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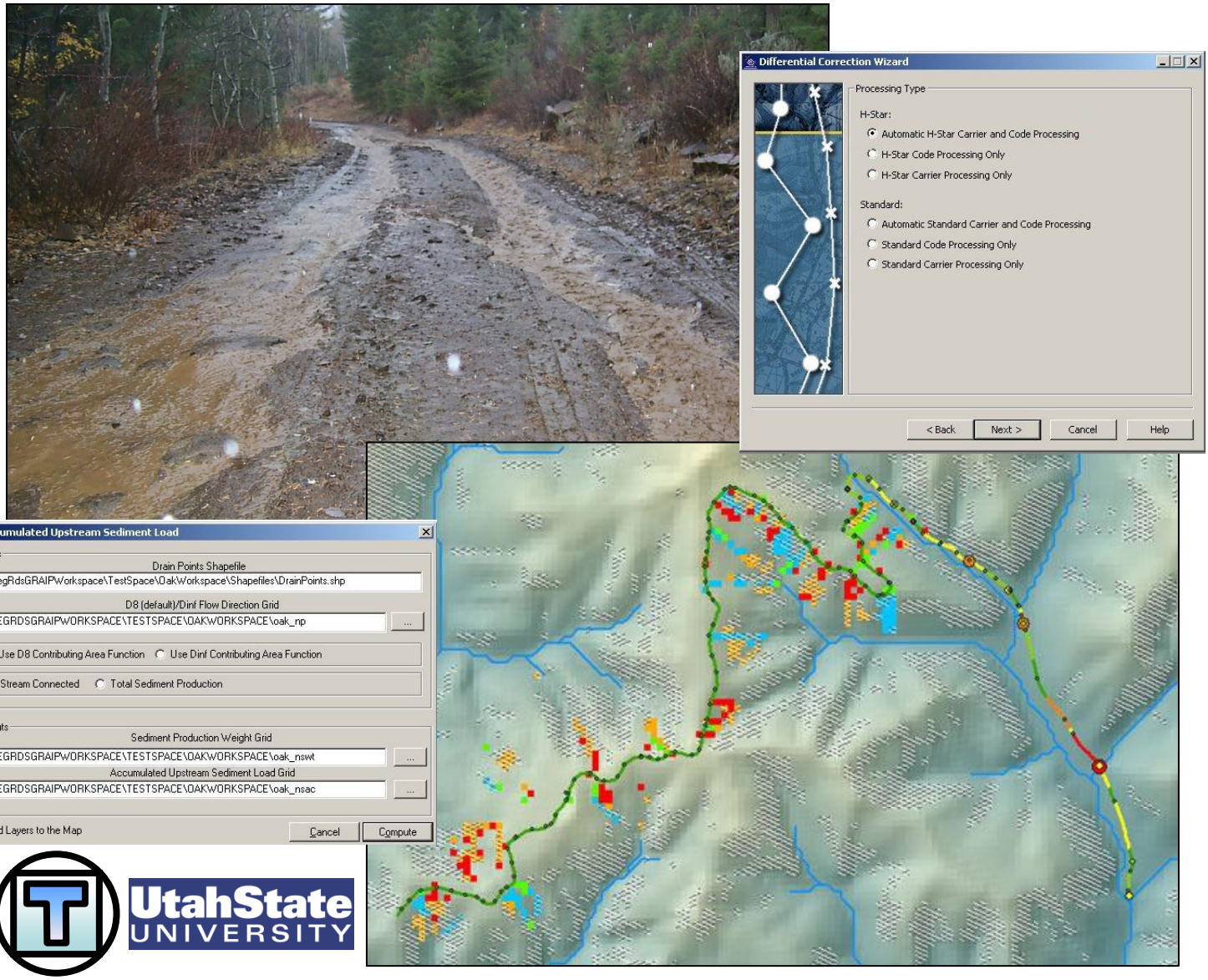
The Geomorphic Road Analysis and Inventory Package (GRAIP) Office Procedure Manual

Richard M. Cissel, Thomas A. Black, Kimberly A. T. Schreuders, Charles H. Luce, Ajay Prasad, Nathan A. Nelson, David G. Tarboton

2011 Edition



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INTRODUCTION: THE GRAIP METHOD

This introduction aims to describe, in a general sense, how this manual is organized and how to use it, what the steps to the data processing portion of a GRAIP study are, and how to keep the many files involved in this process organized. Specifically, this introduction will describe what software and ArcMap toolbars you will need to run the model, and what GIS skills are necessary to have before you begin the analysis. A section on ArcGIS 9 tips and tricks is also included.

This Manual

This manual is part of a set of documents that describe all steps of a GRAIP study, from collecting data in the field, to this office analysis manual, to a tutorial that will give you a better idea of how the model works.

The aim of this manual is to provide a set of fairly specific instructions for all parts of the office portion of a GRAIP analysis. It is organized in the order in which the steps are best completed and grouped in sections that contain steps towards a similar goal. There are three main sections in the manual, organized to reflect the three main steps of the office analysis, outlined below. Screen shots are included in order to reduce confusion.

The best approach is to read though all of the section and sub-section introductions in order to get a complete picture of how the process will progress before beginning the analysis. Read the entire sub-section before you begin, so you have an idea of the results and goals of that sub-section.

There are some conventions used in the manual that warrant explanation. Some terminology definitions are described in Appendix C. *Italics* indicate the title of an option in a menu or toolbar (e.g. *File* and *Road Surface Erosion Analysis*), a field in a window or column in an attribute table (e.g. *Drain Points Shapefile* and *SedProd*), or a button in a window inside ArcMap or an associated program (e.g. *Add* and *Compute*). An effort has been made to capitalize the same words that are capitalized in the various menus, titles, etc. involved in the process. The symbol -> is used to indicate a series of steps that do not need further explanation (e.g. click *This*-> click *That*-> navigate to file X-> click *Add*, etc.). Generally, a specific series of steps is only described in detail the first time because it is assumed that you will be following the steps consecutively. Figures are numbered and captioned only in the parts of the manual that are not step-by-step because the figures used to illustrate each step don't need further clarification. Finally, "dem" is used to represent the name of a generic DEM so that it is easier to refer to grid files based on the DEM with new extensions.

This update includes more details on running the model with certain calibrations (slope stability and gully risk), more details about how the model works (Appendix B), and some changes to the process to make certain steps easier, faster, or more accurate. Additionally, the function of the model has changed slightly to no longer include fish habitat patch information (this feature was time consuming, and its information could be

gleaned more easily from other sources). Fish passage barrier modeling is retained for optional use.

Road Inventories and the General GRAIP Method

An important first step in managing forest roads for improved water quality and aquatic habitat is the performance of an inventory (USDA Forest Service 1999). Methods for making a comprehensive inventory of forest roads and analysis of that inventory for watershed analysis are needed. The design of such methods must consider how roads affect the hydrology and water quality in forested watersheds (McCammon et al. 1998).

The hydrologic and geomorphic effects of forest roads are closely linked to the linear nature of roads. Roads have a tendency to capture water and discharge it in one location. They may also route water across topographic gradients, redistributing and concentrating the flow and thereby increasing the probability of landslides, gully formation and sediment transport below the road drains (Megahan and Ketcheson 1996, Flanagan et al. 1998, Montgomery 1994, Wemple et al. 1996, Luce and Wemple 2001). Beyond the rerouting of water, roads also directly contribute sediments eroded from their surfaces to water bodies (Washington Forest Practices Board 1995, Cline et al. 1984, Megahan 1974, MacDonald 1997, Luce and Black 1999). The fundamental considerations in the design of a road inventory and analysis procedure for assessing watershed related effects of roads should focus on the questions; 1) Where are runoff and sediment generated or intercepted by roads, and 2) Where do the water and sediment go?

The inventory and analysis methods detailed in this document were designed with these principles in mind. It is expected that the GPS and GIS will be the primary tools in the implementation of the inventory and analysis. Because there are errors in location information from GPS and in digital elevation models, some redundancies are built into the procedure to ensure that water movement is specified in the field.

There are two general scales at which to apply the GRAIP method. The preferred appraoch is to inventory an entire watershed at once, with the goals of determining where road problems are located, so that they can be fixed, and of determining how much extra sediment and mass wasting risk is associated with the road network in that watershed (e.g. Fly et al. 2010, Nelson et al. 2010B). The secondary way is to apply GRAIP on a small scale as a project monitoring tool. A road or set of roads is inventoried before and after a road treatment (such as decommissioning or water-bar installation) in order to determine the effectiveness of that treatment (e.g. Black et al. 2009, Nelson et al. 2010A). In this second method, untreated control roads that have similar properties to the treatment roads are also inventoried so that the effectiveness of the treatments can be gauged by re-inventorying all of the roads after a large storm event. Updated reports and more information can be found on the GRAIP website (http://www.fs.fed.us/GRAIP/index.shtml).

The primary goal of a road sediment inventory is to document the sources of sediment and how they interact with the road and are ultimately routed to the hillslope and stream network. It is useful to break the road drainage system up into three components. We examine the road prism and ditches as one component of the system,

where much of the water and sediment are generated. Points where the flow is diverted off of the road are examined as the second component to determine where they occur and how they function. The third component examines the type of surface and flow path where the water is discharged below the road drain point. Basic information about the hillslope flow path below the discharge point will allow us to make inferences about the sediment delivery to nearby streams.

This method is designed to quantify the rate of surface erosion related to overland flow of water. It can also be used to assess the risk of mass movement and gullying. The GRAIP inventory also provides an updated map of the extent of the road network and an inventory and condition map of road assets such as culvert pipes, water bars, gates, and road closures. It is possible to use this inventory opportunity to provide a first order assessment of fish passage potential at stream crossing culverts (Washington State Department of Fish and Wildlife 2000). Significant improvement in fish passage assessments may be achieved by application of a more thorough inventory and analysis procedure such as Fish Xing (Six Rivers Watershed Interactions Team 1999).

When a road inventory is conducted for watershed analysis, the road network will likely include multiple ownerships. The quality and extent of available data on roads may vary dramatically by ownership and region. Due to these limitations of data availability on forest roads and their hydrologic properties, we have chosen to utilize a GPS device to collect the location information on point and line features associated with the road network. Predictions of road sediment production are made for each road segment utilizing the information on road attributes, condition, length and slope. These predictions are made based on either locally collected sediment plot data for typical road segments (Luce and Black 1999, Luce and Black 2001) or values from comparable regions available in the literature (Megahan and Kidd 1972, Megahan 1974, Reid and Dunne 1984, Swift 1984, Bilby et al. 1989, Ziegler et al. 2001). An outline of a simple method for setting up local road erosion plots is available (Luce and Black 1999).

The road network is divided into road line segments, where the entirety of that road segment shares the same condition attributes. The data dictionary used in field data collection allows for a thorough documentation of the parameters of the road (Black et al. 2010). The attributes of the road line, such as the surface type and surface vegetation percent, are divided into classes in the appropriate menu. The road line is ended and a new segment begins when a new drain point is encountered, a grade reversal occurs, or one of the attributes changes from one class to the next. The road line describes three types of information; 1) on which part of the road is concentrated flow traveling (flow path, e.g. ditch location), 2) the drainage feature receiving discharge from that road segment, and 3) the physical condition of the road prism. At each road drainage feature, evidence is collected documenting the ultimate destination of the water as it encounters the hillslope. Each drain point is associated with the contributing road segments using the time stamp given when the drainage feature is opened.

Road inventories completed in this manner are a valuable tool for prioritization of road maintenance and watershed restoration efforts. They are probably one of the least expensive tools applied to the problem of road maintenance and restoration. Engineers from federal agencies and private forestland companies have eagerly used data collected with these methods for many projects.

The Steps

There are three main groups of steps in the data processing portion of a GRAIP study. Each group is organized in the three Sections, and can generally be completed on its own. First, the field data must be made into GIS shapefiles. The field data is imported into Pathfinder Office (discussed below), where it is differentially corrected to remove atmosphere-related GPS error, and then exported as GIS-ready shapefiles.

Next, the shapefiles and the DEM must be preprocessed for GRAIP. The DEM must be clipped to watershed boundaries, the DrainPoints and RoadLines shapefiles used by GRAIP for analysis must be created, and their errors corrected and road lines straightened.

Finally, the actual GRAIP analysis can begin. TauDEM and SINMAP are used to create a series of grids and shapefiles that are used by GRAIP. SINMAP is used to create a series of grids used both for the mass wasting analysis step and for comparison, so that the affect of the roads on slope stability can be assessed. There are three main groups of GRAIP functions in the analysis, found in the GRAIP toolbar. The first group calculates the sediment production, and its accumulation at drain points, as well as its delivery and accumulation in the streams. The second set of GRAIP functions analyzes the impact of the road drainage on terrain stability. A grid similar to that produced by SINMAP, but which takes the water from the roads into account and illustrates slope stability, is produced for comparison, as well an index number at each drain point that indicates the likelihood of gullying at that drain point. The last function analyzes the potential blockage of fish passage at stream crossings. There is more information about what exactly each step and series of steps does available in Appendix B.

Generally, a GRAIP analysis must be completed in the order presented in the GRIAP toolbar. However, certain steps of this process can be completed out of order. Also, there is an additional complication involving the *Combined Stability Index* step, which is presented and explained on the text. You may want to check the quality of the incoming field data daily or weekly, so that a field crew can return to fix any errors that cannot be resolved in the office. You may also want to get as much data ready for GRAIP analysis as possible, but not run the analysis because more data is being collected that will be added to the already collected data. The first thing you must do before anything else is turn the field data into shapefiles. From there, you can straighten the road lines directly or you can run the GRAIP Preprocessor and correct the errors you find, first. If you are conducting a watershed-wide study, it is recommended that the data be checked for errors and corrected frequently, so that any errors that are irreconcilable in the office can be re-visited by a field crew. You can also run TauDEM and SINMAP separately, after clipping and preparing the DEM. If you do this, make sure your file system doesn't change before the rest of the analysis is begun. It is a good idea to complete all of the GRAIP toolbar analysis steps at once.

