Computational Procedure of the Topographic Index Using PHYSITEL

Report N° R833 ***May 2005***

Computational Procedure of the Topographic Index Using PHYSITEL

Training report

Prepared by:

Achraf Hentati
Alain N. Rousseau

Centre Eau, Terre et Environnement
Institut national de la recherche scientifique (INRS-ETE)
490, rue de la Couronne, Québec (QC), G1K 9A9

Report N° R833

May 25, 2005

TABLE OF CONTENTS

LIST OF FIGURES .... **V**

LIST OF ACRONYMS **1**

1 INTRODUCTION **1**

2 PHYSITEL SOFTWARE AND TI COMPUTATION **3**

2.1 PHYSITEL 3

2.1.1 PHYSITEL approach 3

2.1.2 Determination of the drainage structure by PHYSITEL 4

2.2 CALCULATION OF *TI* ON THE YAMASKA WATERSHED 11

2.2.1 Methodology 11

2.2.2 Results and discussions 12

3 CONCLUSION **19**

4 REFERENCES **21**

LIST OF FIGURES

Figure 2.1 : Importation and edition of the initial DEM of the Yamaska river watershed. 4

Figure 2.2 : Computation of slope on the original (unaltered) DEM of the Yamaska river watershed. 6

Figure 2.3 : Importation and edition of the DRLN of the Yamaska watershed. 7

Figure 2.4 : Rasterization and edition of the DRLN of the Yamaska watershed. 8

Figure 2.5 : DEM "burning". 9

Figure 2.6 : Determination and edition of the flow direction matrix. 10

Figure 2.7 : Determination of the flow accumulation matrix. 11

Figure 2.8 : *TI* distributions obtained by D8-LTD for the Yamaska river watershed (resolution 19m). 13

Figure 2.9 : Comparison of *TI* distributions obtained by D8-LAD for the Yamaska river watershed (resolution 19m). 14

Figure 2.10 : Comparison of *TI* distributions obtained by Arc Hydro (D8) for the Yamaska river watershed (resolution 19m). 15

Figure 2.11 : Comparison of *TI* distributions obtained by PHYSITEL (D8) for the Yamaska river watershed (resolution 19m). 16

Figure 2.12 : Histograms of *TI* distributions obtained by the D8-LTD, D8-LAD, D8 of Arc Hydro (D8) and PHYSITEL (D8) on the Yamaska river watershed. 17

LIST OF ACRONYMS

D8	Deterministic-8 Node algorithm
DEM	Digital Elevation Model
DRLN	Digital River and Lake Network
LAD	Least Angular Deviation
LTD	Least Transversal Deviation
TI	Topographic Index

1 INTRODUCTION

Three flow direction algorithms were applied on 16 watersheds in Quebec to calculate the Topographic Index (Rousseau *et al.*, 2005). These algorithms were: D8, D8-LAD and D8-LTD.

In the literature, several studies have shown that the D8 (O'Callaghan and Mark, 1984) as a single flow direction algorithm has limitations. I t cannot predict flow divergence because the flow from one cell is restricted only to a single downslope neighbouring cell. On the contrary, the multiple flow direction algorithms allow flow to be distributed to multiple downslope neighbouring cells. However, they have a problem of a high dispersion of flow.

The D8-LAD (Tarboton, 1997) and the D8-LTD (Orlandini *et al.*, 2003) are biflow direction algorithms which is a compromise between the simplicity of the D8 and the multiple flow direction algorithms. These two algorithms are non-dispersive and provide more accuracy in the delineation of the drainage network both over hillslope areas (divergence zones) and along valleys (convergence zones).

From a practical point of view, we have found that the D8 algorithm was more sensitive to the topography of the studied watersheds than the other algorithms. The D8-LAD algorithm generates numerous "NoData" values but bypasses problems inherent to the D8 algorithm. The D8-LTD gave the best results of the Topographic Index (*TI*) distributions on the 16 watersheds. However, flat surfaces, wide rivers and lakes still represent a major obstacle for the computation of flow directions with any of the three algorithms. To solve this problem, the approach developed by Turcotte *et al.* (2001) that was integrated in PHYSITEL will be investigated in this study.

2 PHYSITEL SOFTWARE AND TI COMPUTATION

This chapter presents PHYSITEL and various steps required for the generation of the slope and flow accumulation matrices that are necessary for the computation of *TI*.

2.1 PHYSITEL

The PHYSITEL software allows for the delineation of a watershed by applying the D8 algorithm on a DEM which is "burnt" according to a Digital River and Lake Network (DRLN) vector map. The implementation of PHYSITEL requires 13 steps. In this study, the focus is only on the first seven steps which deal with the determination of the drainage structure.

2.1.1 PHYSITEL approach

2.1.1.1 D8 algorithm

The Deterministic-8 Node (grid cell) algorithm (D8) is the earliest and the simplest method for specifying flow directions. It stipulates that flow moves from each grid cell to only one of its nearest orthogonal or diagonal neighbours, and in the direction of the steepest downslope (Saunders, 1999).

The D8 algorithm is inappropriate for the identification of wide segments of a river network, such us those that include lakes. Use of the D8-LAD and the D8-LTD bypasses the limitations inherent to the D8 method (Rousseau *et al.*, 2005) but these two algorithms also do not cope with flat surfaces, wide rivers and lakes.

In order to overcome this problem, Turcotte *et al.* (2001) developed a new method using the DRLN as ancillary data to correct the modelled flow directions.

2.1.1.2 The DEM "Burning" using the DRLN

The burning method refers to the process of decreasing grid cells representing a watercourse network to enforce the known drainage structure of a watershed on the flow direction matrix. The DRLN which is used jointly with a DEM shows to the burning algorithm the location of the actual river network. The DRLN takes also into account lakes and hence guides the flow direction algorithm to distinguish between lakes and flat surfaces.

Before applying the burning process, the DRLN needs to be pre-treated. All streams that are large enough to be presented by left and right banks must be replaced by a single arc in the center of the stream and all lakes need to be represented by closed polygons.

The DRLN vector already pre-treated is rasterized. After that, the DEM is altered by burning the surface of the terrain in the vicinity of the DRLN.

2.1.2 Determination of the drainage structure by PHYSITEL

With the aim of testing the ability of PHYSITEL to cope with difficult data such as flat areas, wide rivers and lakes, we have selected the Yamaska river watershed. This watershed has a flat topography and a meandering river network that includes lakes.

The first step is the importation of the Yamaska watershed DEM which is based on a square grid with a resolution of 19m by 19m (see Figure 2.1).

