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Report Title: Determining the Percentage of Areas Cut for Each First-Order Forest Catchment

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DETERMINING

THE PERCENTAGE OF AREAS CUT

FOR EACH FIRST-ORDER FOREST CATCHMENT

by

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Introduction

Forest harvesting, especially clear-cutting, has major impacts on watershed behaviour in general, and on surface- and ground-water quality in particular. However, these impacts are only detectable when the total amount of area cut per catchment is large. Therefore, the total amount of area cut per catchment should be major water quality indicator for sustainable forest management. Conventional forest planning methods, however, identify cutting blocks by natural stand boundaries only. As a result, forest operations are generally not conducted within the wider forest watershed context. In this context, setting a limit to how much forest area can be cut per watershed would add a new forest harvesting constraint. This constraint, if done properly, may not affect strategic timber supply goals, but would have much benefit in terms of improved forest ecosystem and watershed management operations throughout the Fundy Model Forest region.

Objectives

The objective of this report is to introduce computational methods for determining:

- watershed boundaries,
- total forest areas cut per watershed, and
- relationship between percentage of total area cut per watershed and overall first-order stream hydrology.

The emphasis of this report is more on reporting on principles and processes, rather than on detailed field examinations.

Method

Three steps were followed to realize these objectives:

1. Reliable watershed boundaries were obtained from digital elevation models (DEM), corrected to yield the exact geographic positioning of already mapped forest streams and lakes;
2. The percentage area of all cuts within each watershed were determined by superposing land-surface images and forest management records and/or plans on the watershed boundary map (Step 1);

3. a forest hydrology model (Houle et al.,2002) was used to assess the impact of given percentage of cut area (Step 2) on first-order basin hydrology.

Details

It is important to have correct watershed boundaries before percentages of cut area per watershed can be obtained. For this purpose, the existing 70x70 m grid of irregularly spaced digital elevation points (digital elevation model, or DEM, available from Service New Brunswick) was found useful for the general purpose of visualizing watersheds and flow channels, but inadequate by itself for matching these visualizations with actual stream channel locations and watershed boundaries. For one, the irregular 70x70m grid was very coarse, and needed to be converted into a "triangular irregular network" (TIN, see Figure 1). For another, this TIN image must then be converted into a raster grid (Figure 2), to generate a digital elevation number for each pixel of the raster. This was done by way of geo-spatial interpolation. The resulting raster DEM proved to be much finer in detail than Figure 1, but still did not generate a true picture of actual watershed boundaries and flow channels in most cases. For example, stream channels – as calculated with the flow accumulation function in ArcView (ESRI, 1997) - would not exactly correspond to where the stream channels should actually be. To correct this, a digital line representation of the already mapped streams for the same area (Figure 3) was obtained and superposed on the raster DEM. The pixels that lay along each of the mapped streams were then identified, and were assigned to be 20 m lower than any of the nearest raster DEM points, again by way of automated procedure (Figure 4). Doing so forced the flow accumulation function within ArcView to direct all water flows towards actual stream channel and lake locations. Once this was done, a new DEM grid was obtained (Figure 5). From this grid, realistic stream channels, stream order, and catchment boundaries and areas were then determined for any stream, at any point along any stream. The case for determining all first order streams is presented in Figure 6. All of this work was done by way of ESRI's Arcview software, including ArcView 3D Analyst Extension (ESRI, 1997).

To determine the % cut of catchments for each first order stream, it was necessary to overlay with the existing forest management map (forest management shape file) on the first-order watershed shape file. This was done for the particular area of Hayward Brook, which is part of the Fundy Model Forest (Figures 7 and 8). Any harvested areas that intersected within any of the established watershed polygons were summed for each numbered watershed polygon, again by way of automatic procedure.

Results

The percentage areas for each first order catchment areas of the Hayward Brook study area are listed in Table 1, by catchment number. In general, percentage areas for each catchement were low, with 33% being the largest.

Table 1. Percentage of catchment areas cut within the Hayward Brook study area, by catchment number (see Figure 7 or 8).