Necessary Software and ArcMap Toolbars

A GRAIP analysis requires a number of software packages that are not included with the GRAIP download. You must be running Windows 2000 or newer to install a number of these packages. All pieces of software should be installed before GRAIP is installed. You will need ArcGIS 9.2 or 9.3 with the ArcInfo and Spatial Analysis licenses, Trimble GPS Pathfinder Office 4.0, TauDEM, SINMAP 2.0, Hawth's Tools, and finally the GRAIP Toolbar and GRAIP Preprocessor. The GRAIP set should be installed after everything else. Additionally, an internet connection is required for the first steps (Section I).

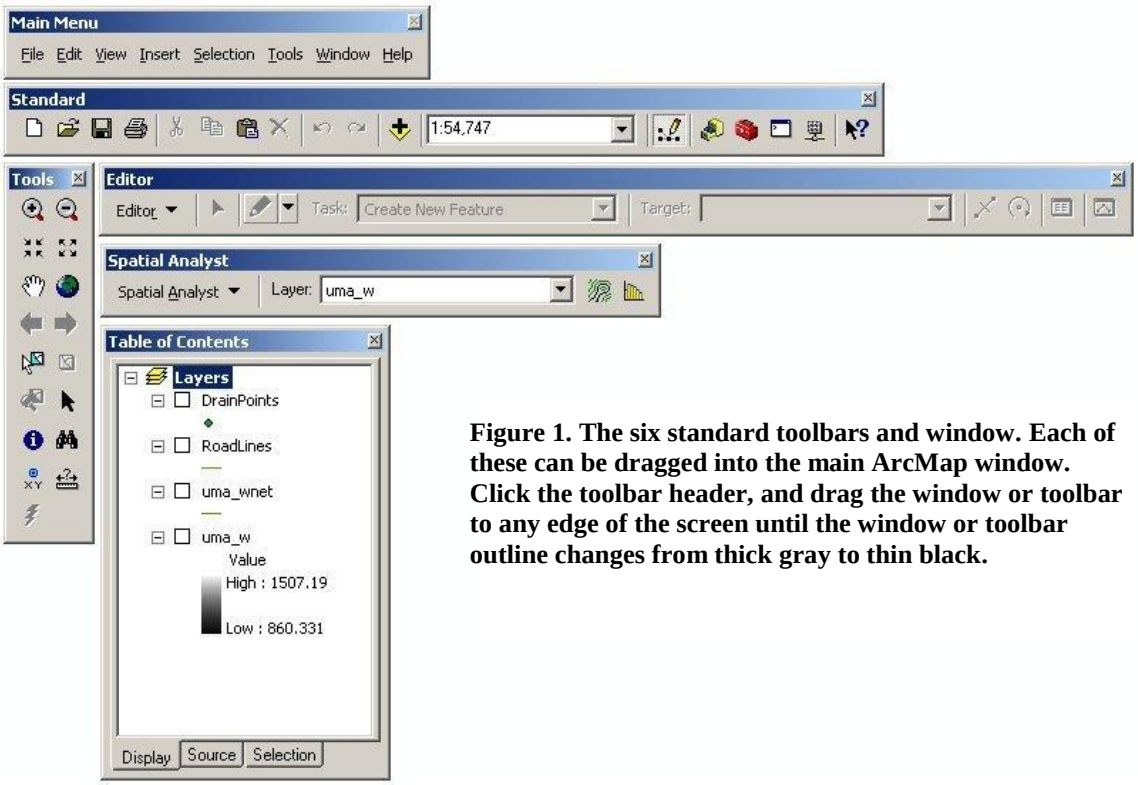


Figure 1. The six standard toolbars and window. Each of these can be dragged into the main ArcMap window. Click the toolbar header, and drag the window or toolbar to any edge of the screen until the window or toolbar outline changes from thick gray to thin black.

For more information about obtaining and installing ArcGIS, see the ESRI website (www.esri.com). For more information on obtaining and installing Pathfinder Office, see the Trimble website (www.trimble.com/pathfinderoffice.shtml). ArcGIS must be installed prior to installing the rest of the toolbars.

There are five toolbars and a window that are standard to ArcMap (Figure 1). It is good to be familiar with them. The *Main Menu* toolbar contains general ArcMap controls, like *Save* and open *ArcCatalog*. The *Standard* toolbar contains buttons that generally do the same things as some of the options in the *Main Menu*, but are more conveniently located. The *Tools* toolbar contains buttons that control the map's extent, feature selection, and some other similar controls, many of which are also under the *Main Menu*, too. The *Editor* toolbar contains tools used to create and edit points, lines, and polygons in shapefiles. The *Spatial Analyst* toolbar contains the Spatial Analysis tools, such as the *Surface Analysis* tools and *Raster Calculator…*. The *Table of Contents* window shows which layers are present in ArcMap, their symbology, their stacking order, and if they are visible or not, and allows you to change those aspects. You can see

what a tool is called by hovering the mouse pointer over the tool until the label shows up. The area of the ArcMap screen that displays the map data is referred to as the map viewer.

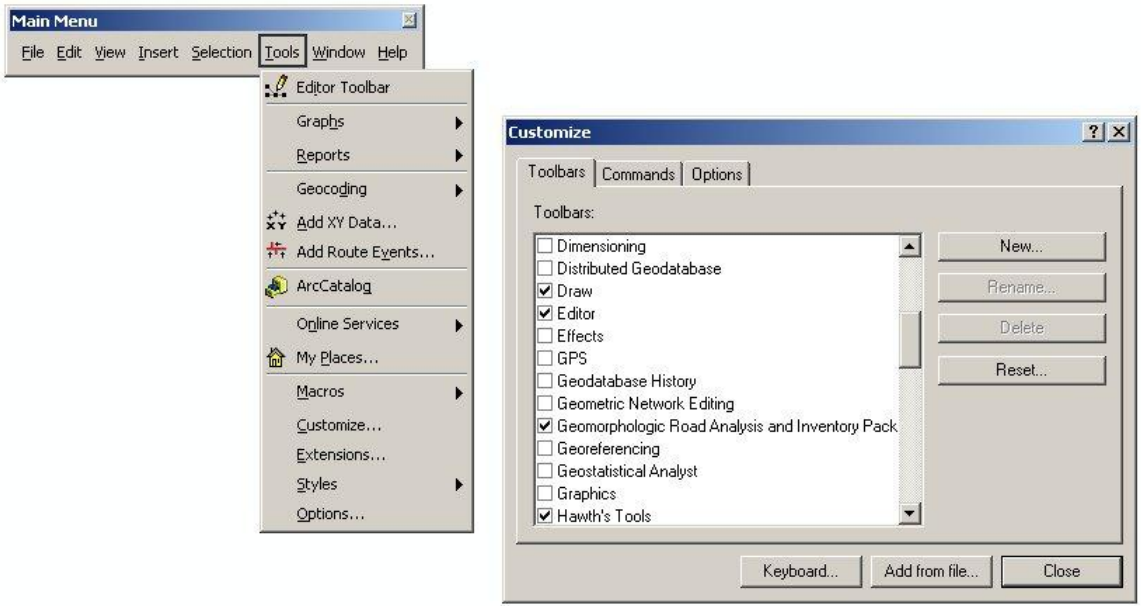


Figure 3. The Customize... window, used for changing which toolbars are displayed and which tools are present in each toolbar.

We recommend TauDEM 3.1, as newer versions may not be compatible with the other aspects of GRAIP. TauDEM 3.1 can be obtained from its website (http://hydrology.usu.edu/taudem/taudem3.1/index.html). Additional information and installation instructions are available there. Download the appropriate files and open the installation executable (extension .exe). Follow the on-screen instructions. Then, in the ArcMap Main Menu-> *Tools*-> *Customize…*-> click on *Add from file…*-> navigate to the location of the installation and click on agtaudem.dll-> click *Open*-> click *OK to added objects*-> scroll to *Terrain Analysis using digital elevation models (TauDEM)* under the *Toolbars* tab and check its box if it isn't already checked-> click *Close* in the *Customize* window (Figure 3). The TauDEM toolbar should now be present in ArcMap (Figure 2). You should only have to do this once (i.e. when you open ArcMap again, the TauDEM toolbar should still be in the window. Other versions can be found at http://hydrology.usu.edu/taudem/versions.html.

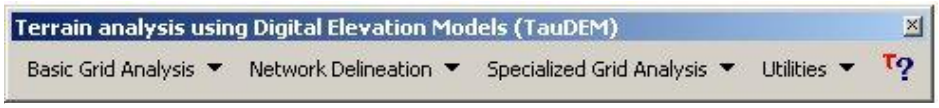


Figure 2. The TauDEM toolbar.

Installing the remaining toolbars is similar. For SINMAP 2.0 (Figure 4), go to its website (hydrology.neng.usu.edu/sinmap2). There is substantial documentation on the website, if you desire to learn more. Download the appropriate file (SINMAP 2.0 setup.exe) and open the file. Follow the installation instructions. In the ArcMap Main Menu, do as before. From the *Customize* window, add the file

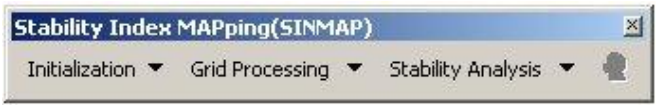


Figure 4. The SINMAP toolbar.

agSINMAP.dll, and check the box next to *Stability Index MAPing(SINMAP)*.

For Hawth's Tools (Figure 5), go to its website (www.spatialecology.com/htools/download.php). Hawth's Tools are now out of date and replaced with Geospatial Modeling Environment, however Hawth's is still available. The Tools work best with ArcGIS 9.3. There is additional information about the Tools on the website. Download and unzip the appropriate file. Open htools_setup.exe and follow the instructions. From the *Customize* window, add the file HawthsTools3.dll and check the box next to *Hawth's Tools*.

Figure 5. The Hawth's Tools toolbar.

For the GRAIP Toolbar and Preprocessor (Figure 6), go to the program website (www.neng.usu.edu/cee/faculty/dtarb/graip/) and download the appropriate files for the current version. Open GRAIPSetup.exe and follow the on-screen instructions. From the *Customize* menu, add the file agGRAIP.dll, and check to box next to *Geomorphic Road Analysis and Inventory Package(GRAIP)*. Additional information and updates can also be found at the main GRAIP website (http://www.fs.fed.us/GRAIP/index.shtml).

Figure 7. The GRAIP toolbar.

The GRAIP Preprocessor and the tutorial package are also installed in the same directory as the rest of the GRAIP package. Additionally, the binary libraries consolidateShp.dll and graipCOMDLL.dll are installed. These files and agGRAIP.dll make up the Preprocessor and Toolbar. The GRAIP database template, GRAIP.mdb, is also installed for use by the Preprocessor. The version of GRAIP.mdb that is included with the GRAIP download above is compatible with the data dictionary (which is what is used for field data collection) INVENT 4.2. The latest (at time of writing) data dictionary is INVENT 5.0, which is available at the Forest Service GRAIP website (http://www.fs.fed.us/GRAIP/downloads.shtml), along with updated versions of GRAIP.mdb. The tutorial folder contains the tutorial manual and a zipped data file that contains the "demo" folder which contains all of the tutorial data (the DEM called dem, and a shapefiles folder that contains BBdip.shp, Diffuse.shp, Ditchrel.shp, Lead_off.shp, ned.shp, Str_Xing.shp, sump.shp, waterbar.shp, and road.shp). In order to follow the tutorial, you need the tutorial files. Unzip them to a good working directory. A shortcut to the

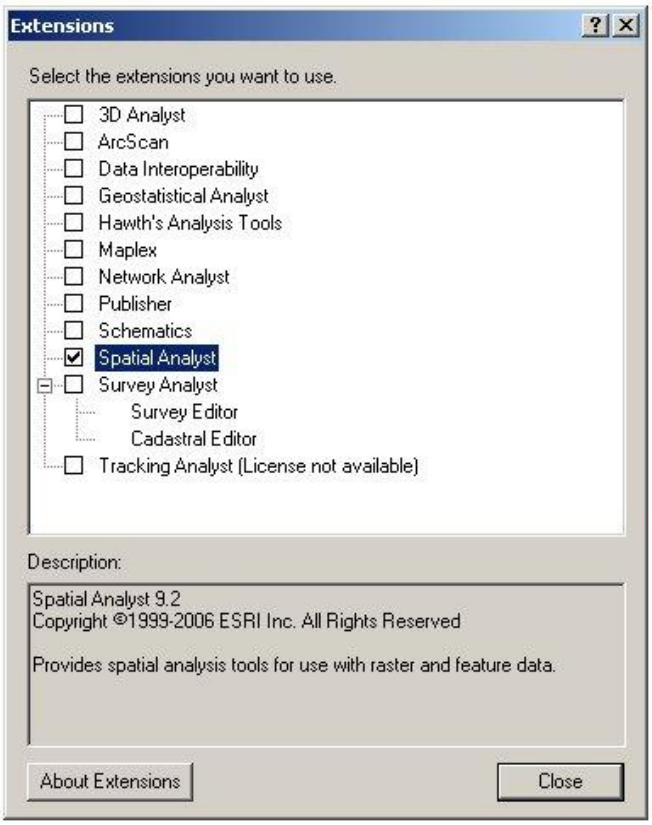


Figure 6. The *Extensions* window. The *Spatial Analyst* extension is highlighted.

GRAIP Preprocessor is installed in the Windows *Start* menu.

The ArcGIS *Spatial Analyst* extension must be unlocked so that GRAIP can use certain features (Figure 7). From the ArcMap Main Menu, *Tools*-> *Extensions*-> check the box next to *Spatial Analyst*-> click *Close*. If the Editor and Spatial Analyst toolbars are not present in the ArcMap window, check the boxes next to them in the *Toolbars* tab of the *Customize* window from above.

