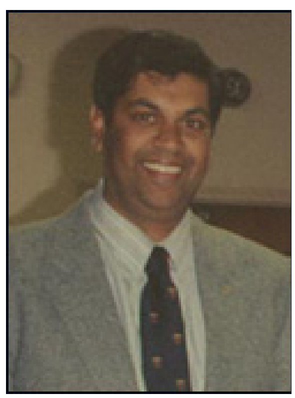
Title:

Development of User Interface in ArcGIS for Watershed Management

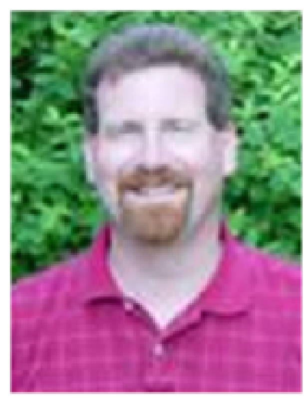
1. **Dr. A. Sarangi,(Author for correspondence),** Post Doctoral Researcher, Agricultural and Biosystems Engineering, McGill University, Macdonald Campus, MS1-019, MS building, 21111, Lakeshore Road. Ste-Anne-De-Bellevue, H9X3V9, Montreal, Quebec, Canada.
   E-mail ID < sarangi@macdonald.mcgill.ca >, Ph- 001-514-398-8785 (Work) Fax 001-514-398-8387
   E-Mail ID after 1st Jan 2004 < ads_wtc@rediffmail.com (contains underscore between ads and wtc)> or <asarangi@iari.res.in>
2. **Dr. C.A. Madramootoo,** Director, Brace Centre for Water Resources Management and James McGill Professor, McGill University, Montreal, Canada
   E-mail ID : <madramootoo@macdonald.mcgill.ca >
3. **Mr P. Enright,** Research Associate, Brace Centre for Water Resources Management, McGill Univ., Canada E-mail < enright@ macdonald.mcgill.ca >

Fax no – 011-514-398-8387

Dr. A. Sarangi



Dr. C.A. Madramootoo



Er. P. Enright

For details about the authors, refer the web sites at:

1. http://mail.iari.res.in/~asarangi/
2. http://www.mcgill.ca/agreng/staff/madramootoo/
3. http://www.mcgill.ca/agreng/staff/enright/

Development of User Interface in ArcGIS for Watershed Management

A.Sarangi[1], C.A. Madramootoo[2] and P. Enright[3]

Abstract

Integrated Watershed Management (IWM) plays a significant role in achieving sustainability in agricultural production. The estimation of watershed morphological parameters is an essential pre-requisite for holistic watershed management. These parameters not only assist in estimating hydrological responses such as runoff and sediment losses, but also to prioritize intervention on different watersheds, based on the susceptibility of their natural resources to degradation. Geographic Information System (GIS) tool was used to develop an interface (built-in macro) within ArcGIS for the estimation of watershed morphological parameters. This was developed using Visual Basic for Applications (VBA) language based on Arc Objects technology developed by the Environmental Systems Research Institute (ESRI). The developed interface Watershed Morphology Estimation Tool (WMET) estimates watershed-specific geomorphological parameters from user-specified inputs of watershed, contour and natural drainage network coverage features. The interface generates all standard geomorphological parameters of the watershed including drainage density and hypsometric integral along with hypsometric curve from DEMs or digitized watersheds. The interface can quickly perform a sequence of activities including watershed delineation, stream network generation, and estimation of geomorphological parameters. It can be customized as an icon in the toolbar of ArcMap version 8.1 and above, developed by ESRI. This interface was tested on a DEM of the Cowansville region and on the St-Esprit watershed both located in Québec, Canada. The generated drainage networks for both watersheds were almost in line with the digitized drainage network. Moreover, the estimated geomorphological parameters precisely define the hydrologic behaviour of the watershed and qualitatively validated by interpreting the observed data. It was observed that the user interface in ArcGIS was an efficient tool for repetitive morphological parameter estimation, with minimal time and effort.

Key Words: ArcGIS; Interface; Digital Elevation Model; Visual Basic for Applications; watershed; Geomorphology;

[1] Post Doctoral Fellow, Agricultural and Biosystems Engineering, MS-1-019, Macdonald campus, McGill University, Montreal, Canada, H9X3V9 E-mail ID sarangi@macdonald.mcgill.ca Phone- 001-514-398-8785 Fax- 001-514-398-8387 (**Author for Correspondence**)

[2] Director, Brace Centre of Water management and James McGill Professor, Agricultural and Bio-systems Engineering, McGill University, Montreal, Canada

[3] Research Associate, Brace Centre for Water Resources Management, McGill Univ., Canada