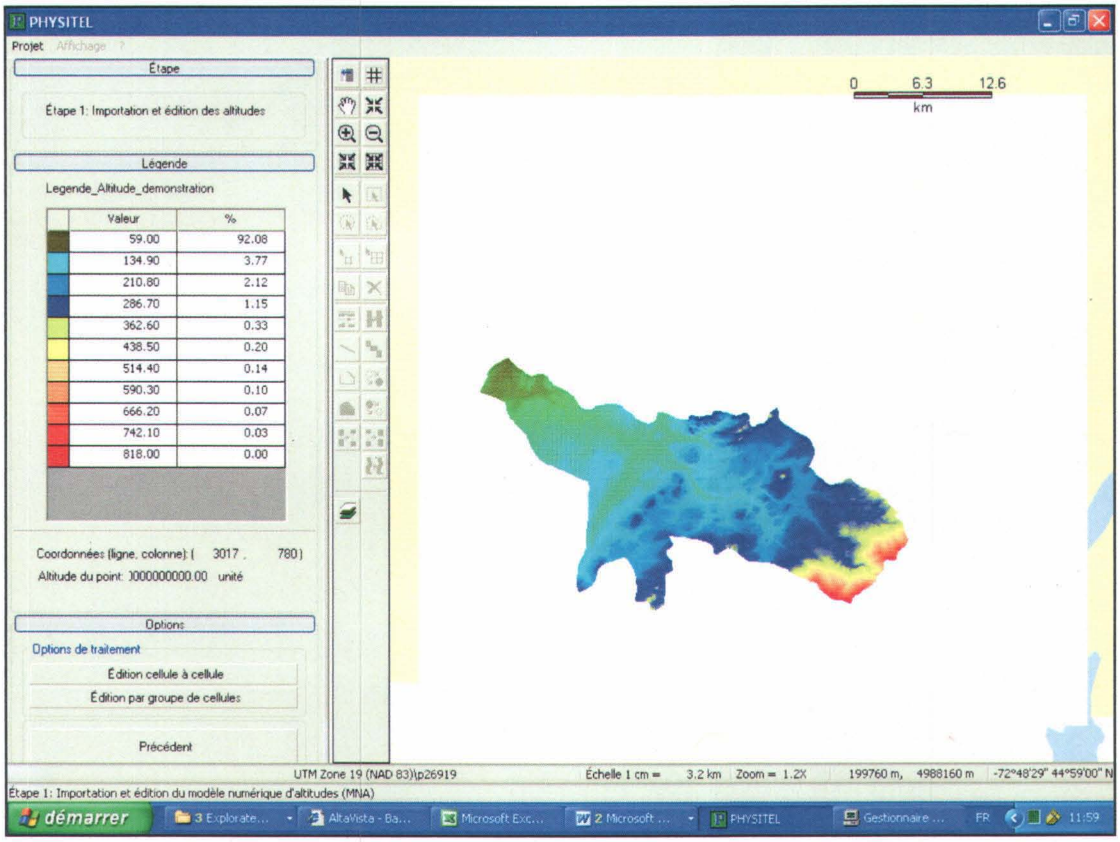

Figure 2.1 : Importation and edition of the initial DEM of the Yamaska river watershed.

The dimension of this DEM matrix is 3185 columns × 3021 rows.

The second step generates a slope matrix (see Figure 2.2). For the D8 algorithm, the slope is calculated as follows:

$$slope = 1000\frac{e_c - e_n}{d_{cn}} \tag{2.1}$$

Where e_c and e_n are respectively elevations of the central cell and its neighbouring cell. d_{cn} is the distance separating the centers of these two cells.

Step 3 focuses the importation and all functionalities for the edition of the initial DRLN (see Figure 2.3). This stage is prior to the rasterization of the DRLN vector map. The DRLN must be pre-treated to create a fully dendritic drainage network. Therefore, the connectivity between all the stream network segments must be ensured.

In order to achieve this task, the following steps must be taken:

(i) All off-stream network lakes and linear features that are not connected to the stream network have to be removed. It is evident that these lakes and stray stream segments should be without great influence on the drainage structure of the watershed;

(ii) In-stream lakes must be converted to closed polygons;

(iii) All streams in the DRLN that have a left and a right bank must be replaced by a single arc in the center of stream. If the river is thinner than the grid resolution it is sufficient to keep one of the two ridge lines of the river;

(iv) The main stem of the drainage network must extend to the edge of the corresponding DEM. Then, the location of the watershed outlet has to be determined and

(v) The full connectivity starting from the outlet watershed is achieved.

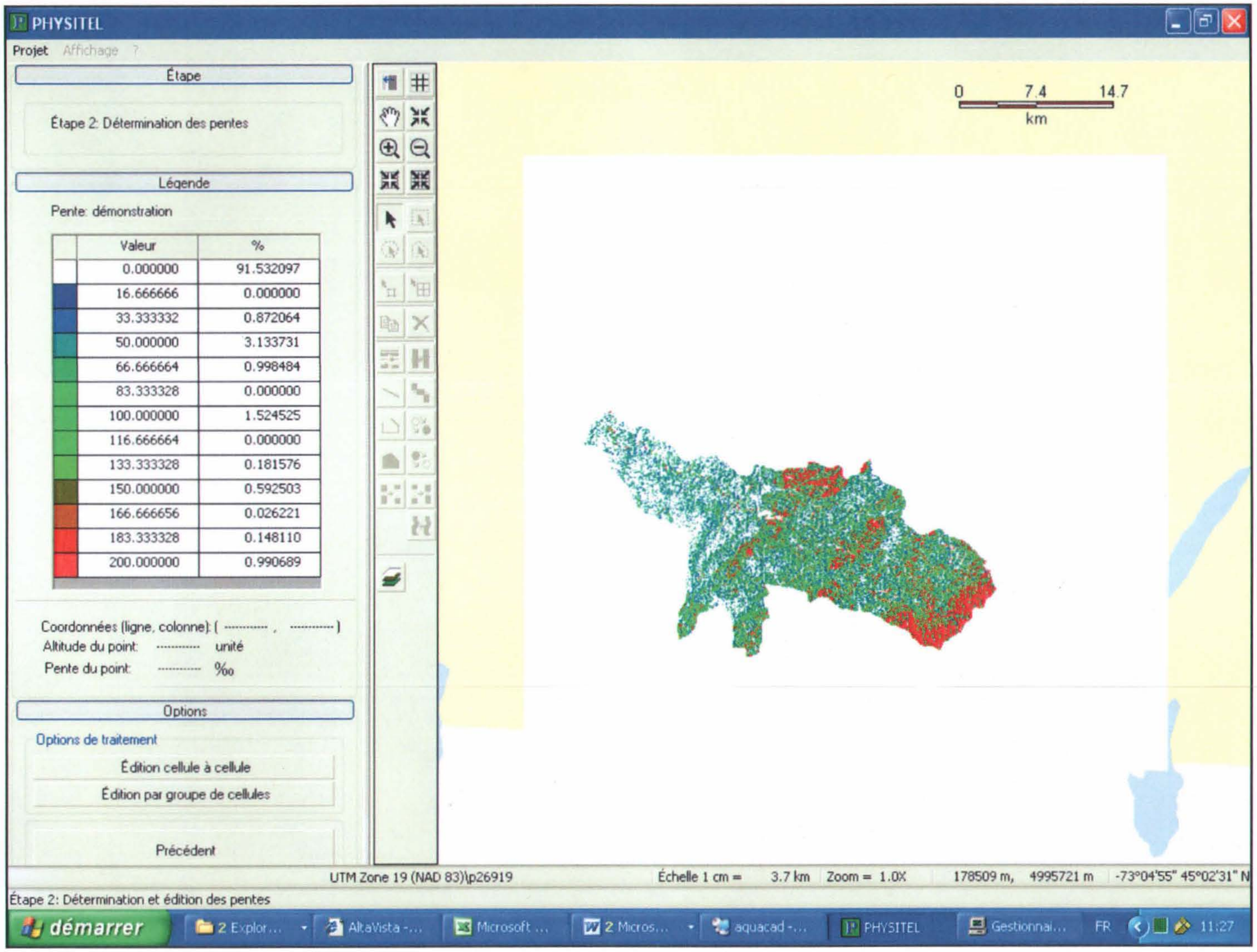

Figure 2.2 : Computation of slope on the original (unaltered) DEM of the Yamaska river watershed.