Necessary GIS Skills

It is helpful to have basic GIS skills before you use the GRAIP tools, but not necessary. This manual assumes a novice GIS skill level so that more people will be able to use it. Most basic processes are explained in enough detail so that someone who has never done that process before will be able to without trouble. It is best to at least know the general layout of ArcMap and ArcCatalog, and have a reasonably high level of computer literacy. It is helpful to be comfortable with defining and changing projections, using the Editor toolbar to edit shapefiles and their tables, and changing the symbology of layers in ArcMap. Also, it is good to be comfortable with using the tools in ArcToolbox, and moving and making copies of layers, and creating new workspaces in ArcCatalog.

Organizing Your Files

File organization is an important component of any GIS task, and a GRAIP analysis is no exception. There are multiple stages of the same basic data, and many files are created and modified during the process. Many of the files are very large, often resulting in very large workspaces. Even if you have multiple sets of roads in the same watershed (as you might if you are comparing a set of roads before and after they are worked on), you will want each set of data to have its own unique set of DEMs and other rasters (such as the TauDEM- and SINMAP-created files). It is recommended that you have a file system established before you begin analysis.

Some guidelines are useful when creating your file system. First, whenever you want to create a new workspace, or move or copy a GIS file (shapefiles, grids), use ArcCatalog. This is much simpler and more reliable than the same tasks in Windows. You won't have to find all of the separate files that go into making one shapefile or grid. Second, do all of your work in ArcInfo Workspaces instead of regular folders. These can be created in ArcCatalog by right-clicking in the directory in which you want to create the workspace and choosing *New*-> *ArcInfo Workspace* (Figure 8). Keep in mind that you will have a hard time finding old data if you do not name everything clearly and consistently. Include a text file with your naming scheme and file system in the main workspace if you intend to store the data for long periods. Thirdly, as suggested above, create all of the necessary workspaces and structure before you begin analysis. This can reduce confusion later. It helps to write down all of the file paths in the file system for reference so you don't have questions about what should have gone where. Fourthly, do

not put your files and workspaces directly on the C drive. Finally, TauDEM, SINMAP, and GRAIP all require that there are no spaces in any file paths that they need to use, and that all files that they use directly (shapefiles, grids) have no more than eight characters (your workspaces can have long names, but no spaces). The DrainPoints and RoadLines shapefiles are exceptions to this rule. Generally, if you are renaming a shapefile or grid, do not allow the name to have more than eight characters. It is recommended that you complete the metadata for your final grids and shapefiles for documentation purposes.

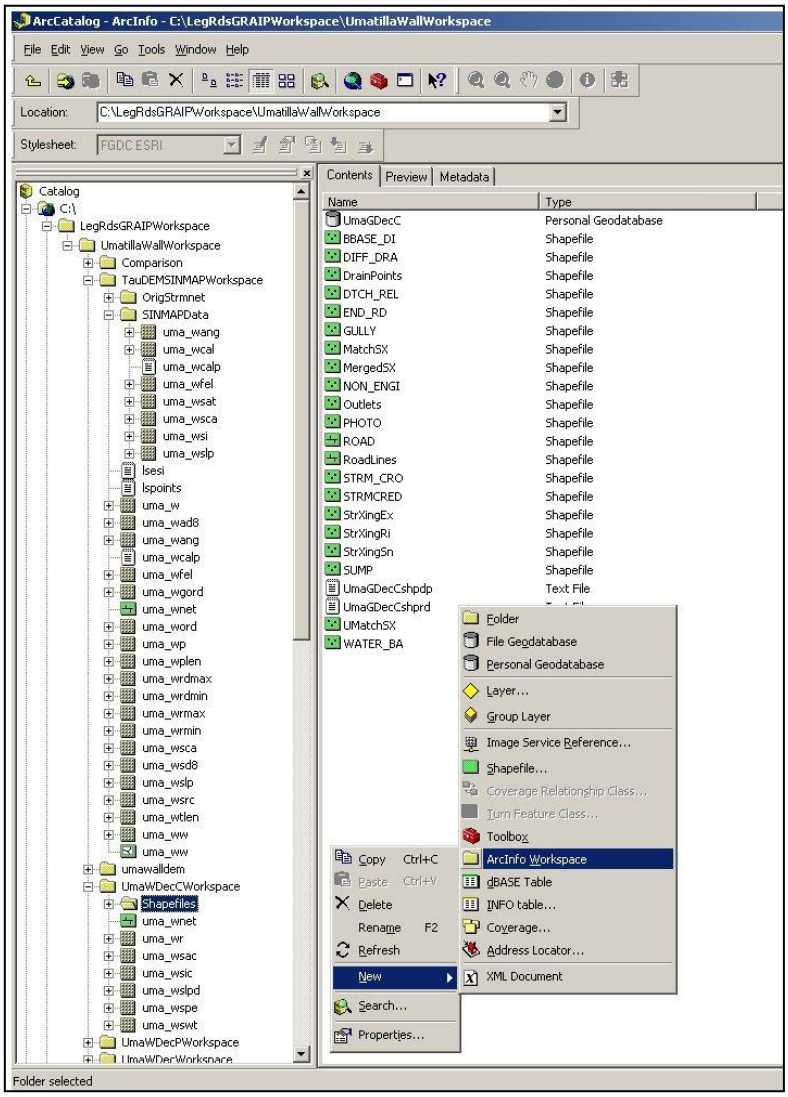


Figure 8. A completed GRAIP project and its file system. The DEM is called uma_w, and the other grids were created by TauDEM, SINMAP, or GRAIP. Also shown is the path to create a new ArcInfo Workspace.

Each basic file system should have a working workspace that contains only and all of the files that apply to that particular site or area. In this workspace, you should have a copy of the DEM you are using, as you plan on using it (clipped, with the correct projection; see Section II) in its own workspace. Also under the working workspace, there should be a workspace for the shapefiles, as well as the files created by the GRAIP Preprocessor. TauDEM will save its files to the DEM's workspace, and SINMAP will create its SINMAPData folder there. During the GRAIP process, there are some grid files that are created. Their default saving locations (to the DEM's workspace) should be okay. An example file system can be found in Appendix A.

There are other systems possible, some of them probably simpler. The important part is that you understand your system. It is worth noting that, often in the GRAIP process, a file will be created that is used later in the process. If you move the location that the file is saved to, GRAIP will remember that as the default location for that file as long as that GRAIP file remains open. If you close and re-open ArcMap or otherwise have to re-open the GRAIP file, you will have to manually locate those files which were saved elsewhere than default. This applies to renamed files, too. Finally, if you are sharing this data with other people, it is easiest to export the GRAIP files (DrainPoints, RoadLines, demnet) as layer files so that the person on the receiving end does not need to use your file system or even have GRAIP installed.

Tips and Tricks for ArcGIS 9

ArcGIS is a large and complicated set of programs. Tools don't always work the way they should, or they may not work with your specific dataset for some reason. ArcMap and its toolbars can crash. Some small detail within the data can be wrong or corrupted, and the data won't work with the tools you need.

GIS help and training is abundant, and usually very useful. There is a desktop help that comes with ArcGIS. Go to the ArcMap Main Menu-> *Help*-> *ArcGIS Desktop Help*. ESRI has an extensive online help section, accessible from the *Help* menu or via the ESRI website (www.esri.com). The ESRI website also has some training options. Here are some tips and tricks for using GIS in general, as well as a couple of specific examples that apply to a GRAIP study. Remember, patience is a virtue!

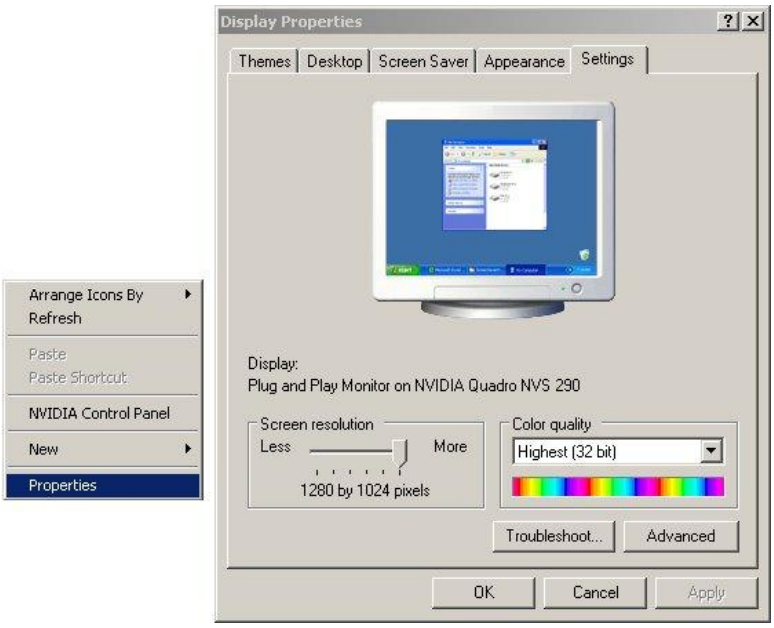


Figure 9. The *Display Properties* window on a Windows XP machine.

First, there are some usability tricks. The GRAIP process uses a lot of toolbars that you will probably want to display all at once. If your screen resolution is too low, you might have to move toolbars around to make the most efficient use of your screen space at any one time. To increase the screen resolution, go to the computer desktop-> right-click-> *Properties*-> *Settings* tab-> *Screen area* field-> slide the bar over towards *More*-> click *Apply*-> click *OK*-> click *OK* (Figure 9). This process is slightly different from computer to computer, depending on the operating system, etc.

The individual tools that are available in the *Standard* toolbar and *Tools* toolbar are customizable (Figure 10). In order to customize which tools are displayed, go to the ArcMap Main Menu-> *Tools*-> *Customize…*-> *Commands* tab. From here, you can navigate through the *Categories* and drag the *Commands* you want to the appropriate toolbar. Some useful commands, where the underlined commands are not in

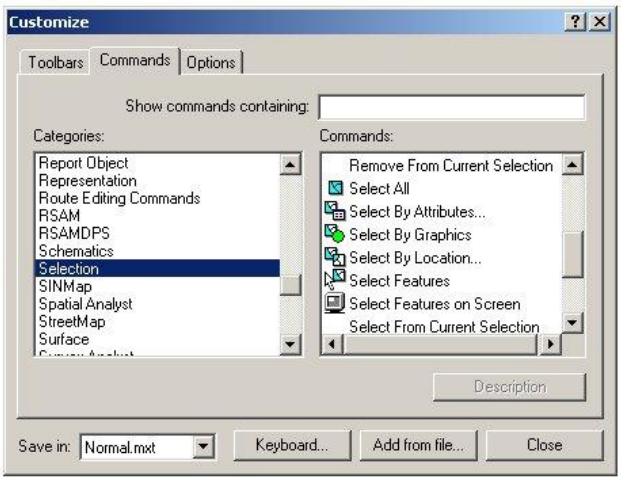


Figure 10. The *Commands* tab of the *Customize...* window. Some useful tools are displayed under the *Selection* category.

the toolbars by default, are, Zoom In/Out, Fixed Zoom In/Out, Pan, Zoom Full Extent, Go To Previous/Next Extent, Clear Selected Features, Pan To Selected Features, Zoom To Selected Features, Identify, and Measure in the *Tools* toolbar, and New Map File, Open, Save, Delete, Add Data, ArcCatalog, ArcToolbox, and Add Image Service (for Forest Service users; available online at http://fsweb.rsac.fs.fed.us/imageserver/imageserver.html) in the *Standard* toolbar.

There are times when there is a certain sub-full extent is useful to be able to return to, such as if you have a regional background image displayed, and you want to zoom to the relatively small watershed you are working in. You can create an extent bookmark. Go to the ArcMap Main Menu-> *View*-> *Bookmarks*-> *Create…*-> type a name-> click *OK*. To use the bookmark, go to *View*-> *Bookmarks*-> click on the bookmark name. In ArcCatalog, you may need to refresh a window before the modifications you have made in ArcMap (such as the creation of new shapefiles) show up. Right-click in the directory-> *Refresh*.

One of the most important things you can do is save your work often. However, you do not usually need to save the map file, because changes made to individual shapefiles and their tables are made directly to those. If you are editing a shapefile, save the edits in the Editor toolbar frequently (Editor-> *Editor* drop-down-> *Save Edits*). When you create a new shapefile or grid, it is saved on the hard drive. On a related and more important note, back up your data at least once daily. The back-up file system should be the same as the working file system.

Data projections are sometimes tricky. It is important to have all of the data in the same projection, whether or not that projection is defined. If the data was exported to shapefiles in the wrong projection, it will likely not be registered correctly with the DEM or background image, and you will have to re-project it into the correct projection (see Section II). If the DEM is in the wrong projection, you may re-project it, but make sure to use the correct technique (see Section II). ArcMap attempts to "project on the fly," where the first layer added to the map file defines the projection for everything else that is added, but only if what is added does not have a defined projection. When you open a new map file, the projection of the viewer is reset. Whenever you change or define the projection of a shapefile or grid, open a new map file and re-add those layers. Open a new map file whenever you change the dataset you are working with (as opposed to removing the layers in the map and adding new layers). You will probably encounter messages about data you are adding or editing being in the wrong projection, or not having a defined projection. Usually, you can ignore those. If you encounter another problem and you have encountered one of those messages in regards to a layer you are working with, the projection/ projection definition is the first thing you should check and fix. To check this, right-click in the layer name in the *Table of Contents* in ArcMap-> click *Layer Properties* to open the *Layer Properties* window for the layer-> *Source* tab-> scroll down to *Spatial Reference*, expanding the line if necessary.

