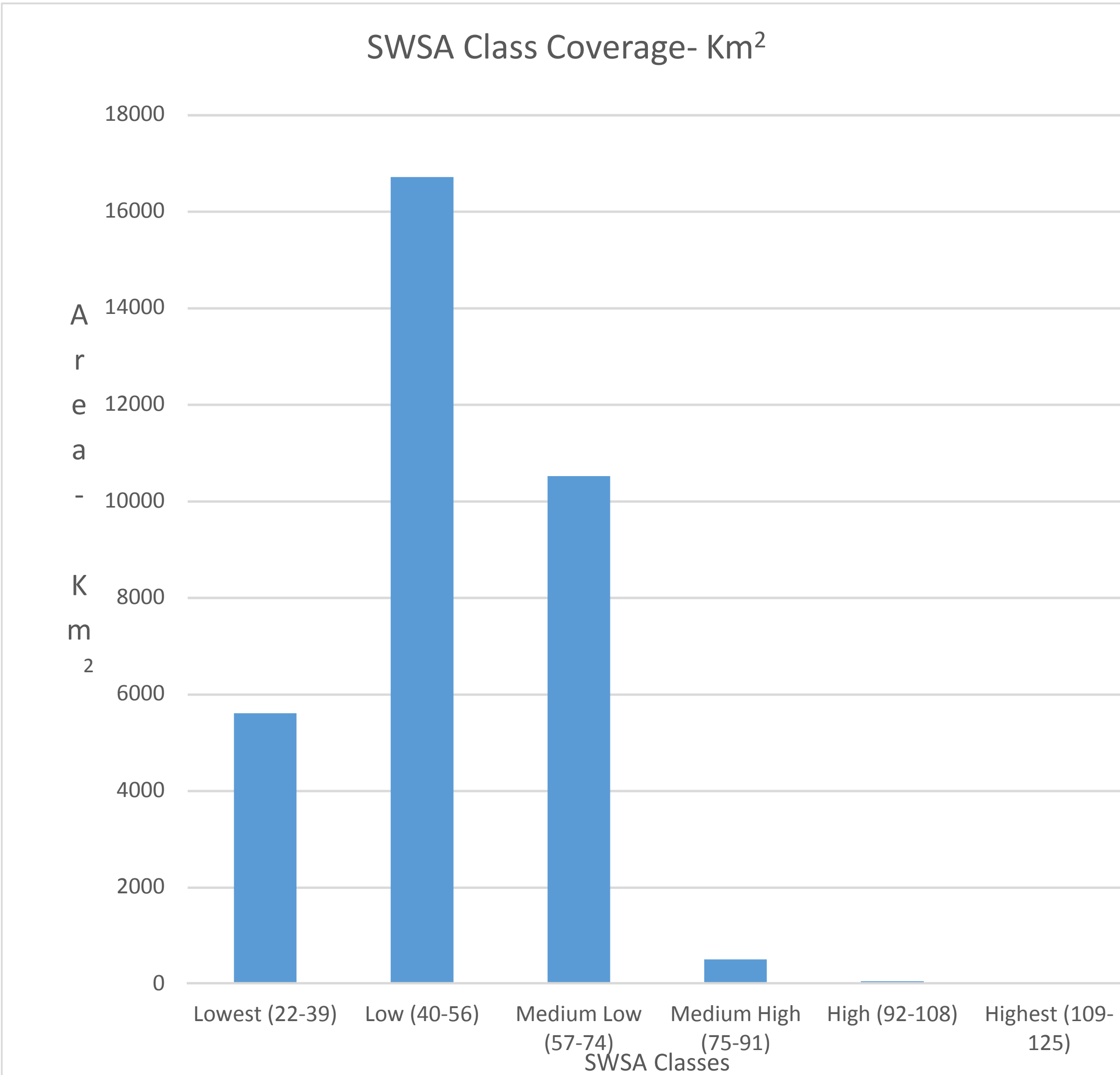


Figure 11, Total area coverage of SWSA classes by percent

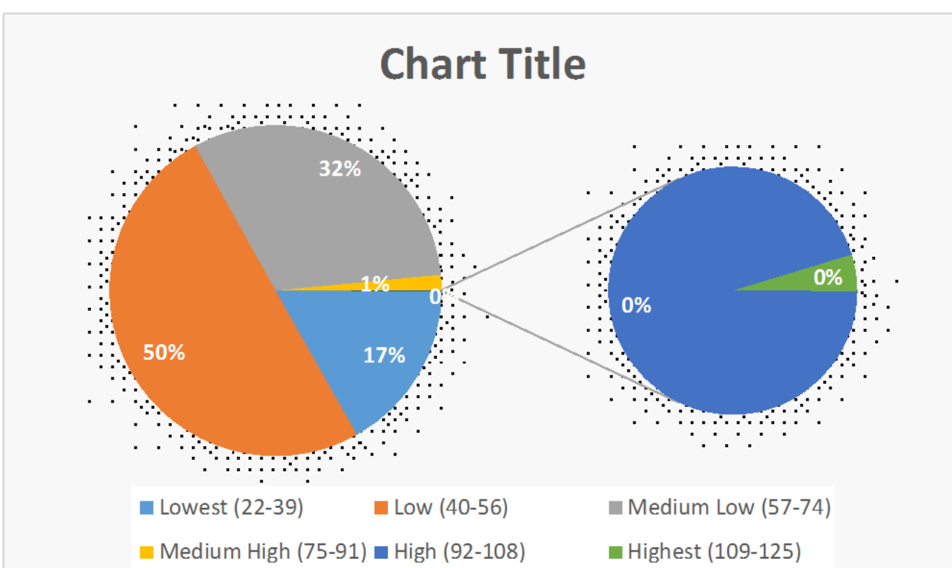
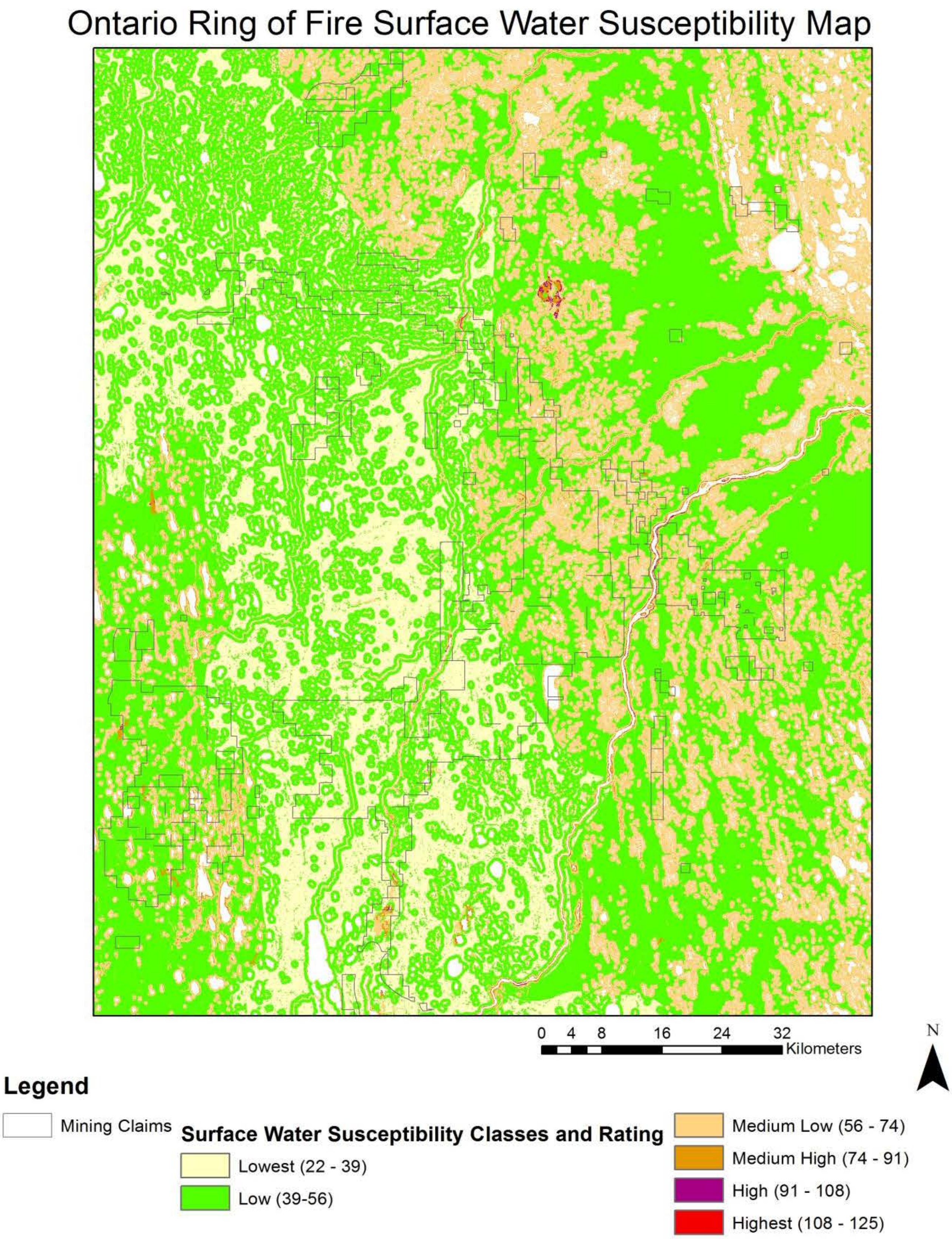


Figure 12, SWSA Map with Mining Claims



Conclusion

The final SWSA map will be useful to developers and planners in the Ring of Fire to identify areas that should be preserved or protected. As Noront is taking measures to mitigate surface contamination, through underground mining and processing, dust collection systems and treating waste water before discharging it (2013), risk of contamination seems minimal, at those operations that will occur underground. Nevertheless, contaminates have the ability to accumulate in the environment over the projects total lifespan, especially due to the low runoff in the region.