1. Introduction

Advances in computational power and growing availability of spatial data have made watershed-based analysis more systematic and meaningful. Watersheds are appropriate spatial units for managing environmental problems and reflect the hydrological responses of the delineated spatial unit. The key property of watershed delineation is the creation of a watershed boundary. The watershed boundary uniquely defines the land area from which the surface water drains to the watershed outlet. The advent of spatial data in the form of Digital Elevation Models (DEM), Triangulated Irregular Network (TIN) and Digital Line Graphs (DLG) has led to the use of improved tools for watershed management and hydrologic modeling. Geographic Information System (GIS) software has made the task of spatial data management much easier, interactive and informative. In this paper, a user interface in GIS has been developed for watershed delineation, natural drainage network generation and drainage density estimation from the available DEM. The DEM is a digital representation of land elevation and can be stored in one of the three data structures such as grid, TIN, and contour based. Grid structure usually consists of a square grid matrix with an elevation value specified at each grid square, called a cell. Most of the DEMs available now are in grid structure format (Garbrecht *et al*., 2001)

Watershed management requires physiographic information such as watershed slope, configuration of channel network, location of drainage divide, channel length and geomorphologic parameters *viz*. relative relief, shape factor, circulatory ratio, bifurcation ratio, drainage density and Hypsometric Integral (HI) for watershed prioritization and implementation of soil and water conservation measures. Traditionally, these parameters are obtained from topographic maps or field surveys. Over the past two decades this information has been increasingly derived from digital representation of topography, generally called the DEM (Moore *et al*., 1991; Martz and Garbrecht, 1992). The automated derivation of topographic watershed data from DEMs is faster, less subjective and provides more reproducible measurements than traditional manual techniques applied to topographic maps (Tribe, 1992).

1.1 Background information on User Interfaces (UI) in GIS.

In order to facilitate the implementation of the concepts for watershed delineation and drainage network generation, User Interfaces (UI) in GIS have been developed, which provide communication between the user and the GIS software through a set of methods or procedures. The interfaces developed perform integration of multiple databases, simulation models and flow logic to arrive at the desired result with minimal time and without expert GIS knowledge by the user. Initially, the interfaces were developed in Arc View 3.x using Avenue script language, in ArcInfo workstations using AML (Arc Macro Languages) and now it is done through VBA (Visual Basic for Applications) programming language with ArcGIS, a recent GIS software by ESRI (Environmental Systems Research Institute). The VBA is COM (Component Object Model) compliant and is supported by the ArcObjects technology of ESRI, which are embedded in Arc View 8.1 and higher software versions of ArcGIS [1] (at http://www.esri.com).

In a review of the interfaces developed for watershed generation and stream network generation, Olivera and Maidment (2000) developed CRWR-PrePro, an interface with ArcView 3.2 of ESRI with spatial analyst extension for accomplishing watershed delineation and natural drainage network generation from DEMs. This interface was developed at the Centre for Research in Water Resources (CRWR) of the University of Texas at Austin as a Pre-Processor (Pre-Pro) for establishing the topology of hydrologic elements and prepare a watershed parameter input file for use in running HEC-HMS (Hydrologic Engineering Centre-Hydrologic Modelling System) hydrologic model. The interface is written in Avenue script, the in-built macro language embedded with ArcView 3.2 (ESRI) GIS software. The process of watershed delineation from DEM is covered through a number of steps such as filling the sinks and preparing a depression less DEM, flow direction and flow accumulation using D-8, watershed delineation based on user specified threshold on contributing number of grid cells making up the drainage basin or a branch of drainage network. Moreover, there is also the option for interactive selection of watershed outlets. The sub-basins are thus generated for the DEM along with the drainage network. Finally, the raster coverages of sub-basins and stream network are converted to vector files for further analysis.

The Arcview Interface for SWAT (Soil and Water Assessment Tool) i.e. AVSWAT 2000 (DiLuzio *et al*., 2002) [2] (at http://www.brc.tamus.edu/swat/avswat), is a complete preprocessor, interface and post processor of the hydrological model SWAT. AVSWAT 2000 has been developed as an extension of ArcView 3.x GIS entirely in avenue script and dependent by spatial analyst and dialog designer extensions. The Spatial Analyst functions are used within the Watershed Delineation and Landuse and Soil Definition components while the Dialog Designer controls have been used to build up all the user interface tools. Its interface is different from CRWR-PrePro, but it follows the same procedure as described for watershed delineation and stream network generation.

Valenzuela and Olivera (2002) developed an interface WSDT (Watershed and Stream Delineation Tool),[3](http://ceprofs.tamu.edu/folivera/GISTools/wsdt/home.htm) for watershed delineation and stream network generation from DEMs. The concept of this is similar to the basics of watershed delineation with the steps *viz.* filling the DEM, flow direction grid formulation, flow accumulation, stream grid generation, Links grid generation, watershed grid formation, topology building and vectorizing the stream and watershed grids. This is developed in VB programming language and shows a simpler UI in which all the steps for watershed demarcation and stream network generation is achieved by clicking a single command button on the interface VB form within ArcView 8.1 and higher version GIS.

