

FOR 3457- Forest Watershed & Forest Fire Management

Lab Session (February 24, 2016) - Potential Soil Loss in Killarney Lake Park and associated Consequences.

Background Information

Accelerated soil loss (erosion) occurs across all landscapes and the rate at which this loss occurs depends on the extent of disturbances to the area. The two predominant disturbances associated with soil loss are the interconnected forest road network and associated road-stream crossings. Hydrologically, forest roads are much more detrimental to aquatic habitats than clear-cuts.

The development of forest roads and trails not only removes vegetation, but also compacts the soil surface, reducing the infiltration capacity of the soil and resulting in excess runoff. Due to the reduced area of vegetative cover, excess precipitation reaches the surface of the soil. Upon hitting the surface, the excess precipitation accumulates and flows down-slope to nearby watercourses, eroding the soil surface as it traverses the landscape. This runoff and accompanying dislodged sediment is deposited into the watercourses most commonly at road-stream crossings. This process results in 2 significant consequences:

- 1) Higher sediment concentrations in watercourses
- 2) Alteration to the frequency, intensity and duration of peak flows (larger and more frequent flooding).

Therefore, the location of road installations is an essential component for estimating potential soil loss and amounts of downslope sedimentation.

Models

Within GIS, models are an excellent method for automating sequences of tools allowing simultaneous processing. These models allow the user to change parameters to easily analyze the outcomes of multiple scenarios.

The Culvert Diameter Model

The culvert diameter model involves 3 processes:

- 1) locates road-stream crossings within the confines of Killarney Park,
- 2) calculates peak discharges at each road-stream crossing,
- 3) calculates the minimum diameter requirements for each crossing required to withstand a 2-year peak flow/ flooding event.

Firstly, the model locates road-stream crossings and, secondly, the model applies the Burkli-Ziegler formula (Rothwell, 1978) to calculate the peak discharge (equation 1):

$$Q = C \times I \times A \quad (\text{Eq.1})$$

where: Q = peak discharge (ft³/ second)

C = Runoff coefficient (typically 0.3)

I = Rainfall intensity/ hour for severe event (inches/ hour) (0.7087 for Fredericton)

A = Catchment area (acres) - from flow accumulation raster

The model then applies the Manning formula (Rothwell, 1978) (equation 2) to calculate the minimum diameters of road-stream crossings required to adequately maintain 2-year peak flows:

$$D = (2.159 \times Qn / S^{0.5})^{0.375} \times 30.48 \quad (\text{Eq.2})$$

where: D = Culvert Diameter (cm)

Q = peak discharge (ft³/ second)

S = Slope of culvert (typically 0.015 (1-2%))

n = culvert roughness coefficient

*Note: the multiplication of 30.48 is to convert feet into cm.

The Channel Velocity Model

The channel velocity model applies equations to calculate mean annual and bankfull channel widths and discharges for all watercourses (retrieved from Caissie, 2005). Assuming that the cross-section of a watercourse during bankfull flow is a half circle, the model calculates the depth, wetted perimeter and hydraulic radius on a cell-by-cell basis. This information is then applied to the Manning velocity equation (Rothwell, 1978):

$$V = (kn/n) \times HR^{(2/3)} \times S^{0.5} \quad (\text{Eq.3})$$

Where: V = channel's cross-sectional average velocity (m/s)

kn = conversion factor (Length^(1/3)/Time) (1m^(1/3)/s)

n = Manning's roughness coefficient

HR = hydraulic radius (m)

S = channel slope (m/m)

The Soil Loss and Sediment Yield Model

Involves 8 processes:

- i. Firstly, the model runs the Culvert Diameter sub-model to locate road-stream crossings.
- ii. Secondly, the model 'intersects' the "Soils" and "Boundary" feature classes, limiting the soil types to just the Killarney Park boundary.
- iii. Next, it creates a new field and assigns soil erodibility (susceptibility to erosion) values to each soil type found within the park.
- iv. Thirdly, it converts these erodibility values into a new raster.
- v. Next, the model transforms the "Roads" feature class into a raster and reclassifies the raster to represent just roads (all roads are assigned a value of 1).
- vi. Then, the model applies the Revised Universal Soil Loss Equation (RUSLE) (equation 4) to calculate the annual average soil loss occurring on the roads and trails:

$$\mathbf{A = R \times K \times LS \times C \times P} \quad \mathbf{(Eq.4)}$$

where: A = annual average soil loss (tonnes/ ha/ year)