Catchment	Total Area (ha)	Harvest by Catchment (ha)	Percent by Catchment
4	36.7	0.9	2.4
6	44.3	5.5	12.4
7	125.4	1.1	0.9
10	95.1	31.4	33.0
18	130.1	30.0	23.1
19	49.2	7.5	15.3
20	99.6	7.9	8.0
24	57.7	2.1	3.6
27	177.3	16.0	9.0
Total:	**815.4**	**102.4**	**12.6**

Based on knowing the softwood/hardwood mix within each catchment area, general soil depth and texture, and daily weather records for atmospheric deposition and air temperature, expected levels of stream discharge and water tables were then calculated with the ForHyM model (Houle et al., 2002), for two consecutive years, and 3 levels of harvesting (0, 33, and 100%). The results are shown in Figure 9. Clearly, harvesting is calculated to have discernable impacts on stream discharge and water tables during certain parts of the year, and not so much in other parts, depending on the weather. In particular, 100% harvesting is expected to significantly raise the water table and stream discharge during post-harvest summer months. A 100% level of harvesting is also calculated to accelerate the rate at which snow melts in the spring, as indicated by an earlier peak in stream discharge when there would be significant snowpack accumulations. These calculations indicate relative change in reference to the no cut situation, and also in reference to particular locations within the catchments. Water table increases would be most noticeable in depressions. These depressions may turn swampy after harvesting. Also, increased water-tables mean:

- less water infiltration capacities of soils,
- therefore more surface run-off potentially coupled with soil erosion,
- softer ground within depressions,
- therefore more incidences of soil rutting in depressions, and
- more tree blow-downs along edges that run across depressions.

All such matters would be fairly noticeable in, and adjacent to, buffer zones which are generally located within or near depressions.

Not considered in the calculations is that harvested areas may drain water faster than non-harvested areas, on account of the many access trails that are used to deliver wood from the stump to the road side. In this way, there is often a faster way for water to run off the land than before harvesting. In these cases, stream discharge from harvested areas may become flashier than before harvesting.

Summary and Recommendations

A method was developed that would allow Fundy Model Forest managers and others to determine the % of area cut in each first order forest catchment of the entire Fundy Model Forest area, and elsewhere. For demonstration purposes, this report only deals with the Hayward Brook area, where overall cutting levels for first order stream catchments were fairly low, and peaked at 33 % in only one of the many first order catchments of this brook. In applying this technique across the entire area of FMF, managers would readily notice areas were per watershed harvesting will be at or near 100%. For these areas, forest managers may take action in terms of re-scheduling planned harvesting activities to other areas. The calculations have shown that cutting entire catchments will have effects on catchment hydrology, and soils such as raising water tables in depressed areas on one hand, and increasing stream discharge on the other. Clearly, such impacts would be reduced if the extent of harvesting per each catchment would be reduced overall. There is likely no actual threshold that is “safe”. Instead, there are only levels below which effects may be negligible or acceptable.

References

ESRI. 1997. Environmental Systems Research Institute, Ince. ArcView GIS.

D. Houle, L. Duchesne, R. Ouimet, R. Paquin, F.R. Meng and P.A. Arp. 2002. Evaluation of the FORHYM2 model for prediction of hydrological fluxes and soil temperature at the Lake Clair Watershed (Duchesnay, Quebec). For. Ecol. Manage. 159: 249-260.

Achnowledgements

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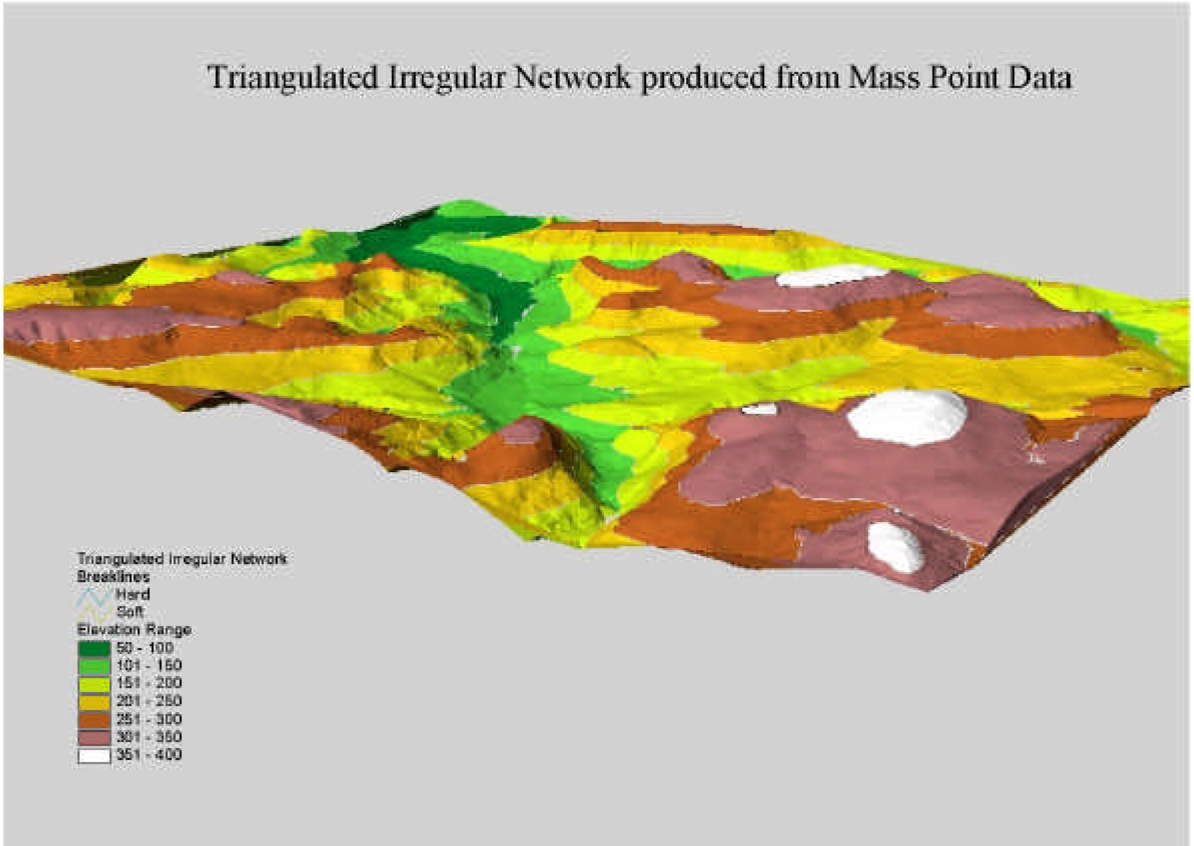