Tarboton (2002) developed a set of tools for terrain analysis *viz.* TAUDEM (Terrain Analysis Using Digital Elevation Models)[4], which uses a DEM and operate within ArcGIS 8.1 and higher version. The interface performs DEM preprocessing and multiple methods for the delineation of channel networks including curvature-based methods sensitive to spatially variable drainage density and objective methods for determination of the channel network delineation threshold based on stream drops and stream ordering. It also performs delineation of watersheds and sub-watersheds draining to each stream segment and association between watershed and segment attributes for setting up hydrologic models. Moreover, it also incorporates some specialized functions for advanced terrain analysis.

It is evident from the literature that there is a need for development of an User Interface in ArcGIS for estimating the geomorphological parameters to understand the watershed morphology and interpret their impact on watershed hydrology.

2. DEM Data Acquisition

A 7.5' USGS (United States Geological Survey, 1990) DEM of scale1:50,000 representing the Cowansvile and St-Espirit regions of Quebec, Canada were obtained from the Walter Hitschfeld Geographic Information Center Library, McGill University, Montreal, Canada for generating the output using the developed interface. The data of digitized stream drainage network from topographical survey maps was also acquired to validate the output from the interface. The geographic location of both east and west DEMs of Cowansvile covered longitude -73^0 00' to –72^0 30' and latitude 45^0 00' to 45^0 15'. The DEM covering the St-Espirit watershed were within longitude –74^0 00' to –73^0 30' and latitude 45^0 45' to 46^0 00'north latitude. The location of St-Espirit watershed is within -73^0 41' 32'' and -73^0 36' 00''west longitude to 45^0 55' 00''and 46^0 00'00'north latitude (Romero *et al*., 2002). As per USGS standards (USGS, 1990) the 7.5' DEM data have a grid spacing of 30 X 30m and the contour interval of 10m. The DEM has a square grid array and is thus computationally efficient. The DEM is under UTM (Universal Transverse Mercator) projection based on North American datum of 1983 (NAD 83), which is widely used in the North American regions. The projection is for the UTM datum and grid zone 18N.

3. Theoretical Considerations

The WSDT interface [4] processes the DEM to demarcate watersheds and generate stream networks from DEM. On the other hand, threshold condition provides the number of cells constituting one small watershed. This is an engineering decision based on the hydrologic characteristics that the scenario presents and is a function of the cell size and the selected drainage area. This concept used in WSDT interface is :

$$T_N = INT\left(\frac{D_A}{C}\right) \quad (1)$$

Where T_N is Threshold number and, D_A is drainage area in area unit and C is size of the cells in are unit. The threshold number has to be an integer (INT), because it is a function of the number of cells upstream and number of cells cannot be a fraction. For theoretical concepts about morphological parameters used in the analysis and further details, Ritter et al. (2002) and Sarangi et al. (2001) can be referred.

3.1 Concepts used in the Watershed Morphology Estimation Tool (WMET) Interface

The schematic diagram of the Watershed Morphology Estimation Tool (WMET) interface structure is shown in Fig. 2. The basic objective of this tool is to estimate useful geomorphological parameters of watersheds as discussed in the theoretical consideration section of this article. The geomorphological parameters directly or indirectly reflect almost the entire watershed based causative factors affecting runoff and sediment loss. The land morphology of the watershed needs to be investigated and quantified in form of geomorphological parameters for studying the watershed hydrologic responses. Thus, the estimation of these parameters assumes importance in watershed management. The manual estimation of these parameters (Tables 1 & 2) from topological maps and databases are cumbersome and time consuming. Moreover, this interface overcomes all these limitations and is useful for analysis within a GIS environment.

3.2 The VBA programming language in Interface development

The interface is written in Visual Basics for Applications (VBA) programming language, which is COM (Component Object Model) compliant and also supports the ArcObjects technology of ArcGIS developed by ESRI. This is also embedded in ArcGIS 8.2 tool comprising of ArcMap, ArcToolbox, ArcCatalogue modules. The ArcInfo 8.1.2 workstation also has ArcMap module that supports VBA programming language. The VBA programming language is one of the best technologies developed in recent years and ArcGIS with COM can integrate with VBA (Razavi, 2002). The applications developed using VBA are often called macros, which automate repetitive tasks or create complete applications. In the programming code, the interfaces available in ArcObjects are used such as the *pMxDocument.FocusMap* expression returns a reference to the *IMap* interface of the activated map in the ArcMap document available in TOC (Table of Contents). The map object can not be directly activated without the interface, for example: Once *pMap* points to *Imap* interface, then there is access to map object. These interfaces are stored in *arcobjects.olb* file of ArcGIS tool.