If you encounter a problem with a tool in ArcMap or a toolbar, try it again. If it still does not work, close ArcMap, delete any file it might have started to create in ArcCatalog (this will look like whatever file the tool was supposed to create), and re-open ArcMap. Try it again. If the same problem occurs, delete any file the tool may have started to create, close all programs, restart the computer, and try it without ArcCatalog open. If the problem persists, there is some conflict with the tool and your data, with the

tool and ArcGIS, etc. Seek additional help. If you look in the desktop help or online, look up the tool to see if it has any special requirements that are not met by the input data (e.g. the tool might require all projections to be defined). If ArcCatalog is open, make sure that the directory that is displayed is not the same directory you are working under in ArcMap, or things will get confused. Often, it is best to not have ArcCatalog open at all when working in ArcMap.

Restarting ArcMap works at least half the time. In fact, it is a good idea to restart the ArcGIS components on a regular basis as a preventative measure. Keep in mind that, if you restart in the middle of the GRAIP process, and the grids are being saved to a non-default location or have non-default names, GRAIP won't remember, and you will have to specify the name/location of a particular file yourself. As you go along with multiple data sets, you might find that there are certain errors that repeat themselves, either because there is a common problem with the data, or a problem with the tool (or how the tool relates to the your data type, etc.). Note what the solution to these problems are, and repeat that each time. If you locate a problem with GRAIP, please email Tom Black at tblack@fs.fed.us. We will attempt to aid in finding a solution and will add it to our FAQ.

The first example of an error occurred with the *Combined Stability Index* function in the GRAIP toolbar (see Section III). This function uses some inputs that were created with SINMAP, and outputs a grid file. All inputs would be correctly specified and located, but when the function was executed, it would come back with an error. Re-opening ArcMap and restarting the computer did not help. There was no partial file created. However, the DEM that was used had been re-projected incorrectly, and so an error was generated before the output grid file was even created. The solution was to go back to the original DEM (before the re-projection), which had been saved, and re-project it using the correct method, and then re-run the GRAIP Preprocessor and all of the GRAIP toolbar functions to that point (see Sections II and III). This is a good example of a user-caused error, and one that is all too easy to do.

The second example of an error occurred in SINMAP, during the final step. This happened with the same incorrectly re-projected DEM as above. SINMAP needs to be run all in the same session. The error occurred when *Compute All Steps* under the *Stability Analysis* menu in the SINMAP toolbar was initiated. ArcMap would freeze, and a Windows *End Task* dialog would appear. The initial solution was to click *End Task*, go into ArcCatalog and delete all of the already-created grids (in previous SINMAP steps), and then re-run all of the SINMAP functions. This happened twice before SINMAP fully worked. However, this was not a very good solution. The errors in the DEM that were generated by the incorrect re-projection were the cause of this error, and the series of restarts and deletes were only good luck. A better solution was to do the same as above—correctly re-project the original DEM. This better solution was not discovered until the first error example had happened, and the correctly projected DEM got through SINMAP without any errors.

That last example illustrates that a solution such as closing and re-opening ArcMap is often just a Band-Aid for some other problem that has a better solution. However, it is often difficult to pin-point that other problem, so finding the better solution is impractical. The Band-Aid restart is usually good enough. If that is the solution you pursue, you should pay extra careful attention to the output data from that point forward

to ensure that all of the data makes sense and no unforeseen errors or inaccuracies have occurred.

SECTION I: FROM FIELD DATA TO GIS SHAPEFILES

This section describes the first step in a GRAIP study; changing the data from the format used by the GPS systems in the field to the format used by ArcGIS. The data must first be brought into Pathfinder Office with the correct format. Next, a differential correction is performed using downloaded base station data in order to remove data points that have very low precision (an internet connection is required for this step). Finally, the differentially corrected files must be exported into their final format, which is the GIS shapefile. These instructions are for Pathfinder Office 4.0. Other versions may be different in some respects.

Transferring Field Data into Pathfinder Office

Data is collected in the field with the Trimble TerraSync software. Data is saved as a set of eight or nine files with the extensions .car, .dd, .gic, .gip, .gis, .giw, .gix, .obs, and .obx (the file with extension .car does not exist if there are eight files; Figure 11). The default naming theme that TerraSync uses includes the date and time that the file was created (for example, R071215A was created on 7/12 at 3 pm). An example of a TerraSync file might be R071215A.gic. In order for these files to be usable in Pathfinder Office, their format must be changed to the SSF (file extension .ssf) from that set of files. This is accomplished by transferring the data into Pathfinder Office.

There are a number of devices that can be used for field data collection, from laptops to small handheld field PCs. The methods for retrieving data from each of these devices are different, and so are not explained here. It is assumed that all of the data is accessible from the computer you are using. You will need all eight or nine TerraSync files, depending on how many are created by default with your particular field data collection device.

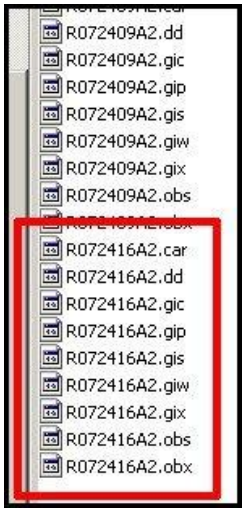


Figure 11. All nine possible TerraSync files.

It is important to keep the raw data and Pathfinder Office files organized so you know where to look in the future. You should keep these data in a folder separate from the ArcGIS workspace, and, if you have multiple sites, or will have multiple sites sometime in the future, each site should get its own sub-folder (a site might be all roads in a watershed, or the roads in a road decommissioning study before they have been worked on, with a second site for after they have been worked on). You should keep a log of every TerraSync file and what part of which road each file contains.

1. Move or copy all of the relevant raw data into whichever folder your want to use.

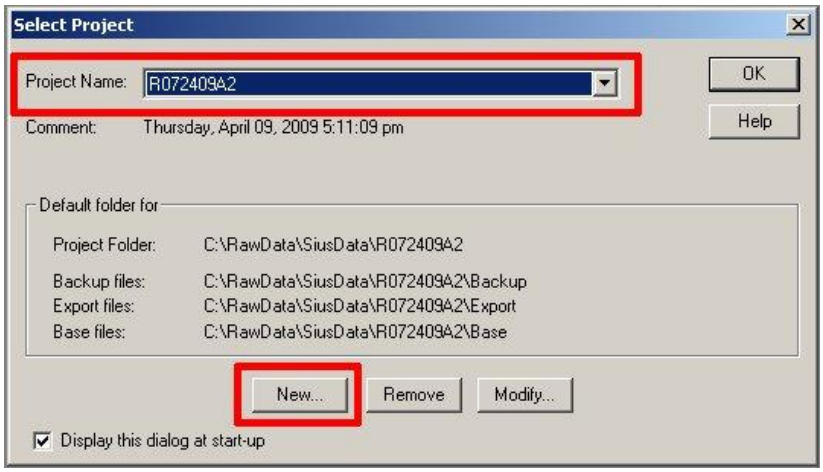
a. Relevant data are all eight or nine TerraSync files for each file name (R071215A.gic, R071215A.dd, etc.).

b. Keep the raw data separate from the GIS workspace.

2. Open Pathfinder Office.

a. Go to the Windows *Start* menu-> *Programs-> GPS Pathfinder Office (version number)-*> click on *GPS Pathfinder Office* to open.

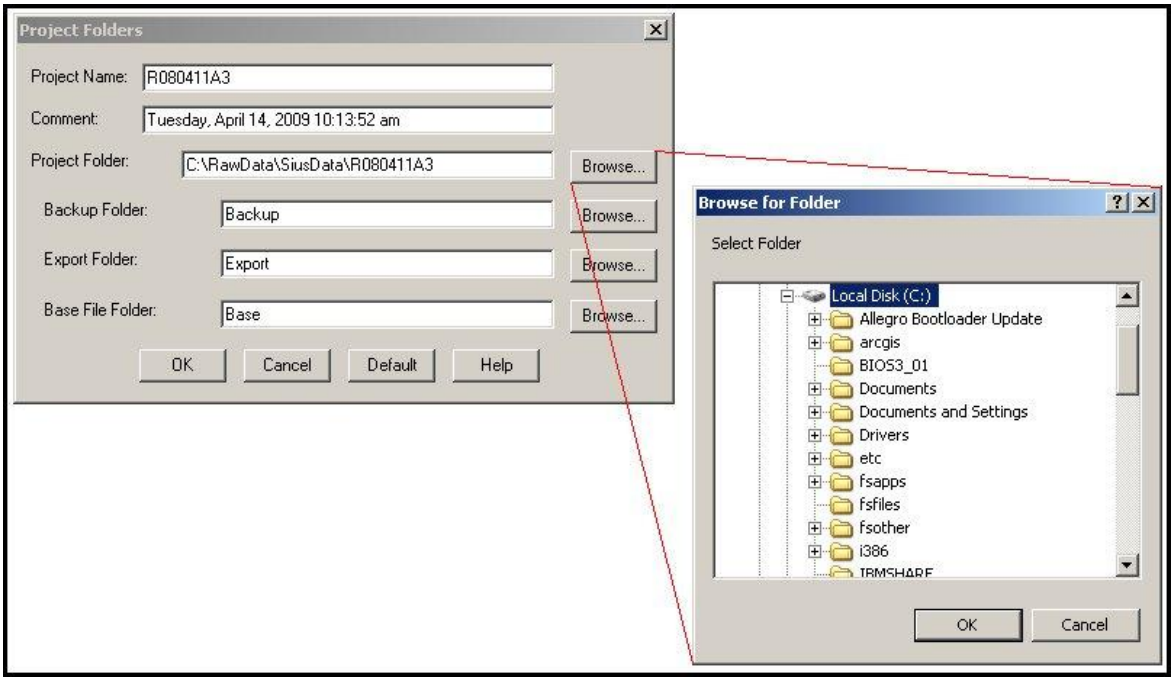
3. Select the project folder. This is the place where all of the files that Pathfinder Office creates will be saved.



a. If the *Select Project* window does not automatically open, go to *File-> Projects*….

b. If you are working with an already created project, use the *Project Name* drop-down menu to select it and click *OK*. Skip ahead to step 4.

c. If you do not have a folder set up for the current project, you must set one up now. Go to *New*….



i. Next to the *Project Folder* field click *Browse…*-> navigate to the location of the raw data files-> click on the folder that contains those files-> click *OK*.

ii. The *Backup Folder*, *Export Folder*, and *Base File Folder* are subfolders automatically created in the project folder. Check to make sure they will be created in the same place by clicking *Browse…* next to one of those fields.

iii. In the *Project Name* field, enter a name that makes it clear which folder is referenced.

iv. Click *OK* to create the project folder.

– Click *Yes* if the error message that says, "Folder already exists; Do you want to continue?" pops up.

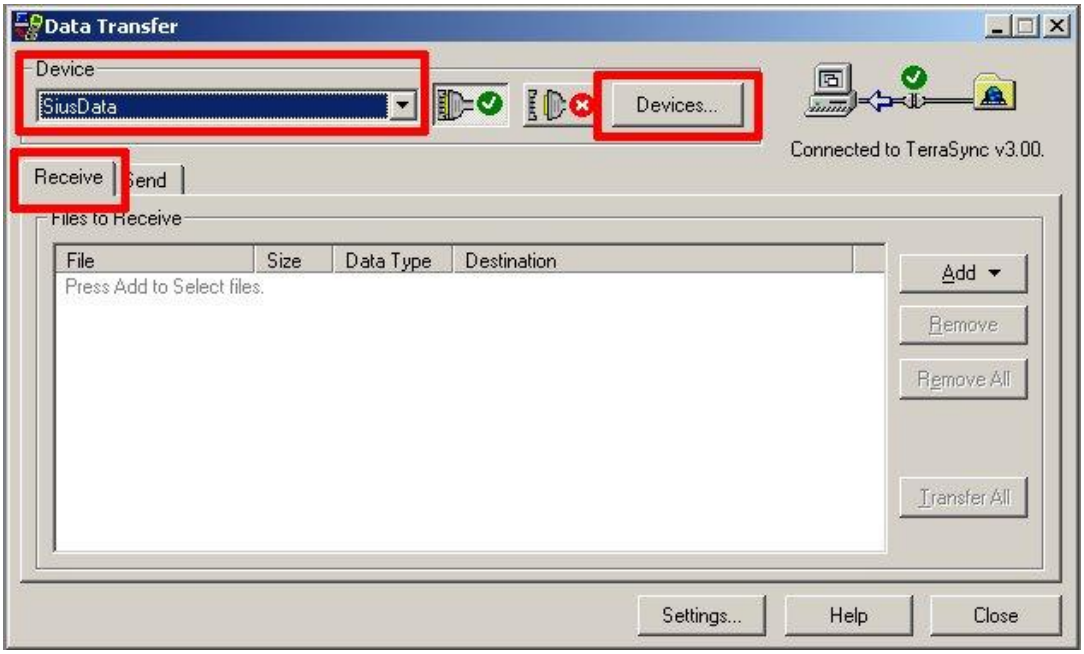
d. Click *OK* to select the new project.