Figure 1. From a digital elevation map, 3-D elevation profiles were produced, point by point. These points were then connected to form a Triangulated Irregular Network (TIN).

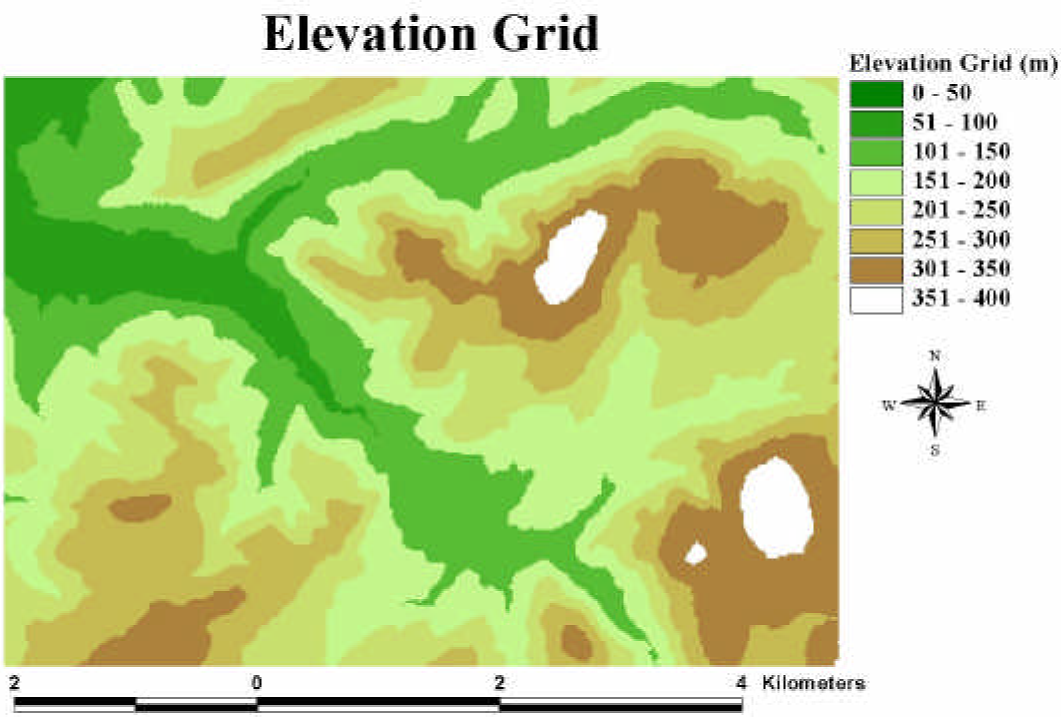

Figure 2. Using ArcView's 3-D Analyst and Spatial Analyst, a new, regularly-spaced elevation grid was produced from the TIN in Figure 1. The resulting elevation grids show the range and distribution of vertical heights within the landscape. This new grid can be used to locate stream channels and watershed boundaries for each stream channel, but the maps so produced do not exactly coincide with the location of the already mapped stream channels. Also, watershed boundaries are often unrealistic.