The VB forms with button controls are developed to link the interface with each distinct activity starting from activation of WSDT interface to estimation of Geomorphological parameters. The geodatabases of the watershed coverages are linked with the programming codes through interfaces, which are detailed in the source code of the interface. The main VB interface has five major sections (Fig. 3). The first section performs watershed delineation and stream network generation using the interface WSDT and adds the digitized layers of watersheds and drainage networks to TOC of ArcMap. The second section indicates the number of layers in TOC and adds all these layers to the combo-box. The third section requires the delineated watershed polygon layer with geo-attribute table for extracting the watershed details including the shape related morphological parameters. The fourth section deals with extraction of stream related morphological parameters including drainage density. The fifth section uses the contour data layer to extract the slope parameters of the watershed, HI value and the co-ordinates for plotting the hypsometric curve. The programme is user friendly and the message boxes displayed while running the interface instructs the user to perform the analysis sequentially. Moreover, the output from the programme is written to specified output files. WMET interface is compatible with ArcView 8.1 and higher versions.

The WMET interface algorithm is targeted towards extracting the attribute information of geo-database tables and incorporates these mathematical relations for estimation of the geomorphological parameters.

4.Methodology

The acquired DEM file was initially unzipped to obtain two data files representing east and west DEMs. These two DEMs are then merged using ArcGIS to represent one DEM. The generated DEM was then projected to real world co-ordinate systems reflecting UTM zone 18N datum using the ArcToolbox processing wizard. This was done to estimate the real surface parameter values of the DEM. The WMET interface is activated by clicking on the macro icon on the tool bar of ArcMap. The popped up interface form displays the command keys to run the module and input the data. Followed by this, the WSDT interface form was activated by clicking the WSDT button shown on WMET interface. Then, following the sequence of operations using the command buttons, the drainage network was generated for three different threshold values *viz*. 50, 100 and 1500. Using the threshold value of 1500, three distinct watersheds were delineated from the DEM. These watersheds were saved as three different polygon coverages and subjected to morphological analysis. The drainage network (line coverage) and watershed (polygon coverage) were overlaid using the intersect command of geo-processing wizard. This operation generated three different polyline coverages corresponding to three watershed intersected with the drainage network. These coverages were also supported with the geo-spatial attribute table including "*Area*" and "*Length*" fields. These fields are selected and analysed using the interface command buttons to obtain the drainage density value of the watersheds. Moreover, the watershed polygons attribute table is also analysed using the interface buttons to estimate the shape factor, circulatory ratio and form factor.

The DEM representing the St-Espirit region was converted to projected co-ordinate system and the St-Espirit research watershed ((Romero et al., 2002)) was clipped over the DEM to extract the DEM representing the study area. The contours with intervals of 5 meters were generated from the DEM and the WSDT and TauDEM interfaces were run to extract the drainage network and compared with the digitized drainage network . The stream ordering was done using hydrologic analysis module of ArcInfo 8.1.2 GIS tool. For achieving this, the Strahler's stream ordering system was followed (Strahler, 1964). Then the WMET interface was used to extract the morphological parameters (Table. 2)

5. Results and Discussions

It was observed that, the drainage network obtained using the WSDT interface was almost in line with the digitized drainage network of the study region. For threshold value of 50, the drainage network generated was more dendritic with more number of links reflecting first and second order streams. However, for a threshold value of 100, the drainage network was almost in line with the digitized network from topographical map sheets. The delineated watersheds along with drainage channels from the DEM are used for estimation of morphological parameters. While operating the command buttons for estimating the parameters, the message boxes and input boxes assist the user to understand different steps and input the desired information. Moreover, the help button in the interface also assists the user in running the interface.

The WMET interface was used for three adjacent watersheds delineated from the DEM and the results are presented in Table. 1. It was observed that, the drainage density values were almost close to each other and the length of the drainage channels increase for bigger watersheds. The low value of drainage density ranging from 0.72km^{-1} to 0.802km^{-1} indicated a well-vegetated and well-forested watershed, which is also true from the ground truth information of the region representing the DEM data. This indicates that in the watershed, there is abstraction of precipitation and better infiltration due to presence of forest and vegetation cover. Moreover, the shape factor varied from 1.39 to 2.68, which is directly related to the shape of the watershed. It was also observed that, due to higher elongation of the 3rd watershed than the other two, its shape factor (2.68) was more than the shape factors (1.39 and 1.73) of 1st and 2nd watersheds. The circulatory ratio was also less for the third watershed i.e. 0.37, indicating the irregular shape of the watershed. The circulatory ratio of the first watershed was highest among the three i.e. 0.55, indicating almost circular shape of the watershed. Therefore, it is interpreted from the values of the estimated parameters that the delineated watersheds are almost in line with the expected behaviour related to geomorphological parameters. This also indicated the estimation accuracy of the developed interface for given set of coverage parameters.