4. Go to the main menu-> *Utilities*-> *Data Transfer…*

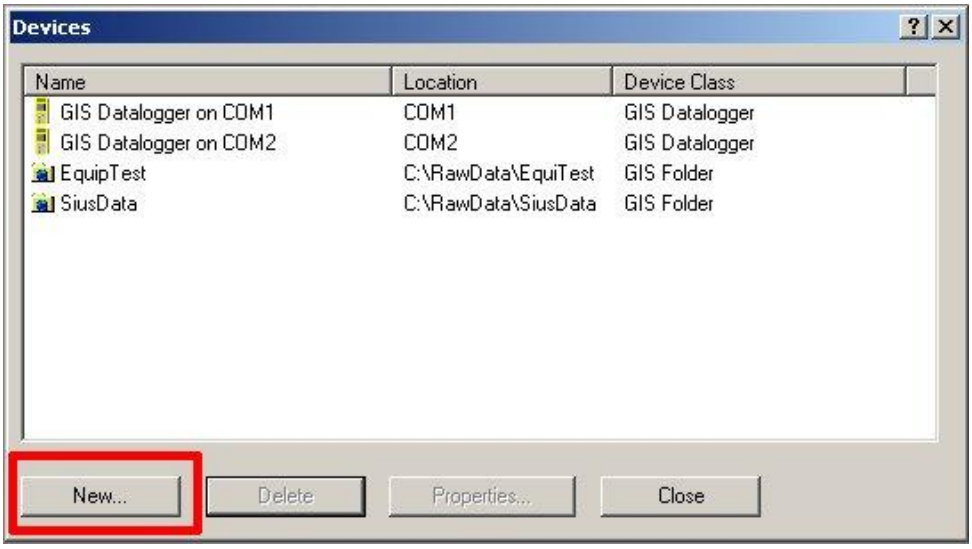
a. Pathfinder Office is set up to talk directly to whatever device you use to collect field data, but we do not want to do this. Instead, we want to use data already on the hard drive of the computer. These methods are un-intuitive because of this.

b. Ensure that the *Receive* tab is selected.

c. If you already have the relevant folder connected, click on the *Device* drop-down to select it and skip to step d. If you do not already have the relevant folder connected, you will need to connect it. Click *Devices…*



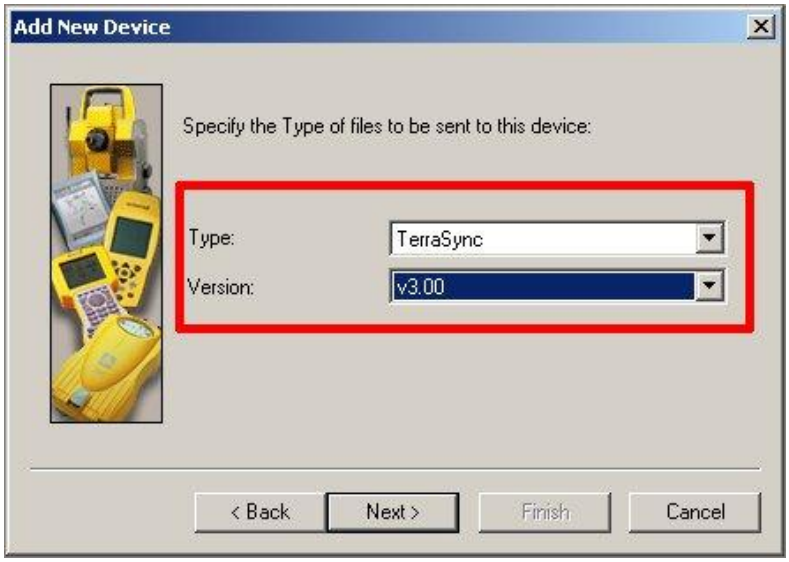
i. Click *New….*



ii. Select *GIS Folder* as the type of device you wish to create-> click *OK*.

iii. Click *Browse…* to navigate to and select the *Project Folder* (created above)-> click *Next*.

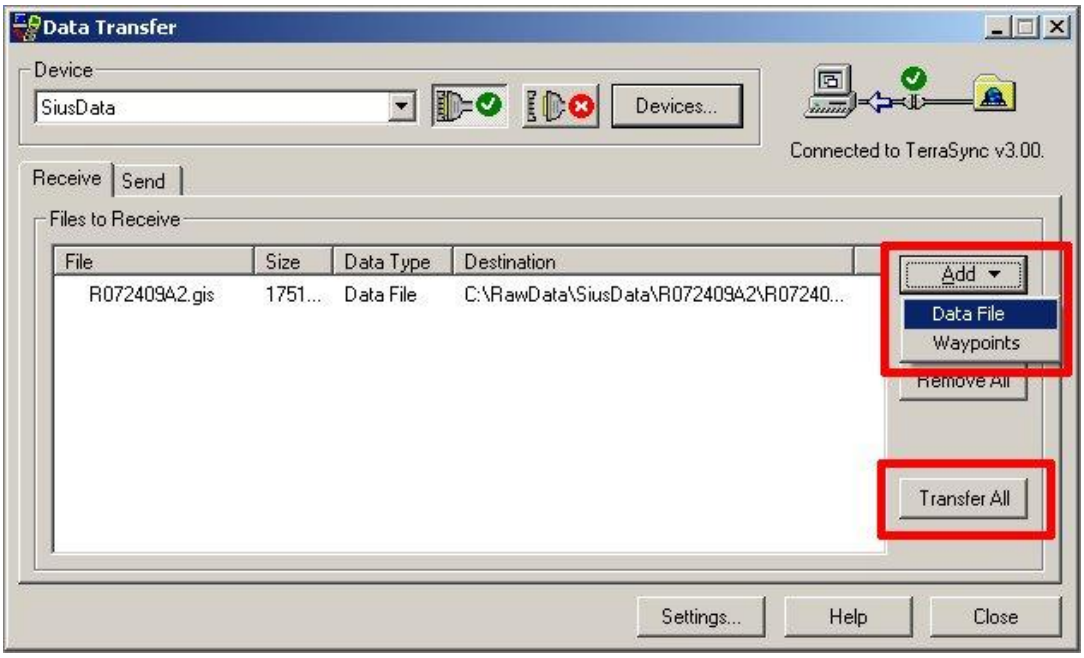
iv. Use the drop-down menu next to *Type* to select *TerraSync*, and then select the *Version* closest to that used in the field-> click *Next*.



v. Give the device a short name (under nine characters) in the *Name* field-> click *Finish*. Click *Close* to close the *Devices* window.

d. Click the *Add* drop-down in the *Data Transfer* window-> wait for Pathfinder to connect to the device folder if necessary-> click *Data File*. Select the relevant data files (only those with a .gis extension show up)-> click *Open*. Those files are added to the *Files to Receive* field.

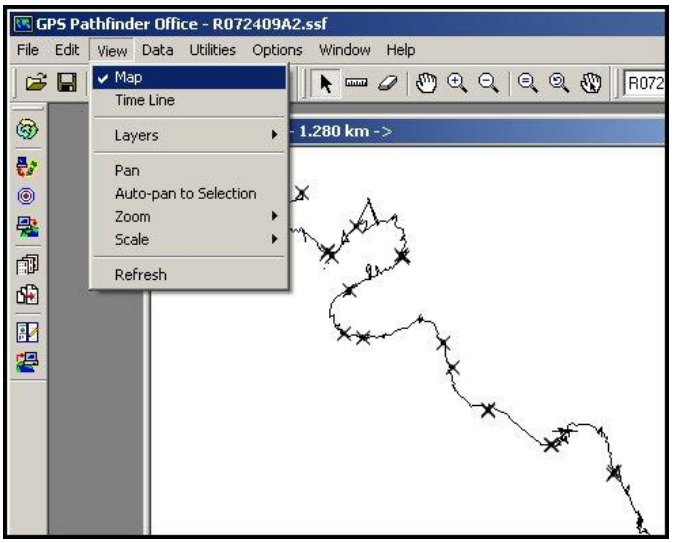
e. Click *Transfer All*.



f. The *Transfer Completed* dialog appears. This dialog will tell you if the transfer(s) was/were successful. You should check on the location of the transferred files by clicking *More Details…*to access the log file and looking at each file path. The files should be transferred to the same directory as the raw data files. The format is converted to SSF (extension .ssf). There is a backup of the SSF file saved to the *Backup* folder in the project folder by default. Click *Close* when satisfied. Click *Close* to close the *Data Transfer* window.

5. View the data to ensure that it is what you want.

a. From the main menu, go to *View-> Map*. If necessary, select the SSF file(s) that you just created-> click *OK*.



Differential Correction

GPS data contains many small errors due to factors associated with the satellite, such as its orbit being slightly off or interference from the atmosphere. Most errors of this type can be eliminated by performing a differential correction after the data has been collected (Figure 12). Differential correction uses data downloaded from a nearby base station to move and delete GPS points in error by comparing points from your data to the base station data. In this way, accuracy is improved.

Not every error can be removed by differential correction (Figure 12). Many, if not most, errors that show up as zigzags in the road line will remain, and must be corrected by hand, as discussed later. If all of the positions that make up a feature (e.g. a road line) are uncorrectable, then the differential correction will remove the feature. There are some steps to take that ensure that this will not occur, and these are discussed below.

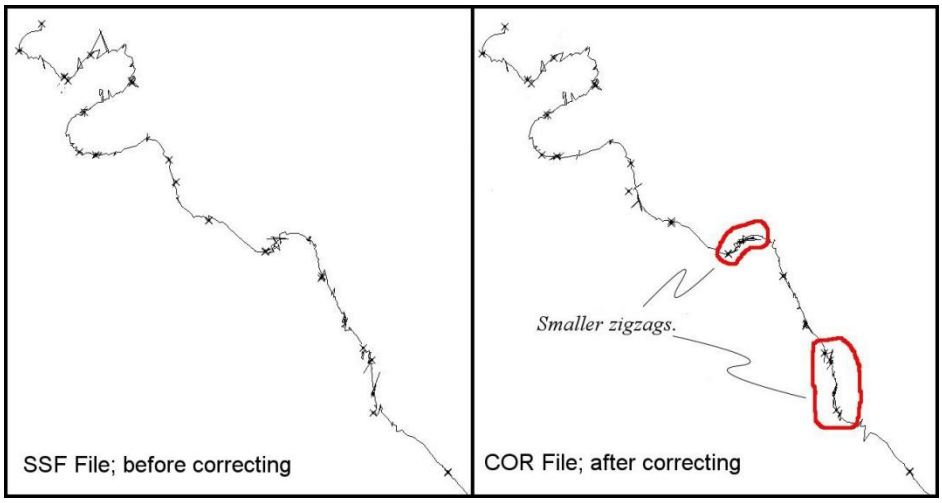
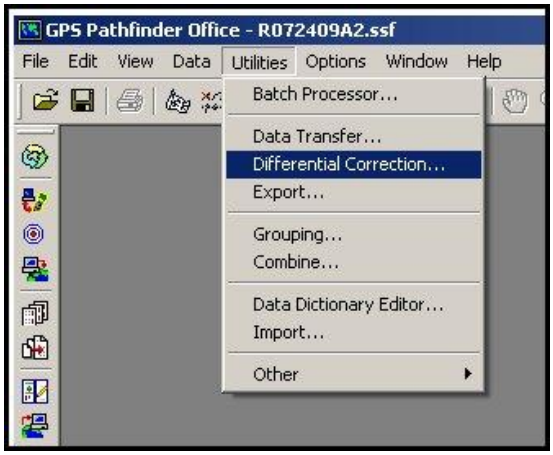


Figure 12. A section of road before (right) and after (left) differential correction. Areas where the differential correction changed the road line are noted.

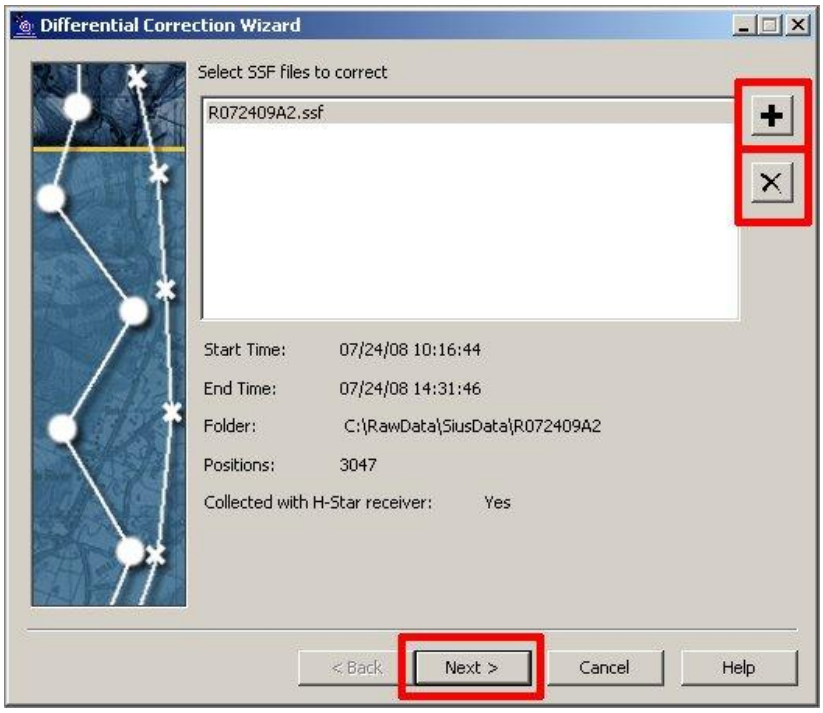
An internet connection is required for this step in order to use the most up-to-date base station data.

1. With the same project folder open as above, got to *Utilities-> Differential Correction….*



2. The *Differential Correction* wizard appears.

a. If the correct files do not appear in the *Select SSF files to correct* field, click the plus sign-> navigate to and select the relevant files-> click *Open*. If the incorrect files appear, in the *Select SSF files to correct* field, select them and click the X below the plus to remove them. Click *Next* when finished.