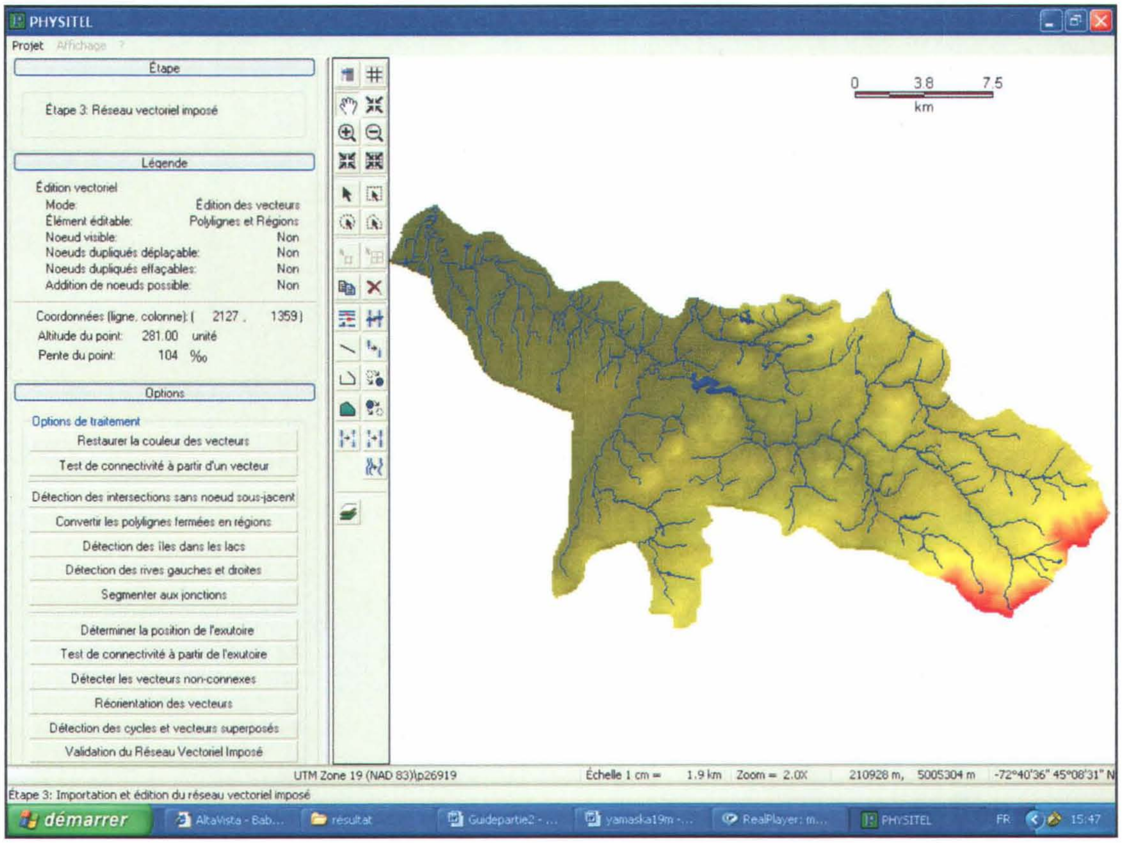

Figure 2.3 : Importation and edition of the DRLN of the Yamaska watershed.

Step 4 consists in converting the DRLN vector resulting from step 3 to a raster representation (see Figure 2.4).

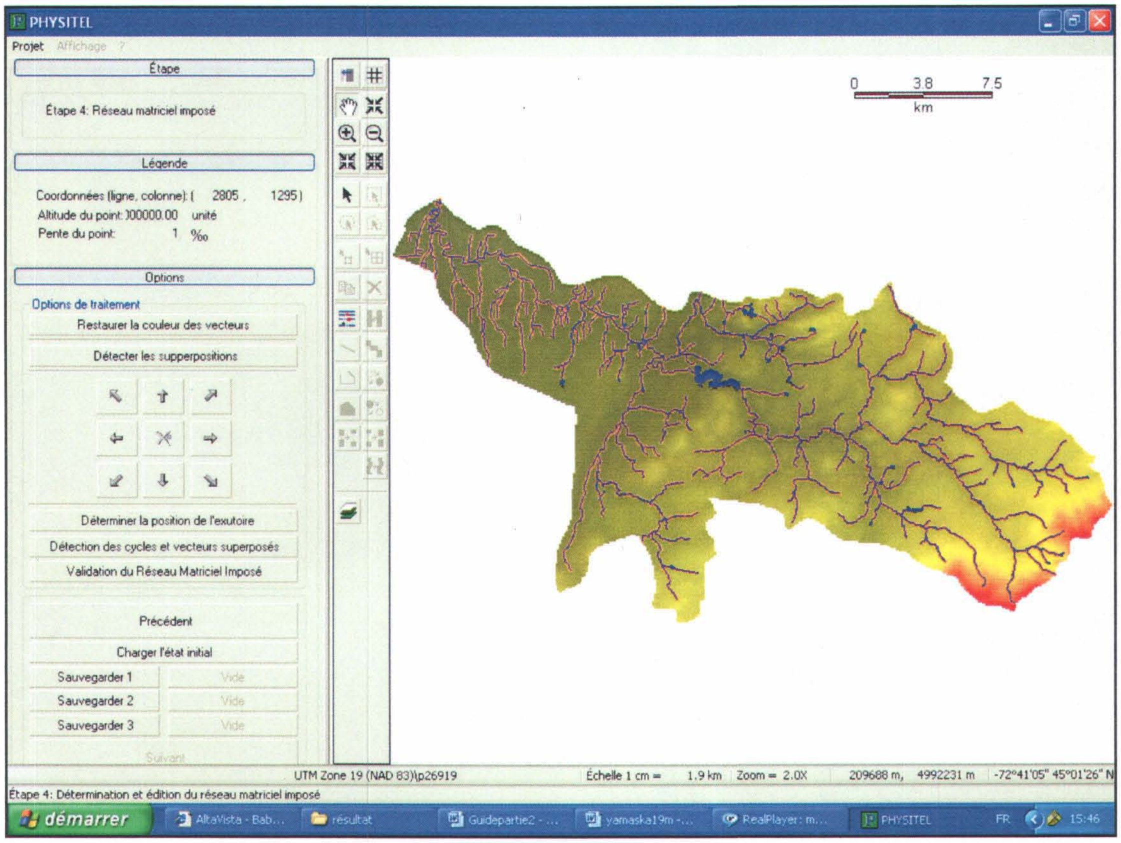

Figure 2.4 : Rasterization and edition of the DRLN of the Yamaska watershed.