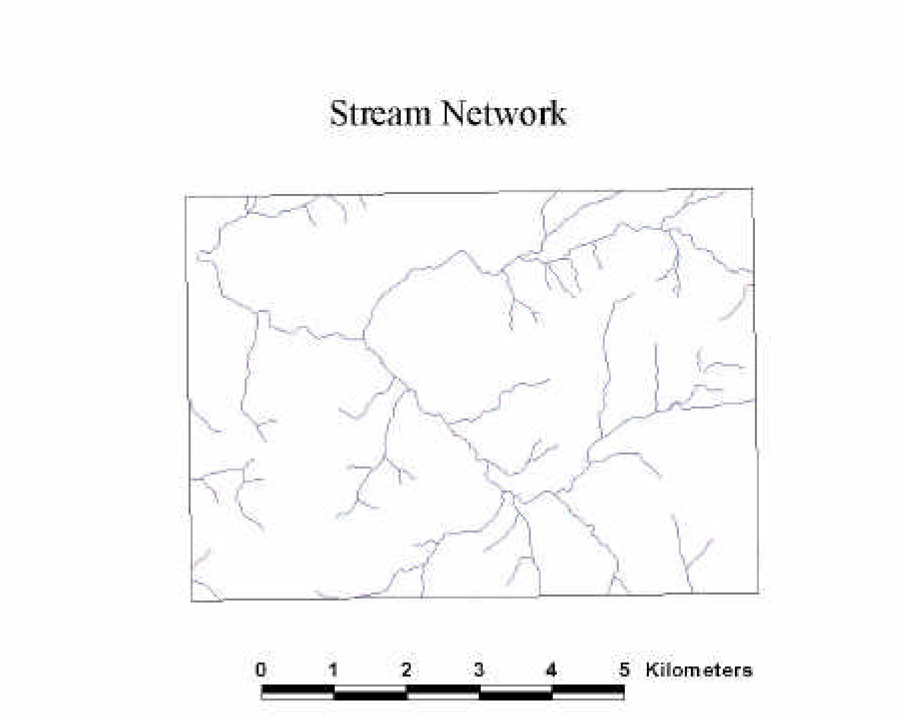

Figure 3. To represent water flow from watershed boundaries towards streams, one needs actual stream channel and lake locations, as represented by this stream network map.

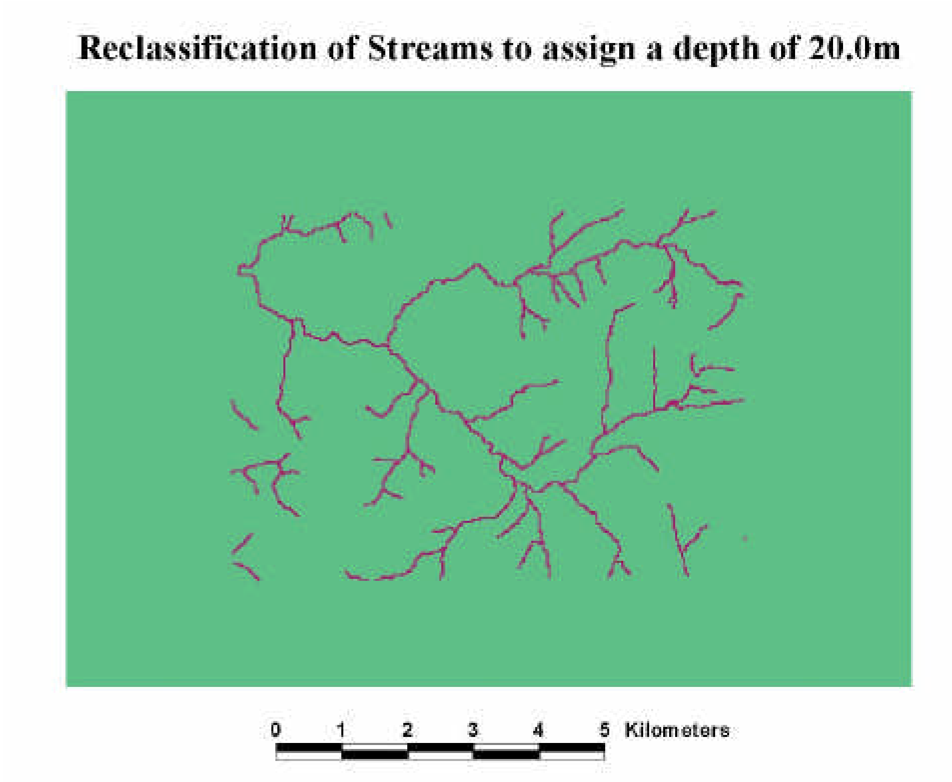

Figure 4. The stream map of Figure 3 was reclassified so that only stream pixels are registered in their exact locations. These pixels were then superposed on the DEM of Figure 2, and used to ensure that each stream channel pixel would be 20 m lower than any of the nearest elevations of Figure 2, i.e.,

New elevation within stream channel =

Uncorrected elevation within stream channel – 20 m.