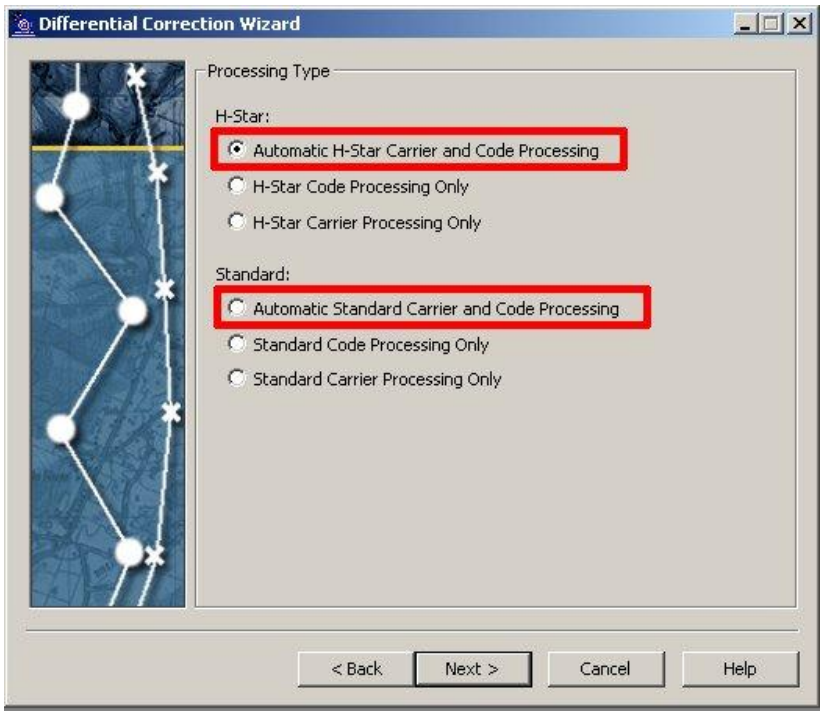


i. Below the *Select SSF files for correction* window, there is some information about the file.

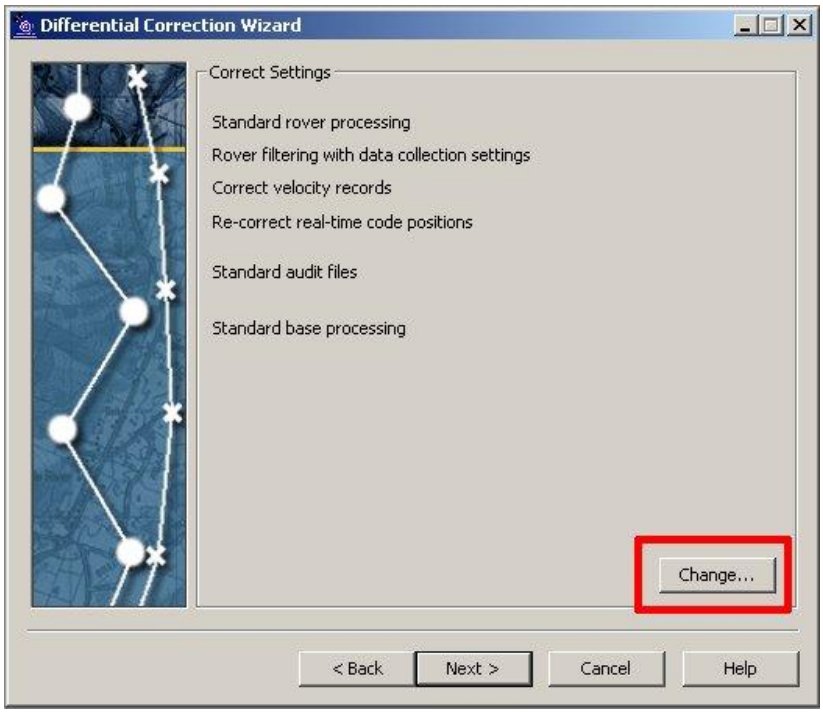
– Date and time range of collection, location on the hard drive, number of GPS positions in the file, and whether or not the file was collected using an H-Star GPS receiver (H-Star allows for greater accuracy).

ii. You should only correct multiple files if they are geographically near (within about 50 miles), because it is necessary to use a nearby base station.

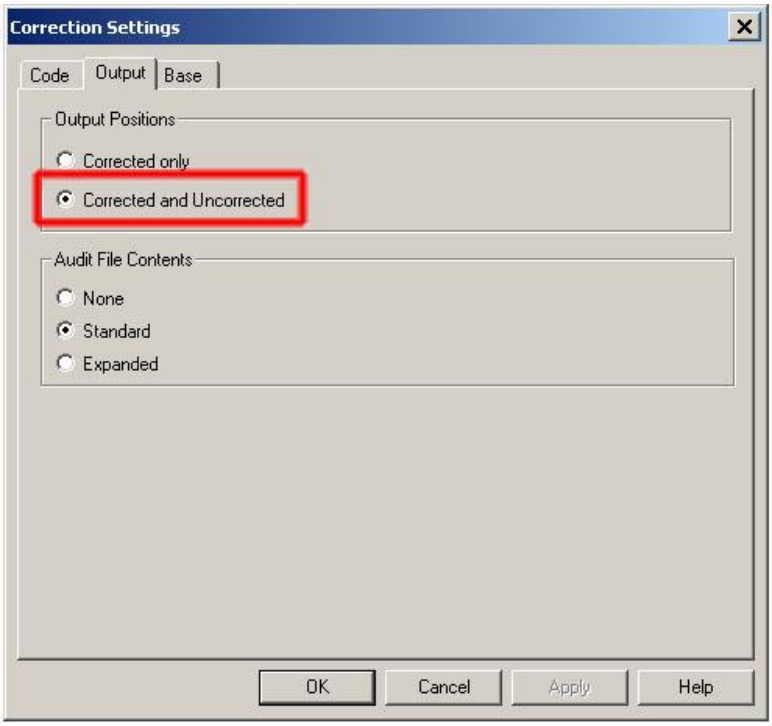
b. If the data was collected with an H-Star receiver, select *Automatic H-Star Carrier and Code Processing*. If the data was not collected with an H-Star receiver, the options under *H-Star* will be grayed-out. If that is the case, select *Automatic Standard Carrier and Code Processing*. Click *Next*.



c. The settings on the next screen can be adjusted by clicking the *Change* button. We want to ensure that differential correction does not remove any feature because that feature's positions cannot be corrected.

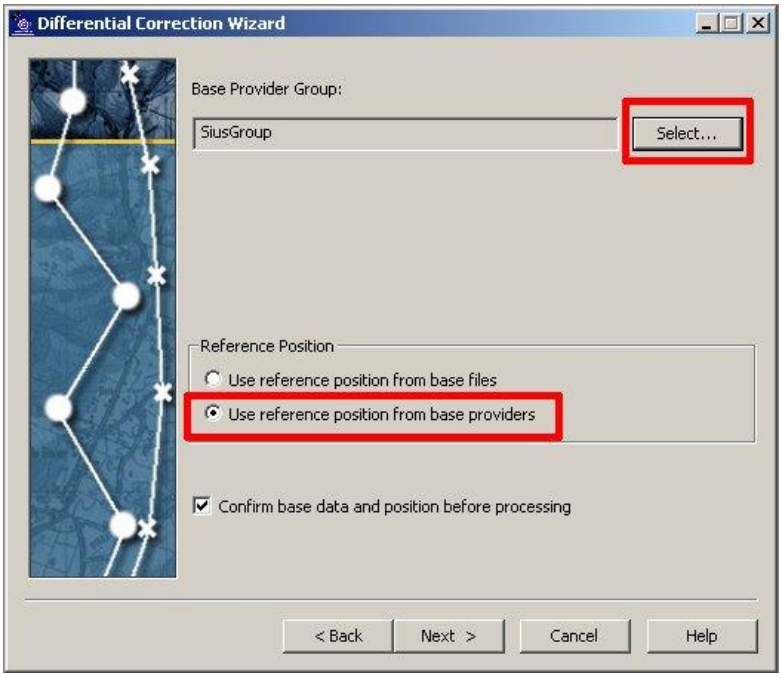


i. Click *Change*-> click the *Output* tab-> under *Output Positions*, ensure that the radio button next to *Corrected and Uncorrected* is selected-> click *OK*-> click *Next*.



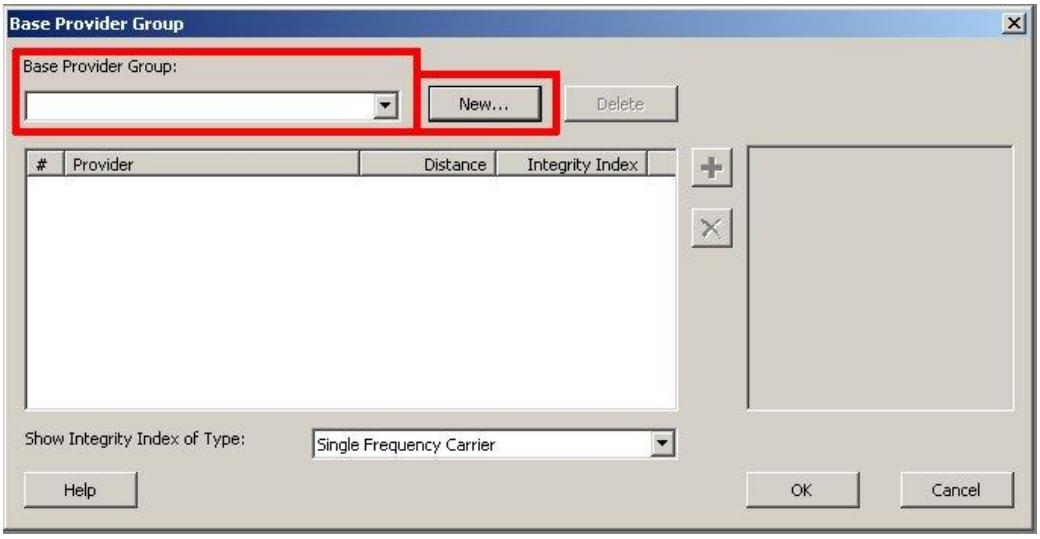
ii. You should only have to do this one time, as these settings are saved. However, since missing this step could result in the loss of data, it is a good idea to check this setting about once per day that you use the differential correction.

d. Click *Select* next to the *Base Provider Group* field.

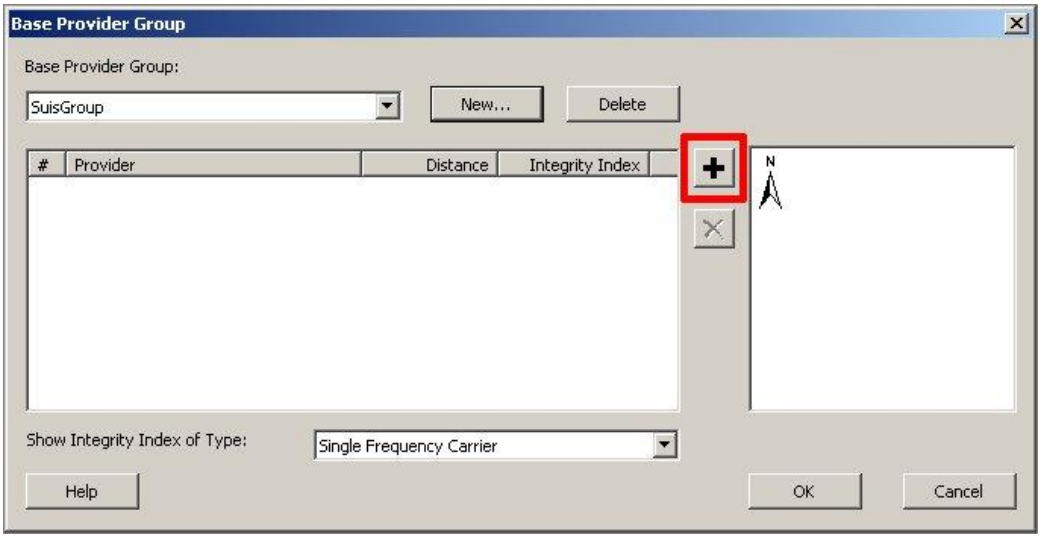


i. This window looks different if your data was collected with a receiver that is not H-Star enabled, but the process is similar. If this is the case, you will click *Select* next to the *Base Provider Search* field, and skip ahead to step iii, below.

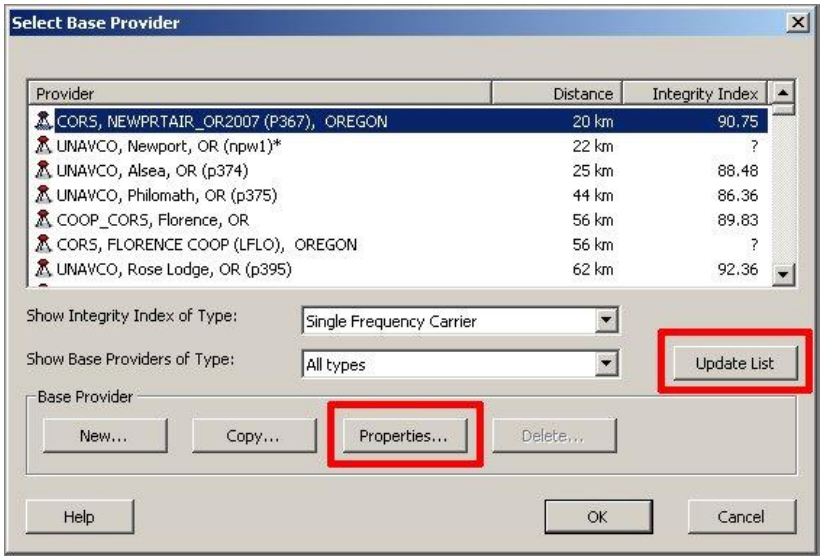
ii. If you have an appropriate group already, select it from the *Base Provider Group* drop-down menu, check to make sure the selected base station is still the best option (plus sign-> *Update List*), and skip ahead to step iii. If you do not already have an appropriate group, click *New…* next to the *Base Provider Group* drop-down menu. Name it something obvious-> click *OK*.



iii. Click the plus sign. A list of base stations appears, with their distance from the data and an integrity index (higher is better).



– Click the *Update List* button to acquire the latest list. The *Downloading base providers…* window appears while the download is taking place.