The DEM "burning" process comes in step 5. This process effectively digs a trench in the DEM following the DRLN (see Figure 2.5). This task is done by subtracting a perturbation coefficient from the original elevations of the DEM. Note that, this process is restricted to a buffer zone around the DRLN raster which is determined by a maximum radial influence parameter.

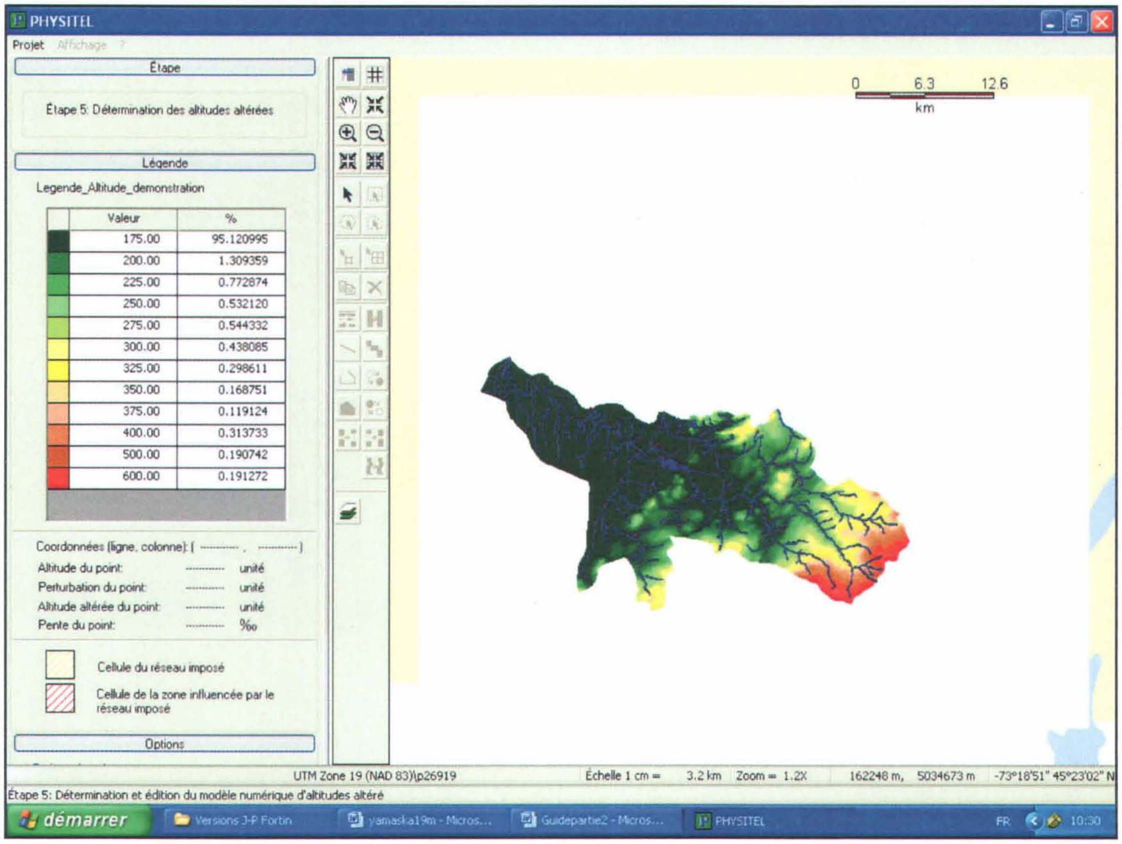

Figure 2.5 : DEM "burning".

The flow direction matrix is generated in step 6 (see Figure 2.6). It is noteworthy that the simulation time of this step and for the Yamaska river watershed (3185 columns × 3021 rows) took 17.5 hours using a Pentium 4 CPU which has 2.8 Ghz of frequency and 480 Mo of RAM.

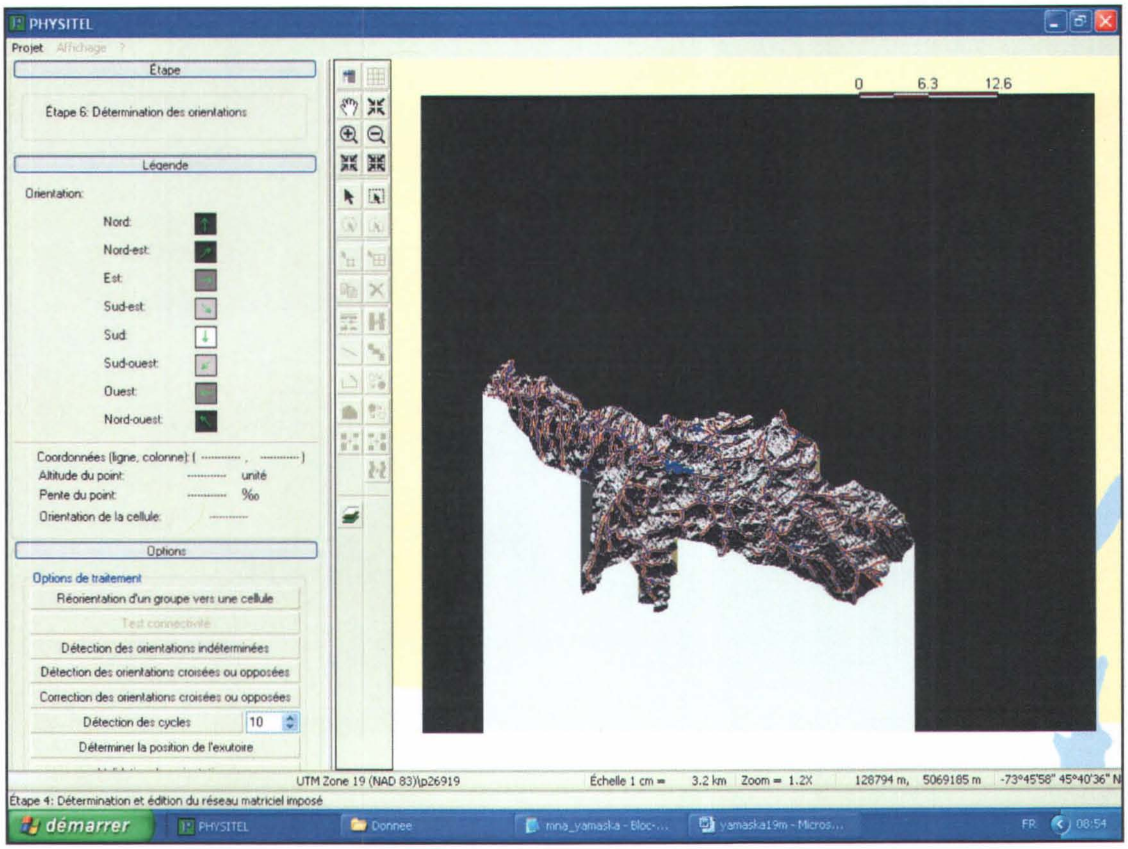

Figure 2.6 : Determination and edition of the flow direction matrix.