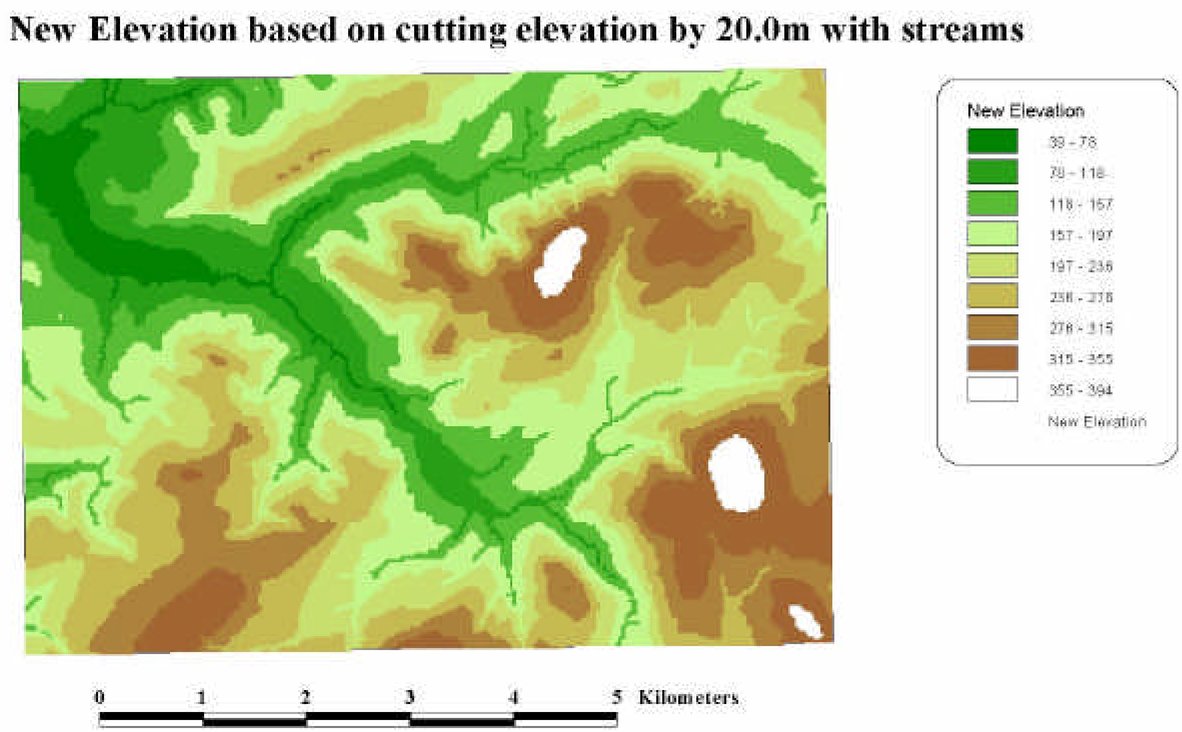

Figure 5. Once the elevation of each stream channel pixel was obtained, and added to the regularly spaced DEM grid, a new digital elevation model was generated. In comparison with Figure 2, the corrected map is significantly more detailed, and appears to suggest many more flow channels than what is apparent from Figures 2 and 3.