The source code and VB forms of the interface can be used for customization to the ArcMap environment. The interfaces is not provided as a *.dll (dynamic link library) file, because the user can modify the interface in linking the attribute tables and geo-databases and add VBA modules to perform some advanced calculations of runoff and sediment yield estimations. Moreover, the interface can not be functional without GIS environment, so the compilation of the interface code to generate *.exe and *.dll files for stand alone application will not be useful. However, the interface form can be customized as a macro icon on the tool bar of the ArcMap (Fig. 8) and by clicking the icon, the interface form (Fig.2) will be activated. The interface source code is also available for use by the researchers.

The results obtained by running the interface WMET 2.0 for St-Espirit watershed coverage layers are displayed in Table 2. It was also revealed that the watershed is almost flat, with low relief ratios and relative relief values, which indicates a higher time of concentration and low peak flows in comparison to a similar watershed having higher relief. Moreover, the moderate values of bifurcation ratio also indicate that the extended time to attain the runoff peak and moderate peak discharge for independent rainfall events in the watershed. This behavior of the watershed is in conformity with the measured data of the St-Espirit watershed. Considering the Hypsometric Integral (HI) Value (0.52). The watershed is susceptible to erosion. The susceptibility of the watershed to erosion was confirmed by analyzing the sediment loss corresponding to the rainfall. It was observed that higher discharge values reflect increased concentration of sediment in the runoff at the outlet of the watershed and the trend is similar for the years 1994 and 1996. Moreover, the drainage density value of St-Espirit watershed (1.974 km^{-1}), is higher than the drainage density values of the three watersheds of Cowansvile region. These values reveal that the St-Espirit watershed has a well-defined drainage network. The forest cover or dense vegetation patches in St-Espirit watershed are less than of Cowansvile to intercept rainfall. Consequently, there is fairly quicker translation of rainfall into runoff at outlet in comparison to watersheds of Cowansvile region. Comparing the HI values of the 4 watersheds, it was revealed that the St-Espirit and the 2nd watershed of Cowansvile region are more prone to erosion than the other two watersheds. The operation of the interface with the HI value message box is shown in Fig 3. The Interface also displays specific interpretations considering hypsometric integral values and shape of the hypsometric curve on erosion status and susceptibility to erosion.

6. Conclusions

The developed interface is a useful tool for integrated watershed management. This also endorses the use of advanced computer assisted technology applied to the management of natural resources on a watershed basis. The interface provides the inexperienced or new user with an entry point to a powerful GIS without any detailed training in hydrological modeling. The interface command buttons perform a series of inherent GIS instructions and displays the results in a user-friendly format. The link of the developed interface with WSDT for watershed delineation and stream network generation assists the user to start watershed management activities from a DEM, without looking for digitization of topological information. The intent of this paper is to link the geospatial database with the interpretive routines for estimation of morphological parameters on watersheds.

The VBA programming language and the ArcObjects technology used in this interface is an emerging field in GIS based applications. The flexibility of the interface for further modification and updation is an added advantage with the interface. This technique will further assist the linkage of hydrologic simulation models for prediction of real time sediment and runoff estimations on watersheds. This interface on watershed morphology estimation within ArcGIS environment is first of its kind and is a useful tool for watershed prioritization and prediction of hydrologic responses.

References

DiLuzio, M., Srinivasan, R. Arnold, J.G.and Neitsch, S.L. 2002. Soil and Water Assessment Tool. ArcView GIS Interface Manual: Version 2000. GSWRL Report 02-03, BRC Report 02-07, Published by Texas Water Resources Institute TR-193, College Station, TX. 346p.

Garbrecht, J., and L. W. Martz**.** 1999. Digital Elevation Model Issues in Water Resources Modeling. Proceedings from Invited Water Resources Sessions, 19th ESRI International User Conference, Environmental Systems Research Institute, San Diego, California, July 26-30, 1999, pp. 1-17

Garbrechet, J., Ogden, F.L., Debarry, P.A. and Maidment , D.R. 2001. GIS and Distributed Models. I: Data Coverage and Sources. *Journal of Hydrologic Engineering*, 6(6):506-514.

Martz, L.W. and Garbrechet, J. 1992. Numerical Definition of Drainage Network and Subcatchment Areas from Digital Elevation Models. *Computers and Geosciences*. 18(6):747-761.

Moore, I.D., Grayson, R.B. and Ladson, A.R.1991. Digital Terrain Modelling: A Review of Hydrological, Geomorphological and Biological Applications. *Hydrological Processes* 5(1): 3-30

Olivera, F., and Maidment, D.R. (2000). GIS Tools for HMS Modelling Support. Chapter 5, *Hydrologic and Hydraulic Modelling with Geographic Information Systems*, D.R. Maidment and D.Djokic, (eds.), ESRI Press, San Diego,Calif.

Razavi, A.H. 2002. ArcGIS Developer's Guide for VBA. OnWard Press, New York.

Ritter Dale, F., R. C. Kochel and J. R. Miller (2002) Process Geomorphology, Mc-Graw Hill, Boston.