Finally, step 7 is dedicated to the generation of the flow accumulation matrix on the basis of the flow direction matrix (see Figure 2.7). The upstream of each grid cell is computed by accumulating cells that flow through this given cell. The cells draining an area greater than a specified threshold are considered as defining the river network.

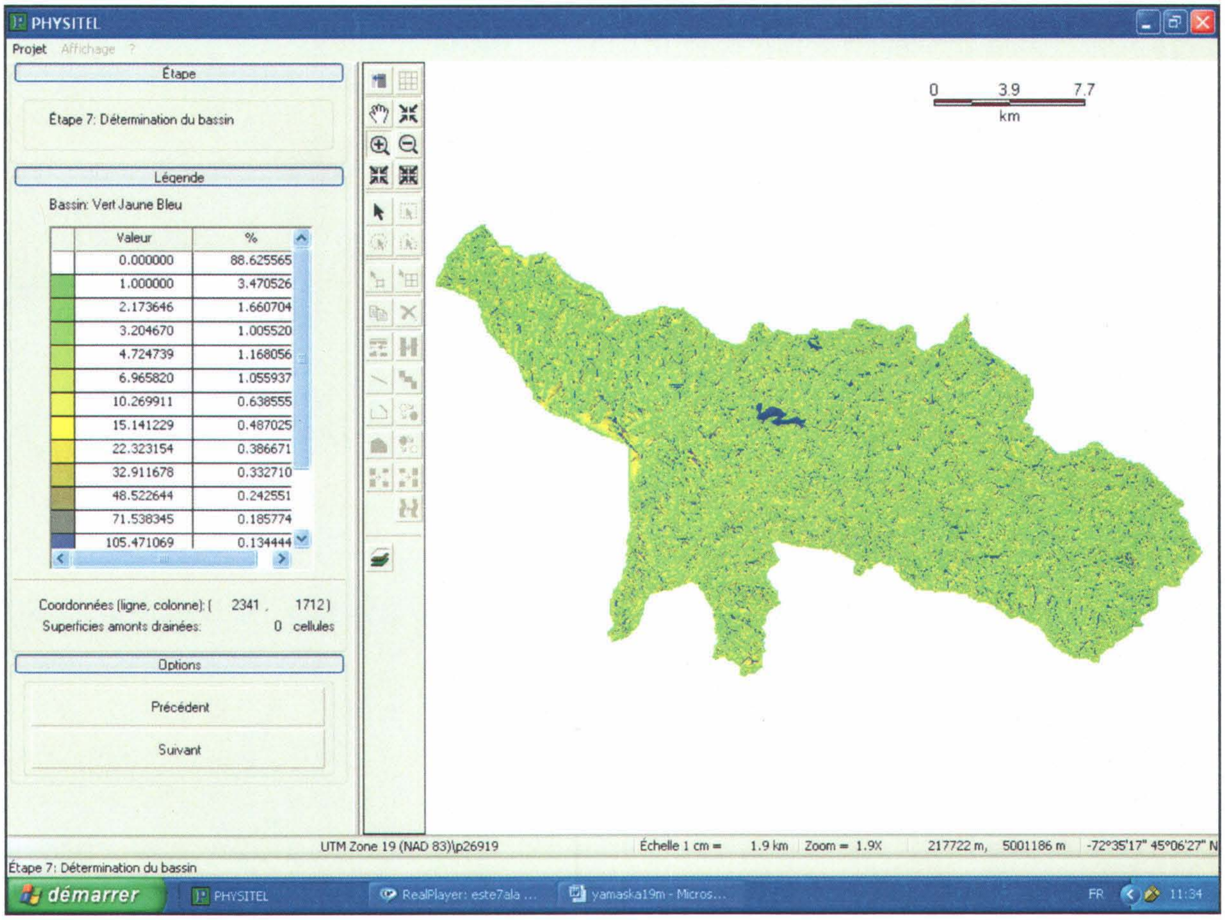

Figure 2.7 : Determination of the flow accumulation matrix.

2.2 CALCULATION OF *TI* ON THE YAMASKA WATERSHED

2.2.1 Methodology

The computation of *TI* distribution is performed by Arc GIS 8.3. Preliminary steps are necessary: The slope and flow accumulation matrices generated by PHYSITEL need to be imported into Arc GIS. This task is done on the basis of the following steps:

(i) Slope and flow accumulation are generated by PHYSITEL in text files format;

(ii) Creation of headers to these two files;

(iii) Replacement of points by commas;

(iv) Modification of the extension of the Slope and flow accumulation files from .txt to .asc and

(v) Conversion of these two files by Arc Tool Box to grid files format which is compatible with Arc GIS.

Finally, *TI* is calculated by the "Raster Calculator" window as follows:

$$TI = \ln\left(\frac{[flow\_acc]+1}{\frac{[slp]}{1000}+1}\right) \tag{2.2}$$

Where, $[flow\_acc]$ is the flow accumulation matrix and $[slp]$ is the slope matrix which are generated by the PHYSITEL.

2.2.2 Results and discussions

In this study, the *TI* distribution for the Yamaska watershed was calculated making use of a slope and flow accumulation matrix that are generated by PHYSITEL. This result was compared to the *TI* distributions calculated in a previous study (Rousseau *et al.*, 2005) by the D8-LTD (Orlandini *et al.*, 2003), D8-LAD (Tarboton, 1997) and D8 (O'callaghan and Mark, 1984) integrated in Arc Hydro Tools (see Figures 2.8 to 2.11). The influence of DRLN is clear on the map of *TI* distribution which is computed by PHYSITEL. In fact, the lakes are successfully simulated within the Yamaska DEM which is burnt following the DRLN.

Regarding wide rivers with two banks, PHYSITEL offers a manual edition of the DRLN so that wide rivers are replaced by a central arc. In the vicinity of the watershed boundary, flat surfaces are sometimes undetermined during the flow direction generation step. However, within the PHYSIEL framework the user can manually assign arrows to cells of flat zones.

Figure 2.12 presents histograms of *TI* distributions for the Yamaska watershed which are obtained by the different algorithms. The histograms which correspond to PHYSITEL and D8-LAD do not contain negative *TI* values which correspond to high areas not contributing to flow accumulation or when $a<\tan\beta$ (where a is the upslope area per unit contour length and $\tan\beta$ is the slope). If we compare *TI* distributions as calculated by Arc Hydro Tools and PHYSITEL which only differ by the way the DEM is burnt, the histograms are almost similar with the exception that Arc Hydro generates negative values of *TI*. But if we cumulate the *TI* values of [-2;0[and [0;2[classes generated by Arc Hydro we find 70% which is the same value of *TI* distribution in the [0;2[class using PHYSITEL. This could be explained by the fact that PHYSITEL does not generate zero values in the flow accumulation matrix.