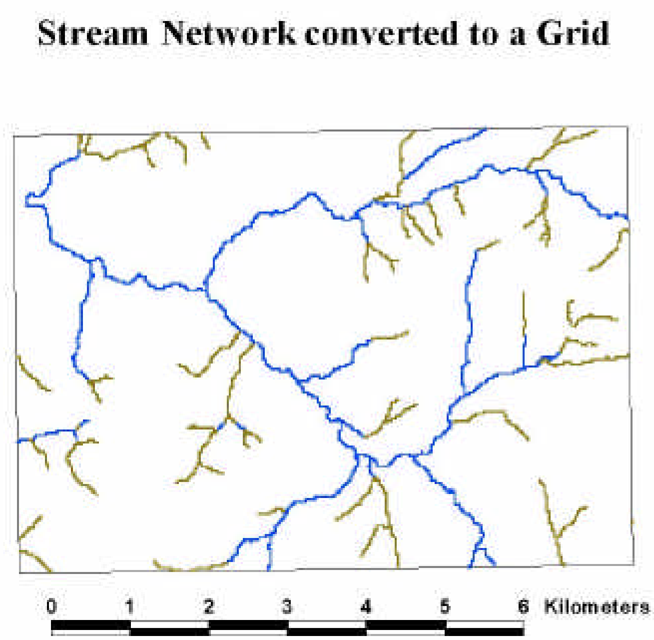

Figure 6. Within ArcView, each stream channel was then re-identified by way of the flow accumulation function. With this function, several tasks can be accomplished:

- identifying each stream channel by its order (first, second,…)
- drawing the catchment area of each stream in reference to any point along that stream
- drawing the flow channels of all those streams that flow into the first order stream. Such channels generally represent the unmapped intermittent streams.

In this figure, all first order streams are shown in olive. Higher order streams channels are shown in blue.

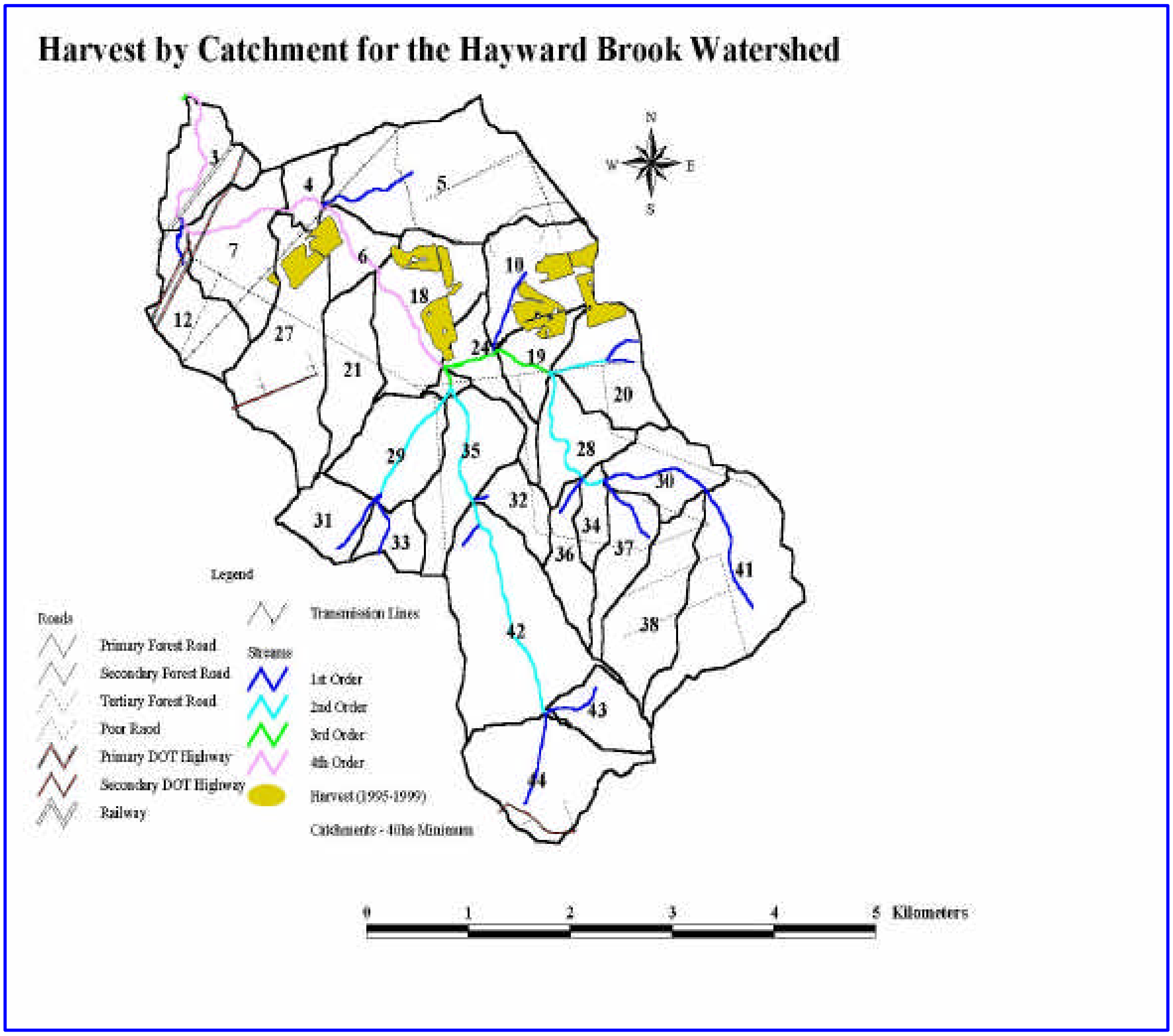

Figure 7. Once the routine for the stream channel correction of the DEM was accomplished, the DEM for Hayward Brook area of the Fundy Model Forest was obtained, all the required stream channel elevations were corrected, and the flow accumulation function was used to determine:

- order of stream channel;
- catchment boundaries starting from first order streams.

In this map, blue is a first order stream, light blue is second order, green is third order, and purple is fourth order. Each catchment area is numbered. Also shown are the locations of the logging roads, and the areas that were harvested.

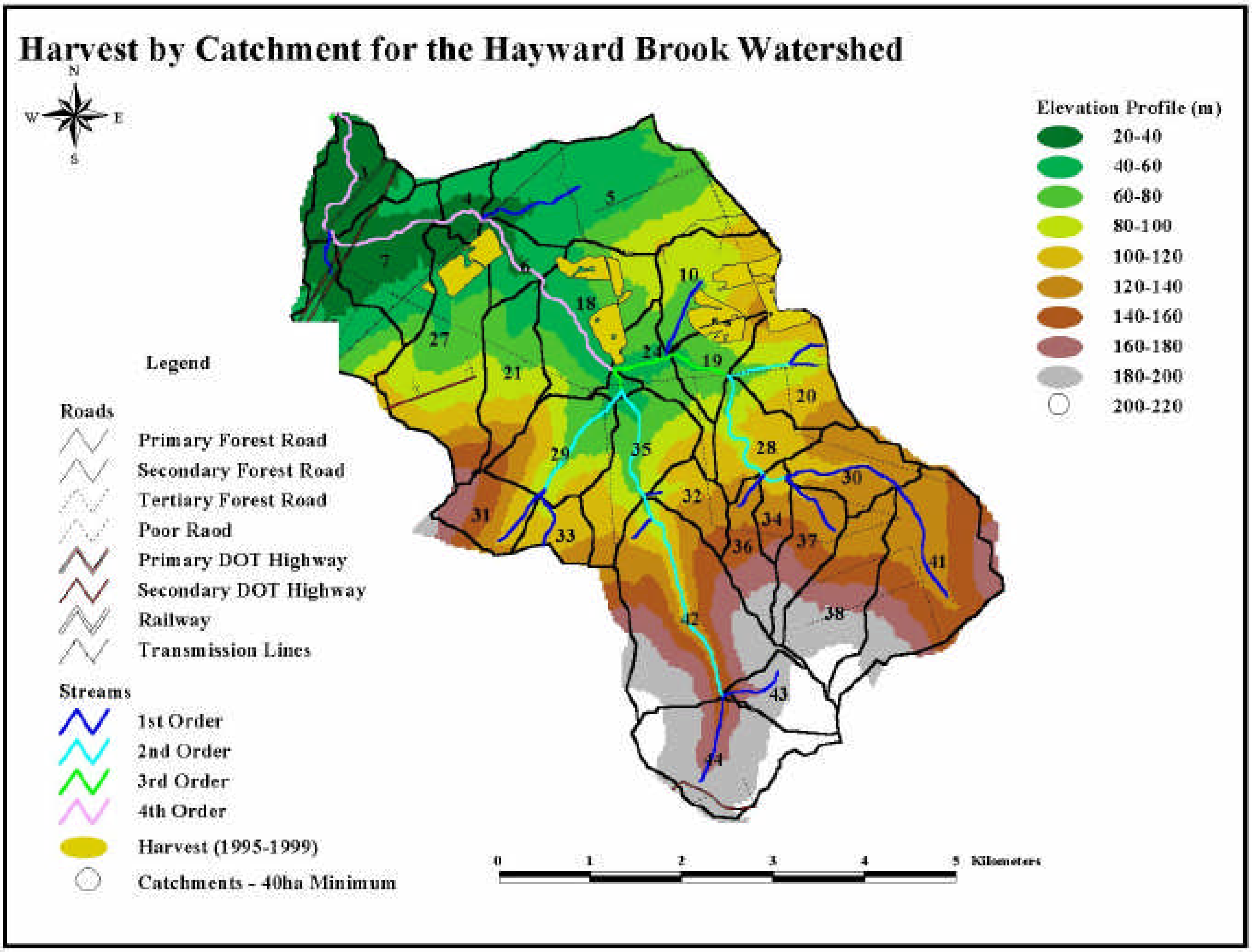

Figure 8. Same map as in Figure 7, but with digital elevation in the background. Elevation grid changes from white (highest location) to dark green (lowest elevation).