Romero, D. C.A. Madramootoo and P. Enright (2002). Modelling the Hydrology of an Agricultural Watershed in Quebec using SLURP, *Canadian Biosystems Engineering*, 44, pp 1.11:1.20

Strahler, A.N. 1964. Quantitative geomorphology of drainage basins and channel networks; section 4-2, in *Handbook of Applied Hydrology*, ed. Ven te Chow, McGraw-Hill, New York

Sarangi, A. Bhattacharya, A.K. Singh, A. Singh A.K (2001) Use of Geographic Information System (GIS) for determination of erosion status of watersheds. *Indian Journal of Soil Conservation,* 29(**3**,)190-195

Tarboton, D.G., Bras, R.L. and Rodrigues, I.1991. On the Extraction of Channel Network from Digital Elevation Data. *Water Resources Research* 5(1): 81-100.

Tribe, A. 1992. Automated Recognition of Valley Heads from Digital Elevation Models. *Earth Surface Processes and Landforms* 16(1):33-49.

U.S. Geological Survey (USGS). 1990. *Digital Elevation Models: data user guide. National mapping programme, technical instructions, data user guide 5*, Department of the Interior, Reston, VA.

Internet References

[1] ESRI web site http:// www.esri.com

[2] Soil and Water Assessment Tool (SWAT) at http://www.brc.tamus.edu/swat/avswat

[3] Spatial Water Budgeting tool model http://www.icasa.net/toolkit/swbm.html

[4] Watershed and Stream Delineation Tool interface http://ceprofs.tamu.edu/folivera/GISTools/wsdt/home.htm

[5] Tarboton D.G.(2002), Terrain Analysis Using Digital Elevation Model (TauDEM) interface http://moose.cee.usu.edu/taudem/taudem.html.