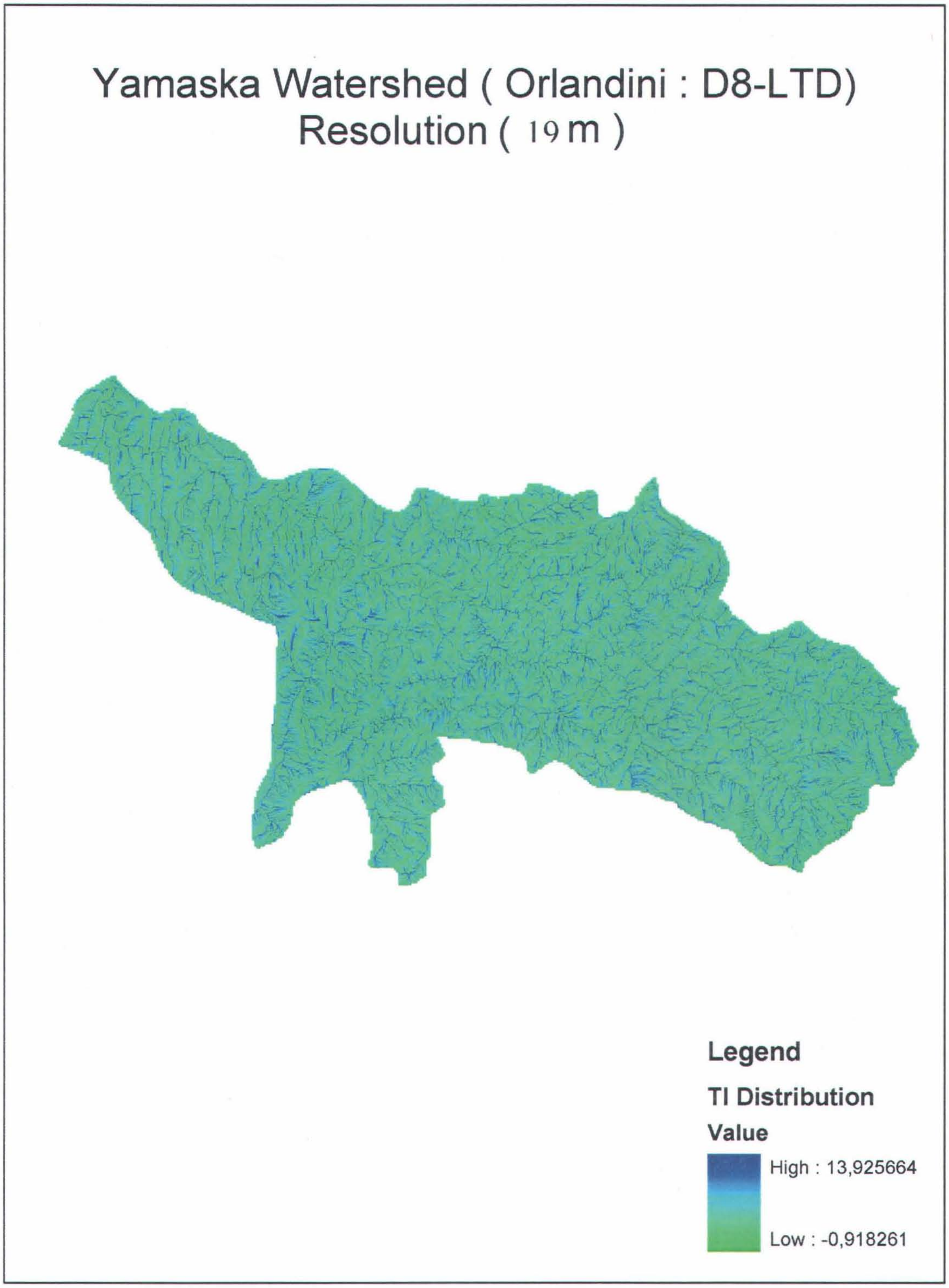

Figure 2.8 : *TI* distributions obtained by D8-LTD for the Yamaska river watershed (resolution 19m).