– Generally, the CORS base stations are the best choice. Select a nearby base station, with a relatively high integrity index and a bias towards CORS stations. If you have H-Star data, you can select multiple base stations. The more base stations you select, the longer it takes to complete the differential correction, but the greater are the chances of correcting all data.

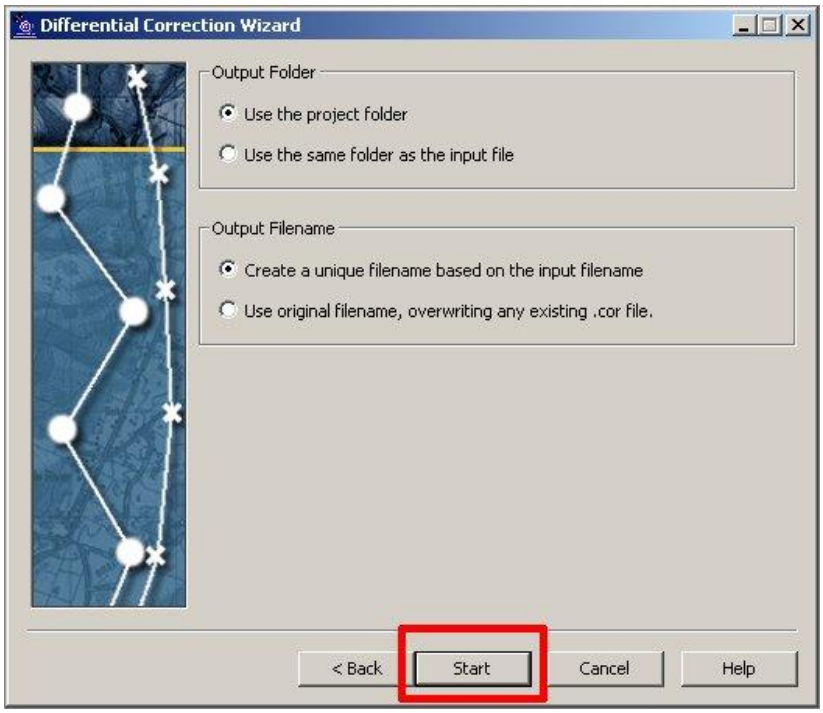
– Click the *Properties…* button to show some more information about the selected base station, such as the organization responsible for running the base station, and its precise location, in latitude-longitude and altitude.

– Click *OK* to exit the *Select Base Provider* window.

iv. Click *OK* to exit the *Base Provider Group* window.

e. Select *Use reference position from base providers* in the *Reference Position* section of the window. Check the box next to *Confirm base data and position before processing*. Click *Next*.

f. Select where you want the new corrected data file (extension .cor) to be saved and how you want it to be named. Click *Start*.



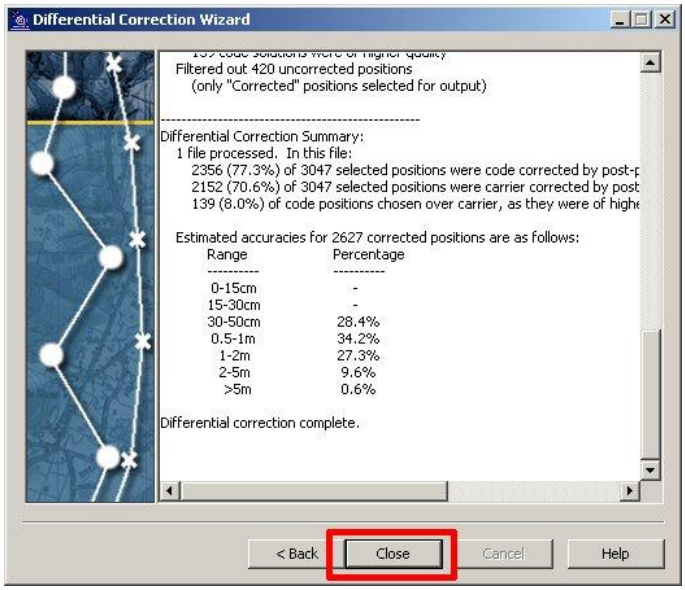
i. If base data cannot be downloaded for some reason, click *Back* twice, select a different base station, and try again.

ii. Click *Confirm* when required.

g. When the process is complete, the window will say "Differential correction complete." You should look at the data in the window to confirm that the correction was successful.

i. Useful data includes the number of positions corrected, the number uncorrected, which method (carrier or code) was used for how many positions, how many positions were thrown out, and estimated accuracies for the data.

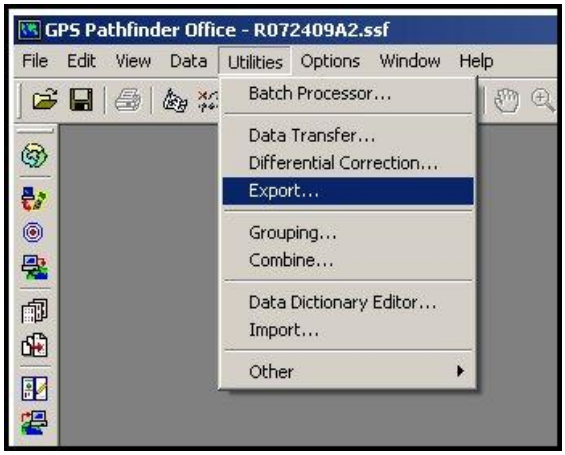
ii. When finished, click *Close*.



Exporting Data as Shapefiles

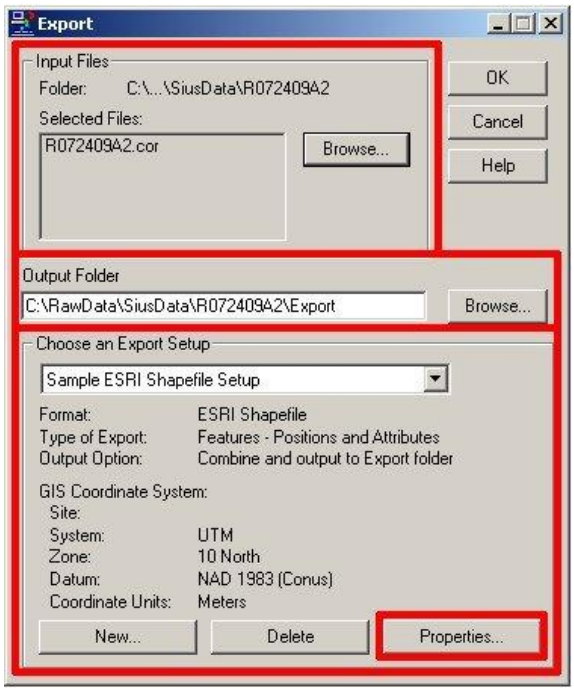
The final data must be in the GIS shapefile format so that ArcMap and GRAIP can analyze it. The differentially corrected data files (extension .cor) are exported as shapefiles. The new shapefiles are saved by default to the Export folder in the project folder. You will want to either move, copy, or save them initially to a workspace for GIS, as discussed in the Introduction. Each single differentially corrected COR file turns into a set of shapefiles, one for each feature. Additionally, you can export multiple COR files at once, and they will all contribute their data to a single set of shapefiles. The number of shapefiles created depends on the data collected. For example, if the crew did not collect any ditch relief points, then there will not be any shapefile exported called DTCH_REL, which would contain the data for the observed ditch relief culverts. All of the possible shapefiles are BBASE_DI, DIFF_DRA, DTCH_REL, END_RD, EXCAV_ST, GATE, GULLY, LANDSLID, LEAD_OFF, NON_ENGI, PHOTO, Point_ge, REVISIT, ROAD, ROAD_CLS, ROAD_HZR, STRM_CRO, SUMP, and WATER_BA. Sometimes, data will be exported so that there are more than one of certain shapefiles (e.g. ROAD and ROAD2). This seems to be due to significant differences in collection dates or in the data dictionaries used for data collection. This does not have any effect on the processing of the data or its results.

1. With the same project folder open as before, go to the main menu-> *Utilities*-> *Export….*



2. The *Export* window appears.

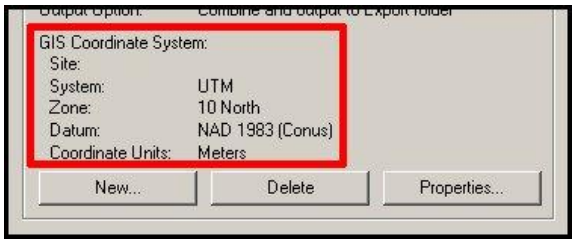
a. In the *Input Files* section, click *Browse...*-> navigate to the location of the differentially corrected file or files that you wish to export to shapefiles-> select the necessary COR files-> click *Open*.

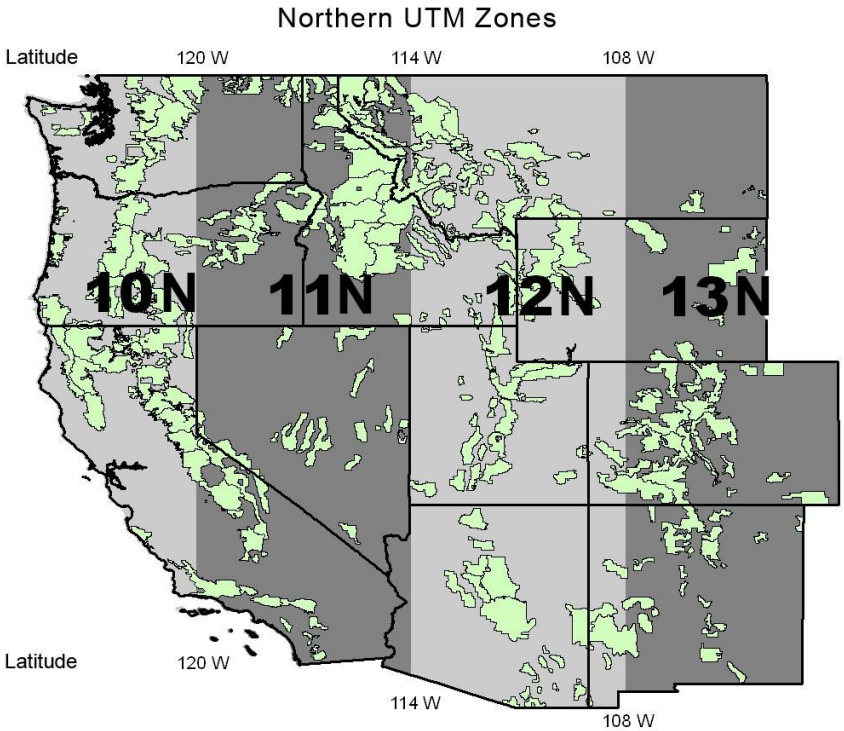


b. You can change the location of the output folder by clicking *Browse…* next to the *Output Folder* field. You may find it easier to use the final destination of the shapefiles (GIS workspace) for simplicity. Note that if you export to a location that already has GRAIP shapefiles in it, you will overwrite those shapefiles.

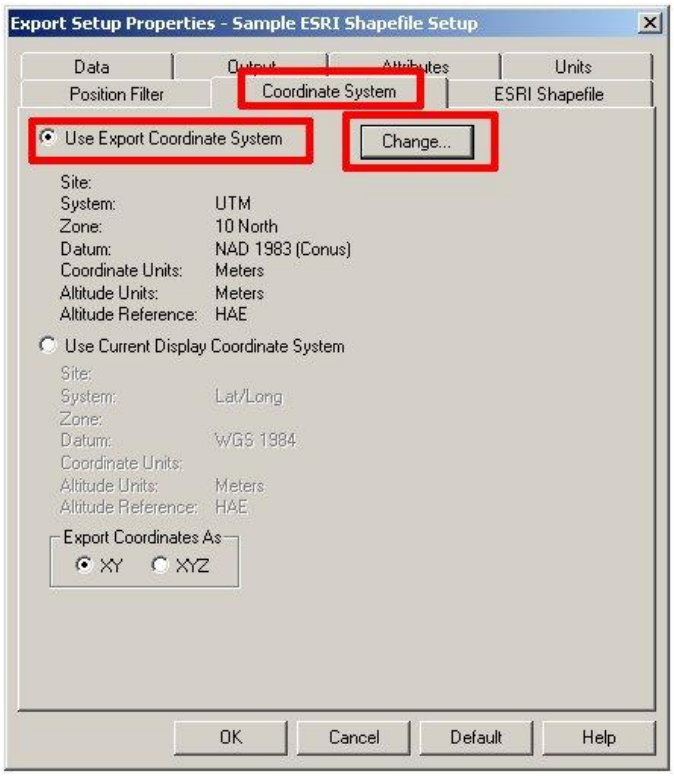
c. In the *Choose an Export Setup* section of the window, choose *Sample ESRI Shapefile Setup* from the drop-down menu.

d. Check the coordinate system in the area under *GIS Coordinate System* to make sure it is correct. If using UTM, make sure the zone is set correctly. Rectangular systems like UTM are best for this analysis.