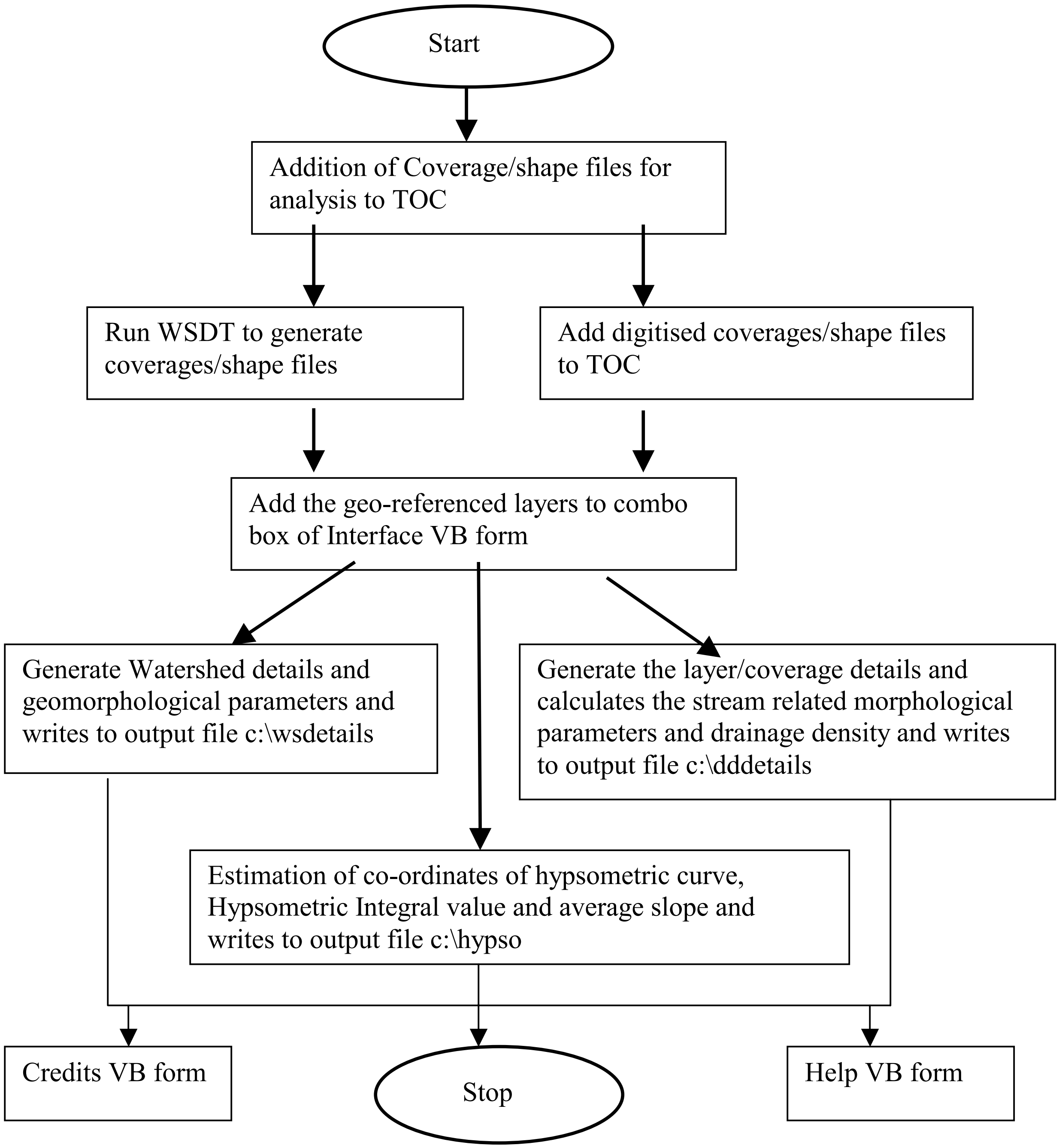


Fig. 1. System Architecture of Interface WMET (Ver 2.0)

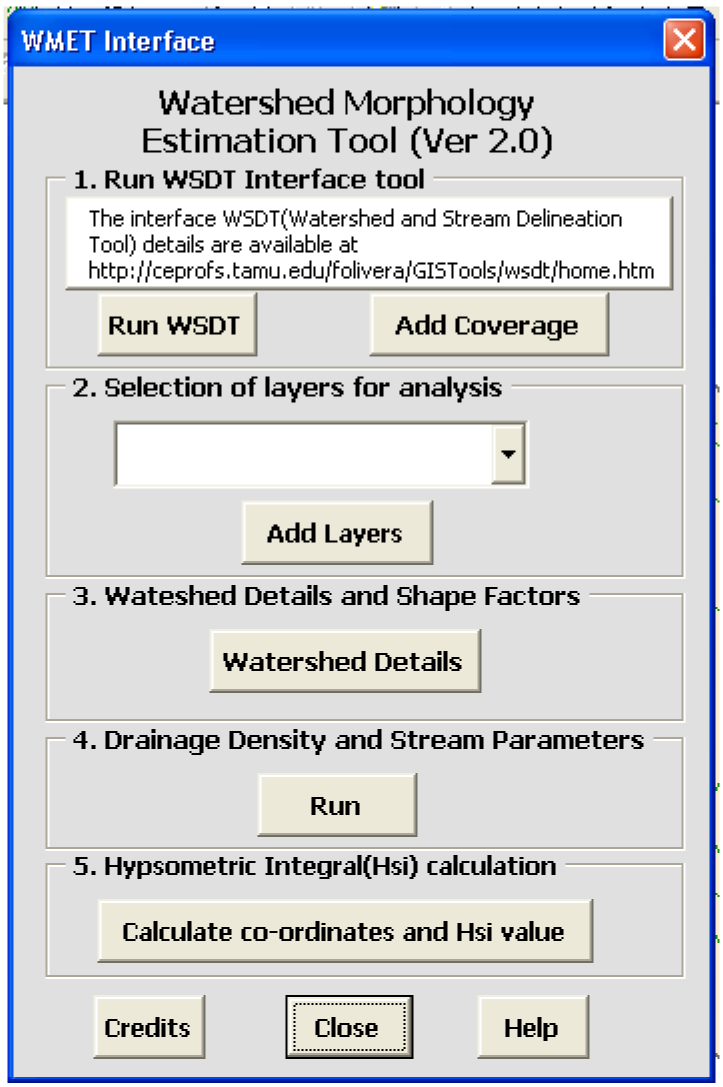


Fig. 2. The activated WMET interface with the command buttons.