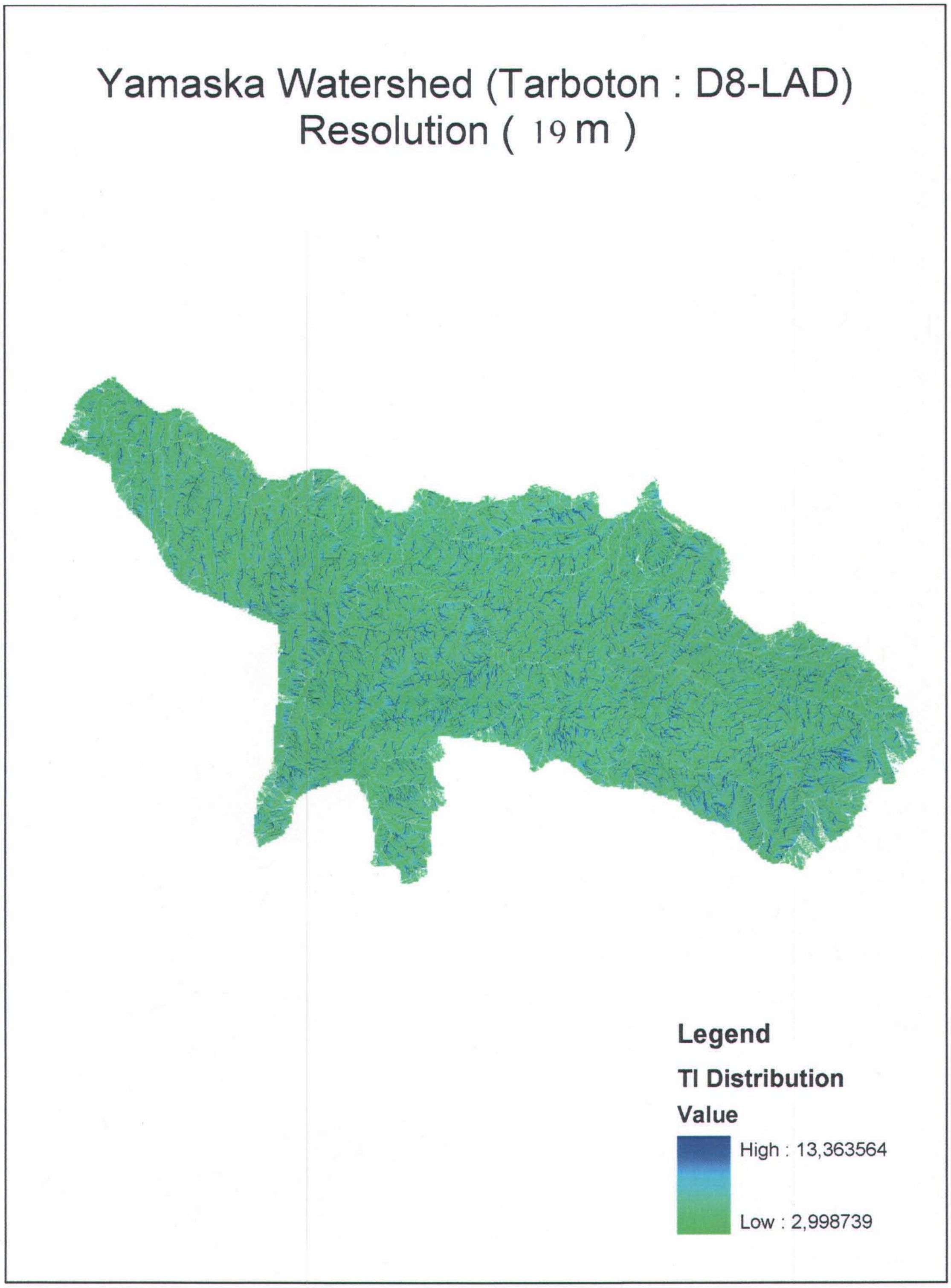

Figure 2.9 : Comparison of *TI* distributions obtained by D8-LAD for the Yamaska river watershed (resolution 19m).

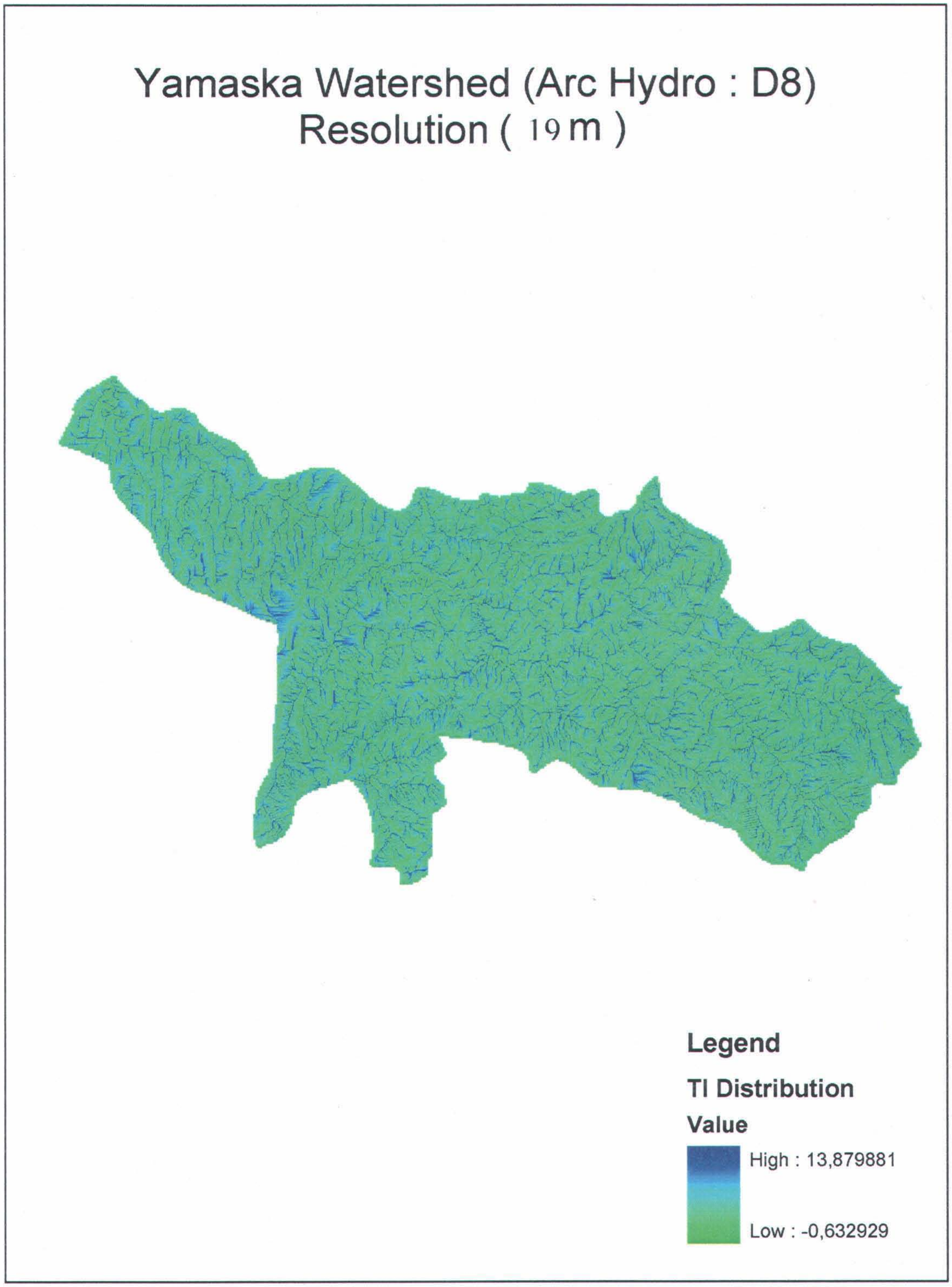

Figure 2.10 : Comparison of *TI* distributions obtained by Arc Hydro (D8) for the Yamaska river watershed (resolution 19m).