The Ring of Fire presents a significant economic opportunity for Ontario, however, as always the economic benefits need to be weighed against the environmental damages they cause, which may include reducing an important carbon sink provided by the peatlands, disturbing endangered species habitat and polluting pristine boreal forest environments. Even though Noront has conducted a voluntary environmental assessment, such a sensitive product should be subject to more rigorous third party scrutiny and assessment.

References

Azam, S. & Li, Q. (2010). *Tailings Dam Failures: A Review of the Last Hundred Years.* Retrieved from:

Bialy, D. & Layfield, K. *Chromite Mining.* Retrieved from Lakehead University, Thunder Bay,Faculty of Natural Resources Management website: http://faculty.lakeheadu.ca/pasmith/files/2012/05/ Chromite_Cliffs_BialyLayfield_14mar12.pdf

Centre for Land and Biological Resources Research. (1996). *Soil Landscapes of Canada, v.2.2.* Ottawa, ON: Research Branch, Agriculture and Agri-Food Canada

CGIAR-CSI. Hole-filled seamless SRTM data v4 2008. Jarvis A., H.I. Reuter, A. &Nelson, E. Guevara [GeoTiff]. Available from: http://srtm.csi.cgiar.org

Das, A.P. and Singh, S. (2011). Occupational health assessment of chromite toxicity among Indian miners. *Indian J. Occup. Environ. Med. 15(1),* 6-13.

Government of Ontario. (2013). *Noront Eagle's Nest Multi-metal Mine.* Toronto, ON: Queen's Printer of Ontario.

Kien, C.N., Noi N.V., Son L.T., Ngoc H.M., TanakaS., Nishina T. and Iwasaki K. (2010) . Heavy metal contamination of agricultural soils around a chromite mine in Vietnam. *Soil Sci. and Plant Nut, 56,* 344-356.

Knox County Tennesse. (2008). *Stormwater Management Manual: Volume 2.* Retrieved from: http://www.knoxcounty.org/stormwater/volume2.php

Lenntech. 2011. Water treatment solutions: Chromium – Cr. Retrieved from: http://www.lenntech.com/periodic/elements/cr.htm. Mar. 1/12

Maponga, O. & Ruzive, B. (2006). Tribute chromite mining and environmental management on the northern Great Dyke of Zimbabwe. *Natural Resources Forum, 26,* 113-126

Noront Resources. (2013). *Eagle's Nest Project: A Federal/Provincial Environmental Impact Statement/Environmental Assessment Report- Draft Copy.* Retrieved from: http://norontresource.wpengine.com/wp-content/uploads/2014/10/pdf/Eagles%20Nest %20Project%20Draft%20EIS%20EA/Volume%201%20-%20Executive%20Summary.pdf

Noront. (2014). *Projects: Eagle's Nest Mine.* Retrieved from: http://norontresources.com/ projects/eagles-nest-mine/

Northern Life. (2015). Junior miner to purchase Cliffs Ring of Fire Properties. *Northern Life.* Retrieved from: http://www.northernlife.ca/news/localNews/2015/03/23-noront-cliffs-sudbury.aspx

Ontario Chamber of Commerce. (2014). *Beneath the Surface: Uncovering the Economic Potential of Ontario's Ring of Fire.* Retrieved from: http://www.occ.ca/Publications/

Beneath_the_Surface_web.pdf

Ontario Ministry of Natural Resources. Ontario Hydro Network- Waterbody 2010. Generated by Adlar Gross; using Scholars GeoPortal. http://geo2.scholarsportal.info.ezproxy.library.yorku.ca/

Ontario Ministry of Natural Resources. Far North Landcover 2013. Generated by Anatoliy Sirokvash; using Scholars Geoportal. http://geo2.scholarsportal.info.ezproxy.library.yorku.ca/

Ontario Nature. (2013). *Ring of Fire Mining.* Retrieved From: http://www.ontarionature.org/protect/campaigns/ring_of_fire.php

Simpson, C., & Dyczko, J. (2012). *Developing Ontario's Ring of fire: Possible Impacts from the Cliffs Chromite Mine.* Retrieved from Lakehead University, Thunder Bay, Faculty of Natural Resources Management website: http://faculty.lakeheadu.ca/pasmith/files/2012/05/Cliffs_DyczkoSimpson_apr20121.pdf

U.S. Department of Agriculture. (1986). *Urban Hydrology for Small Watersheds.* Retrieved from: http://www.cpesc.org/reference/tr55.pdf