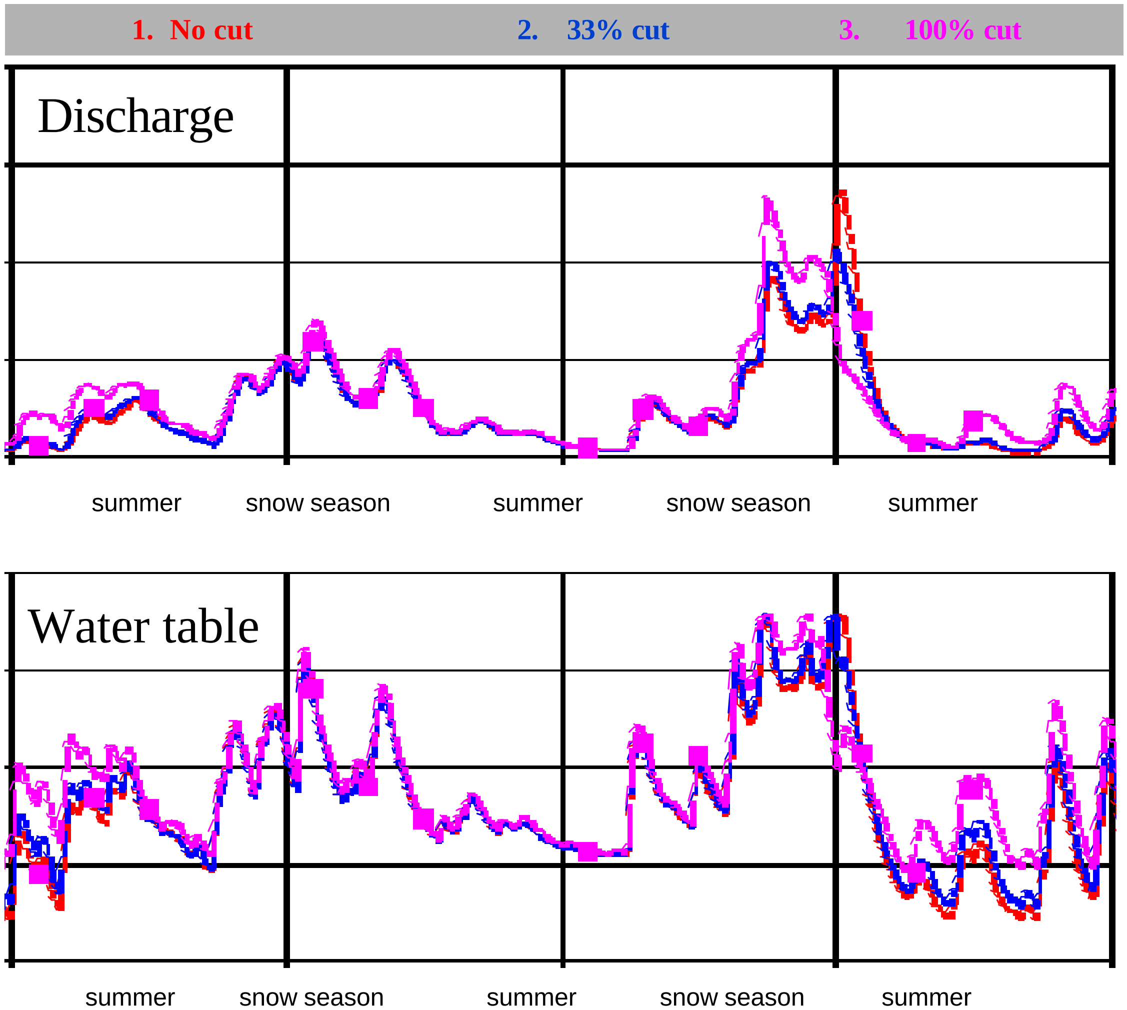

Figure 9. ForHym-simulated relative changes in stream water discharge and water table levels for first order stream catchments in the Hayward Brook area, when harvested at 0 (red), 33 (blue) and 100 (purple) %, for two consecutive years. Note the elevated post-harvest levels for stream discharge and water table during each summer. Also note that harvesting would force snowmelt discharge to occur earlier in spring, when there are significant snowpack accumulations, as was the case for the second snow season.