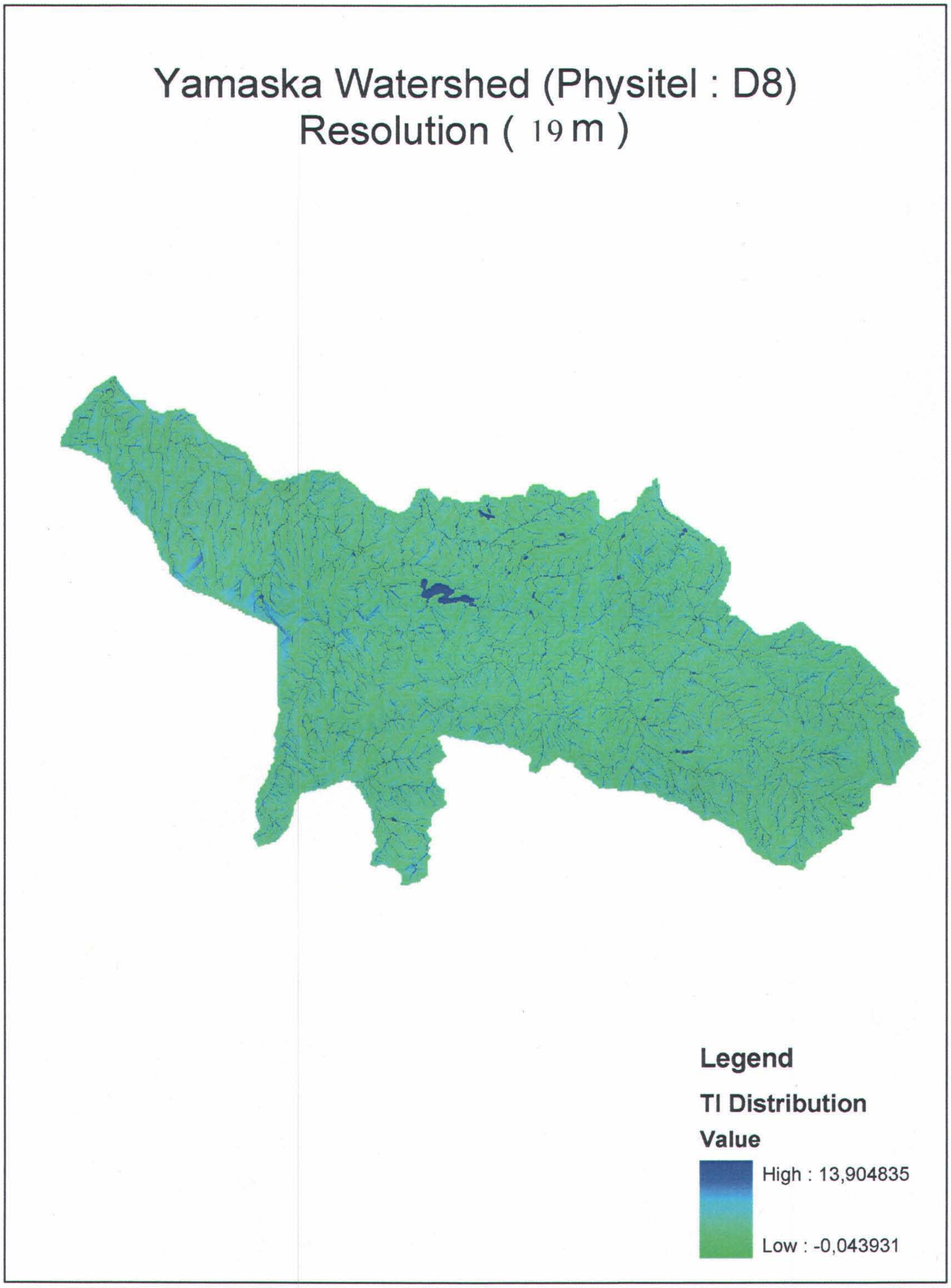

Figure 2.11 : Comparison of *TI* distributions obtained by PHYSITEL (D8) for the Yamaska river watershed (resolution 19m).

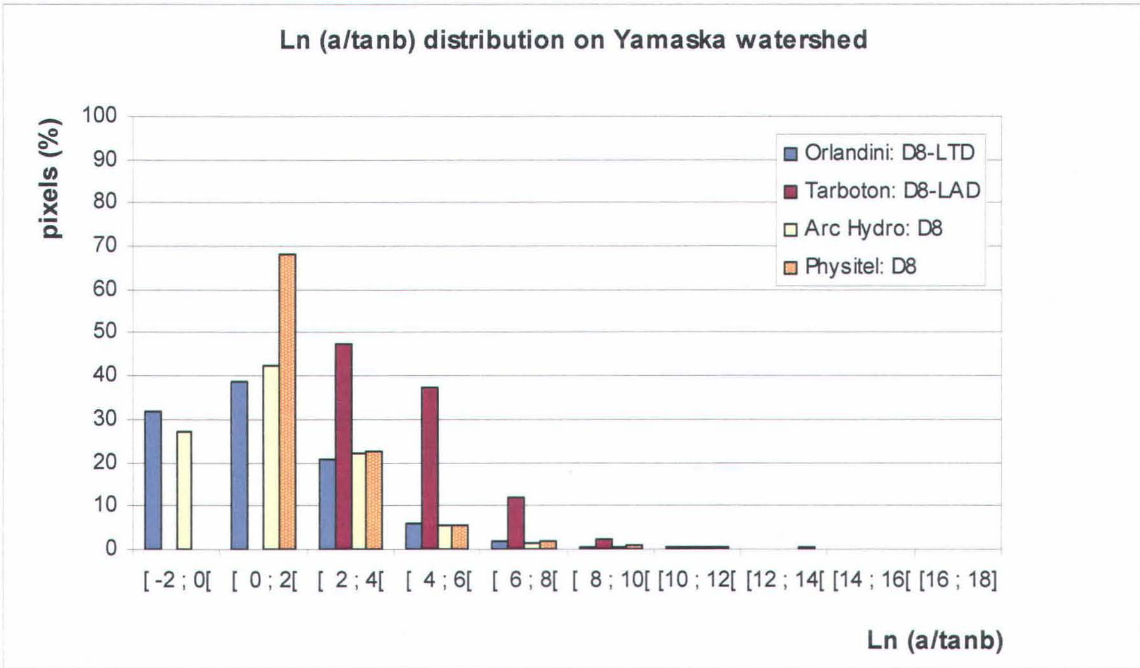

Figure 2.12 : Histograms of *TI* distributions obtained by the D8-LTD, D8-LAD, D8 of Arc Hydro (D8) and PHYSITEL (D8) on the Yamaska river watershed.

3 CONCLUSION

A new procedure for calculating the *TI* distribution by PHYSITEL was proposed in this study. Results for *TI* distribution for the Yamaska watershed are satisfactory. The approach of DRLN integrated in PHYSITEL (Turcotte *et al.*, 2005) bypasses the problem associated with the D8-LAD, D8-LTD and Arc Hydro methods which cannot route water through lakes and wide rivers.

Flat surfaces near the watershed boundary still generate problems of flow direction but they can be manually corrected in PHYSITEL. Eventually, it is noteworthy that PHYSITEL requires a long simulation time to generate the flow direction matrix.

4 REFERENCES

Rousseau, A.N., A. Hentati, S. Trembley, 2005. Computation of the Topographic Index on 16 watesheds in Quebec. Rapport n° R-800-f. INRS-ETE, La Couronne (Qc), Canada.

Saunders, W., 1999. Preparation of DEMs for use in environmental modeling analysis. ESRI User Conference, July 24-30, 1999, San Diego, California.
http://gis.esri.com/library/userconf/proc99/proceed/papers/pap802/p802.htm

Tarboton D.G., 1997. A new method for determination of flow directions and upslope areas in grid digital elevation models. *Water Resources Research*, **33**(2): 309-319.

Turcotte R., J.-P. Fortin, A.N. Rousseau, S. Massicotte, J.-P. Villeneuve, 2001. Determination of the drainage structure of a watershed using a digital elevation model and a digital river and lake network. *Journal of Hydrology*, **240**: 225-242.

O'Callaghan J.F. and D.M. Mark, 1984. The extraction of drainage networks from digital elevation data. *Comput. Vis. Graph. Image Process*, **27**: 323-344.

Orlandini S., G. Moretti and M. Franchini, 2003. Path-based methods for the determination of non dispersive drainage directions in grid-based digital elevation models. *Water Resources Research*, **39(6)**, 1144.