R = rainfall erosivity factor (MJ mm/ ha/ h/ year) (1400 for Fredericton)

K = soil erodibility factor (tonne h/ MJ/ mm)

LS = slope length and steepness factor

C = surface cover and management factor (0 = management)

P = support practices factor (0 = support practice)

- vii. Next, the model extracts values from the "RUSLE" raster, assigning them to the road-stream crossings.
- viii. Finally, the model converts the RUSLE values into sediment yield (mg/L) via equation 4:

$$\mathbf{Yield = (Erosion \times 10^5) / Annual Discharge} \quad \mathbf{(Eq.5)}$$

Where: Annual discharge is measured in mm (715 for Fredericton).

Your Task

Your task is to complete a report that assesses the potential hydrological effects arising from the road and trail network within Killarney Park. The report will consist of typical format and will provide answers to the following questions:

- 1) How many road-stream crossings are in Killarney Park? What are potential impacts these locations may have on soil erosion and sedimentation?
- 2) What is the annual accumulative potential soil loss for Killarney Park? What are the issues with this result (i.e. assumptions), if any?
- 3) How much area (in ha) of the park has soil loss of 100 tonnes/ ha/ year or more? (hint: 1 cell = 10 x 10m)? If any, should these areas be avoided and why?
- 4) What is the density of roads and trails within Killarney Park (km/ km²)? What are potential implications of this density (is it high, low, is there any regulations on how much is allowed)?
- 5) What are possible measures employees could implement to mitigate/ avoid potential soil loss?
- 6) If climate change resulted in an increase in rainfall intensity from 0.7087in/ hr to 1.0236in/ hr, what effect would this have on the road-stream crossings and on the employees responsible for managing the park trails? What about 1.4173in/ hr (use an example from the model)?
- 7) Would a change in the rainfall intensity value change the predicted soil loss values if any? Would you expect it to? Why?
- 8) With the data provided and the output from the models, how could you determine potential locations of road washouts? Is there any data that is missing?
- 9) Where in Killarney is potential soil loss the greatest? What are some potential causes of this?
- 10) BONUS: Based on Killarney Lake bathymetry data ("Killarney_bathymetry" raster), how long would it take for Killarney Lake to infill from both predicted soil loss values and organic matter loss from banks?

To Begin

- Copy the "FOR_3456" folder from the USB key onto your personal data drive.
- Open the "Killarney_Soil_Loss" ArcMap document (.mxd). You will see an aerial image with a red boundary outlining Killarney Park.

- Ensure that the current and scratch workspaces are set to "Killarney_Erosion.gdb" in the environment settings. This allows you to tell ArcMap where the source data and results are to be stored. To set environment settings go to the toolbar and Geoprocessing > Environments... > Workspace.
- Expand the "Soil_Loss_and_Sediment_Yield" toolbox and you can observe the models by right-clicking and select "Edit". To run the model, simply double-click and confirm the inputs and outputs and select "OK".
- Run the "Soil Loss and Sediment Yield" model from the Catalog window. The model will take a few minutes to run. The resulting output will include one point feature class ("Stream Crossings") representing culvert locations (with soil loss, channel velocity and culvert diameter values), the Erosion raster (RUSLE), and the channel velocity raster. The output raster will represent soil loss values for each cell that represents roads.
- Finally, develop the report and answer the previous questions. Make sure to follow the typical report format and include figures with legends when answering questions.
 - Typical format for figure includes figure, legend, scale bar (m or km) and north arrow.

Literature Cited

- Caissie, D. 2005. River discharge and channel width relationships for New Brunswick rivers. *Can. Tech. Rep. Fish. Aquat. Sci.* 2637: 26pgs.
- Rothwell, R.L. 1978. Watershed management guidelines for logging and road construction in Alberta: Information report NOR-X-208. Environment Canada, Forestry Service, Edmonton, Alberta, Canada. 52pgs.