Interface customized in the toolbar

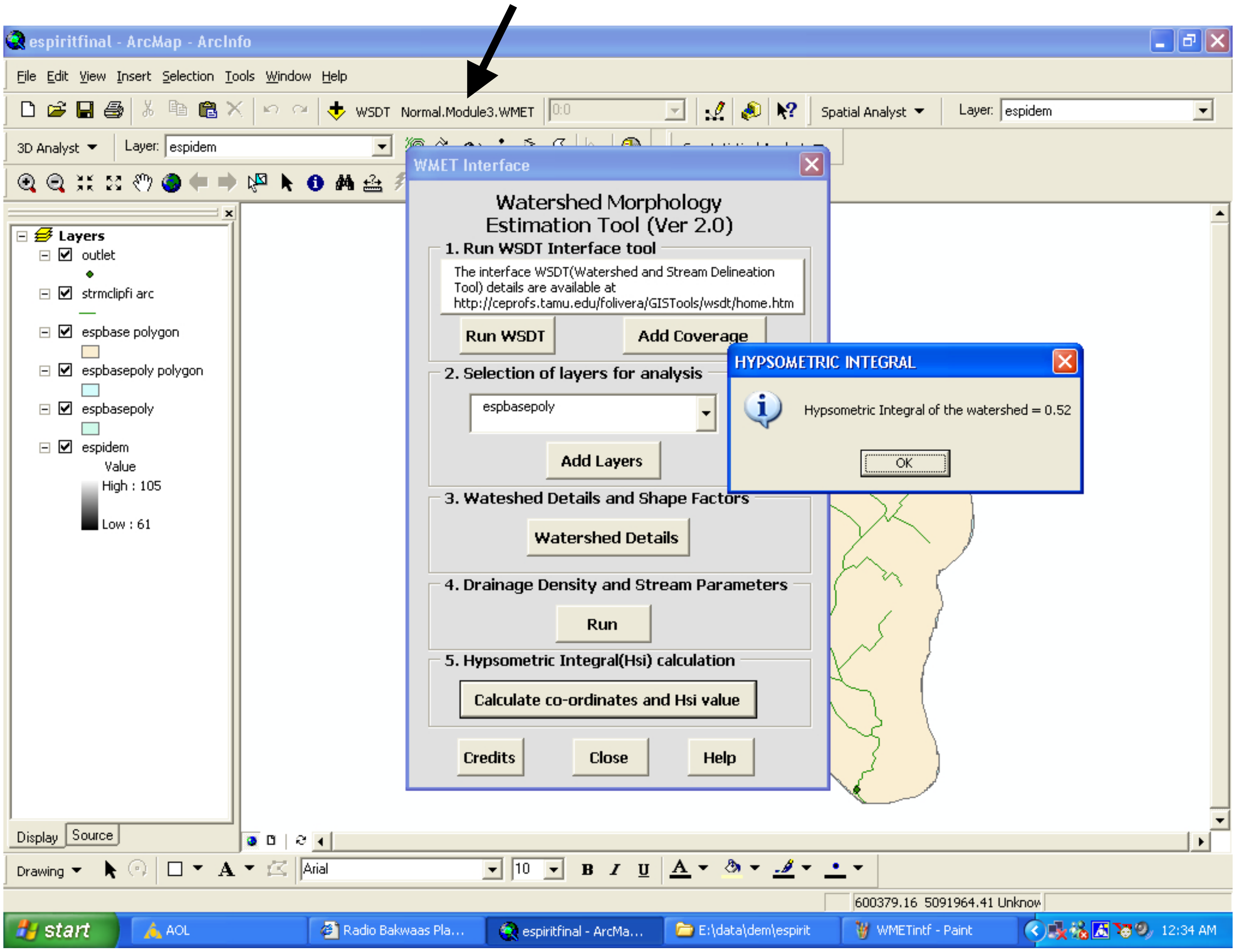


Fig. 3. Opeating the interface and the message box displaying the estimated Hypsometric Integral value of the St-Espirit watershed.

Table. 1 Geomorphological parameters estimated using the WMET interface for three delineated watersheds from Cowansvile DEM.

Watershed details and Geomorphological Parameters	**1st Watershed**	**2nd watershed**	**3rd watershed**
Area (Sq. km.)	161.98	254.4	335.14
Perimeter (km)	82.25	117.96	144.75
Maximum length (km)	15.075	21.113	30.50
Maximum elevation (m)	350	310	800
Minimum Elevation (m)	180	50	80
Relief ratio	0.0113	0.0123	0.0236
Length of drainage channels (km)	130	183	245
Shape factor	1.39	1.73	2.68
Form factor	0.72	0.576	0.37
Circulatory Ratio	0.55	0.48	0.44
Drainage density (km^{-1})	0.802	0.72	0.73
Hypsometric Integral (H_{si})	0.48	0.53	0.39

Table. 2 Geomorphological parameters estimated using the WMET interface (ver 2.0) for St-Espirit watershed, Quebec, Canada.

Geomorphological Parameters	St-Espirit Watershed		
Area (Sq. km.)	26.093		
Perimeter (km)	23.679		
Maximum length (km)	7.35		
Maximum elevation (m)	105		
Minimum Elevation (m)	65		
Watershed Relief (km)	0.04		
Relief ratio	0.006		
Relative Relief	0.002		
Elongation Ratio	0.823		
Average Slope (km/km)	0.012		
Stream Characteristics (Strahler's stream ordering system)	**Number of Streams**	**Length (km)**	**Area (Sq Km)**
1st order streams	40	15.76	10.08
2nd order streams	17	25.89	17.6
3rd order streams	3	7.185	17.83
4th order streams	1	2.663	25.21
Total Length of streams of all orders (Km)	51.5		
Stream length ratios	1st and 2nd order	2nd and 3rd order	3rd and 4th order
	3.865	1.573	1.11
Bifurcation Ratios	1st and 2nd order	2nd and 3rd order	3rd and 4th order
	2.353	5.67	3.0
Stream frequency of the watershed (Km^{-2})	2.338		
Drainage Factor of the watershed	0.60		
Shape factor	1.878		
Form factor	0.533		
Circulatory Ratio	0.765		
Drainage density (km^{-1})	1.974		
Ruggedness Number	0.079		
Hypsometric Integral (H_{si})	0.52		