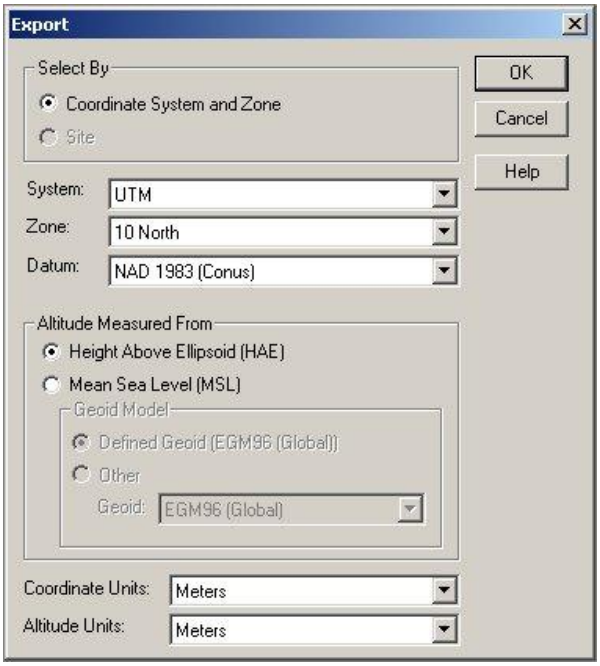




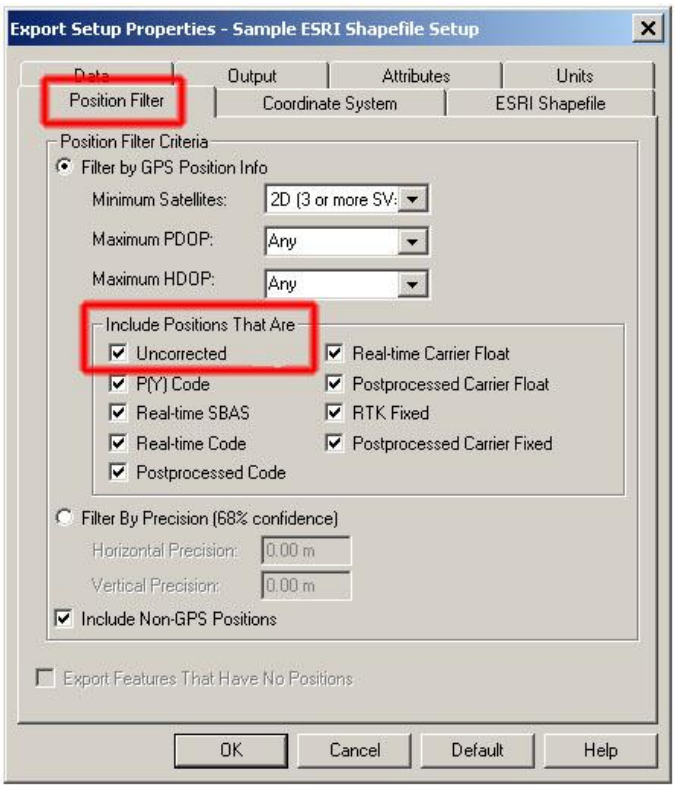
i. If the coordinate system is not correct, click *Properties…*-> click the *Coordinate System* tab-> select *Use Export Coordinate System*-> click *Change…*



– Use the drop down menus to select the appropriate coordinate system and associated properties-> click *OK*.



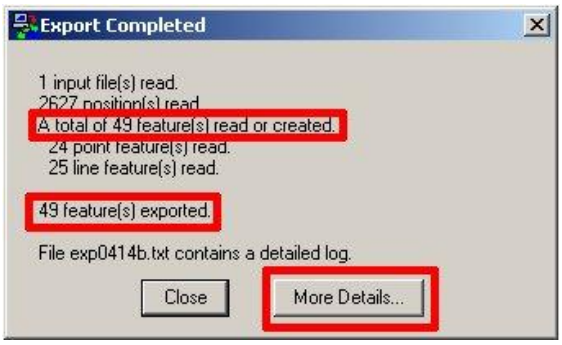
iii. In the *Properties* window, click the *Position Filter* tab. Under *Include Positions That Are*, ensure that *Uncorrected* is checked.



- This will export all features, including those which could not be differentially corrected.
- This setting is saved, but, since missing this step could result in the loss of data, it is a good idea to check this setting about once per day that you export data.

e. Click *OK* to export the file or files.

f. The *Export Completed* window appears when the export is complete. This window shows how many features were in the initial COR file(s), and how many features were exported. There should be the same number of features before and after export. You can click *More Details…* to see exactly which files were created and where they are located in a log file similar to the log file created in the data transfer process. This text file is saved to the same folder as the exported files. Click *Close* when you are finished viewing the *Export Completed* dialog.



3. Each shapefile is composed of a number of files that are readable by ArcGIS. Use ArcCatalog to move or copy the shapefiles into the appropriate GIS workspace if you did not save them there in step 2b above. Pre-processing can now begin.

SECTION II: PRE-PROCESSING

This section describes the necessary steps that must occur before the GRAIP toolbar analysis can begin. The DEM must be clipped to the right watershed, a new set of files must be created with the GRAIP Preprocessor, the errors generated during the creation of those files must be corrected, and the road lines must be made to both reflect the actual shape of the road and be free of excess zigzag.

Preparing the DEM

You need to obtain the DEM and HUC boundaries first. Part of these instructions can be applied to any DEM that needs to be clipped to a polygon. 30 meter resolution DEMs have proved to be best for this analysis. Rectangular coordinate systems such as UTM are best.

The extent of the DEM should encompass the smallest full watershed that contains all of the roads (up to the headwaters and down to the mouth). However, in some instances, entire watersheds are too big to be practical (the maximum size for TauDEM and SINMAP is 7000 x 7000 grid cells, and smaller sizes may hang up or crash). The final DEM should at least encompass all of the necessary roads, the complete sub-watersheds that contain those roads, and all sub-watersheds that contain runoff from these roads until all surface flow paths converge. If there are two roads in two sub-watersheds of, for example, the large Alsea River watershed on the central Oregon coast, the HUCs that encompass those sub-watersheds that contain those two roads are necessary, and so are any other HUCs that encompass their drainage to the Alsea River, and those that encompass the Alsea River in between those sets of drainages (Figure 13). Some of the steps below might not be necessary, depending on the size of the watershed and size of the HUCs.

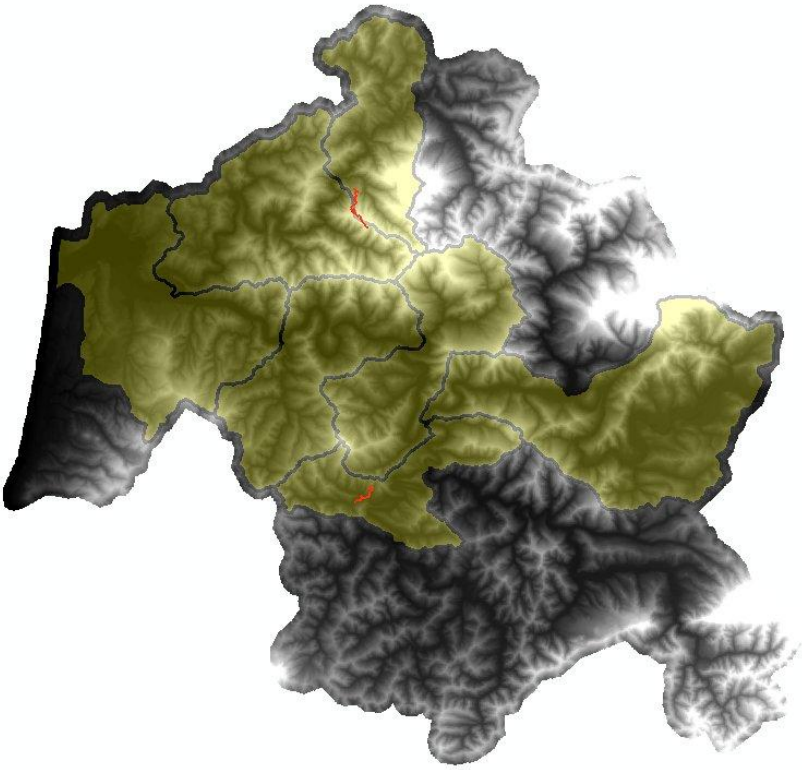
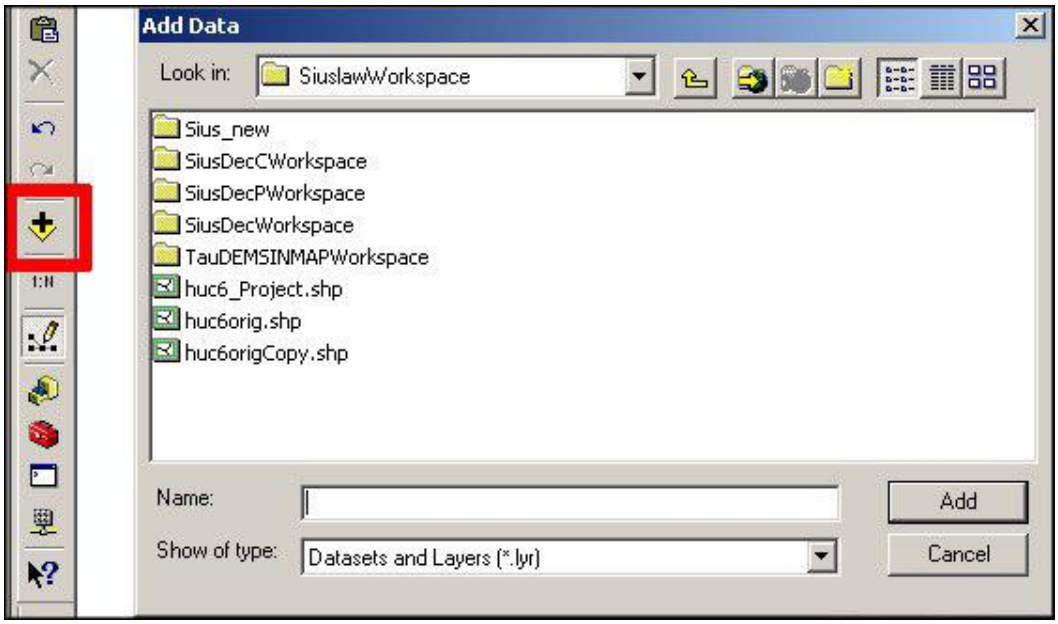


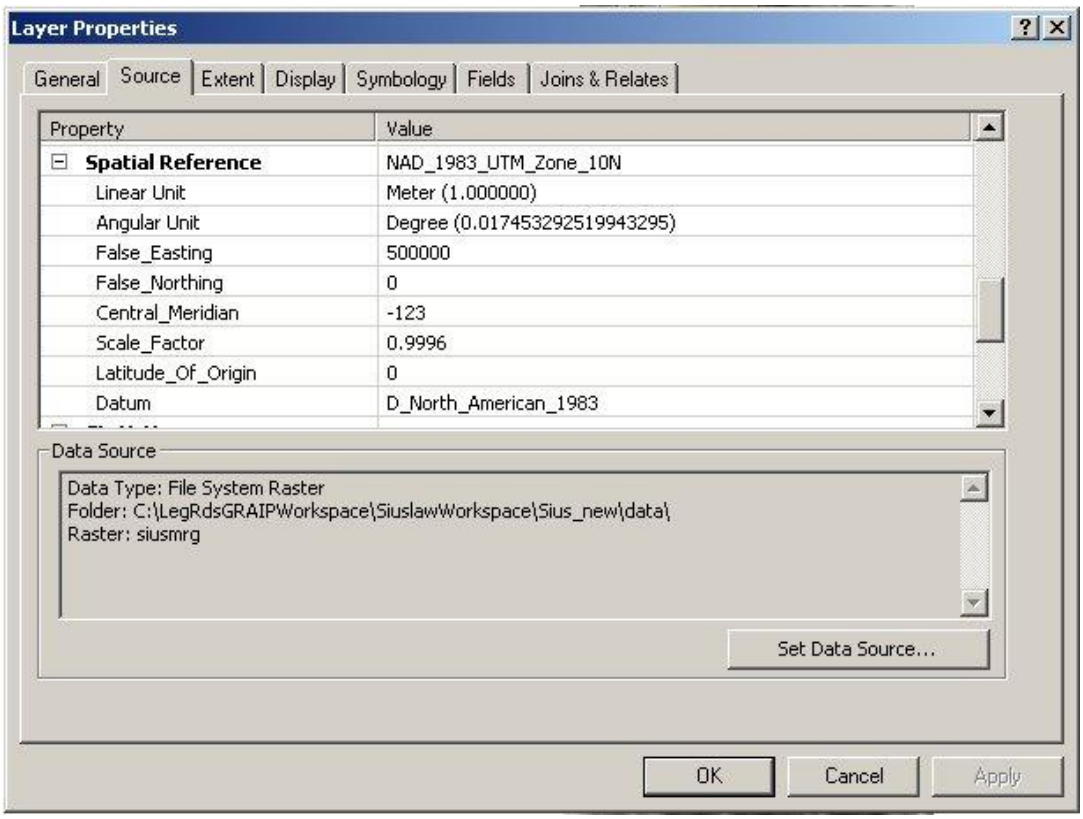
Figure 13. The Alsea River watershed DEM with the necessary HUCs overlaid in yellow and the necessary roads in red. Each of the HUCs present covers part of the path water would take from each road on its way to the mouth of the Alsea River.

1. Open ArcMap and add the DEM and the HUC boundaries.
   a. Go to the Windows *Start* menu-> *Programs*-> *ArcGIS*-> *ArcMap*.
   b. In ArcMap, go to the Main Menu-> *File*-> *Add Data…*-> navigate to the location of the DEM-> click *Add*. The DEM is added to ArcMap, and is displayed in the *Table of Contents*. Do the same for the HUC boundaries.



      i. You can also use the *Add Data* button in the *Standard* toolbar, in the red box, above.

2. Make sure the HUCs and the DEM are in the same projection as the shapefiles of the field data. It's good to make copies of both with ArcCatalog before changing their attributes.
   a. Right-click in the layer name in the *Table of Contents*-> click *Layer Properties* to open the *Layer Properties* window for each layer-> *Source* tab-> scroll down to *Spatial Reference*, expanding the line if necessary. If the two layers have the same *Spatial Reference* as the shapefiles, move on to step 4. If they do not, or if one is undefined, proceed, even if both layers are overlapping in the map viewer window as expected.



3. It is important to use the correct method when projecting DEMs, because the wrong method will result in artifacts in the data that will cause errors. If the HUCs or the DEM are in the wrong projection, they should be projected or re-projected to the same coordinate system as the shapefiles.

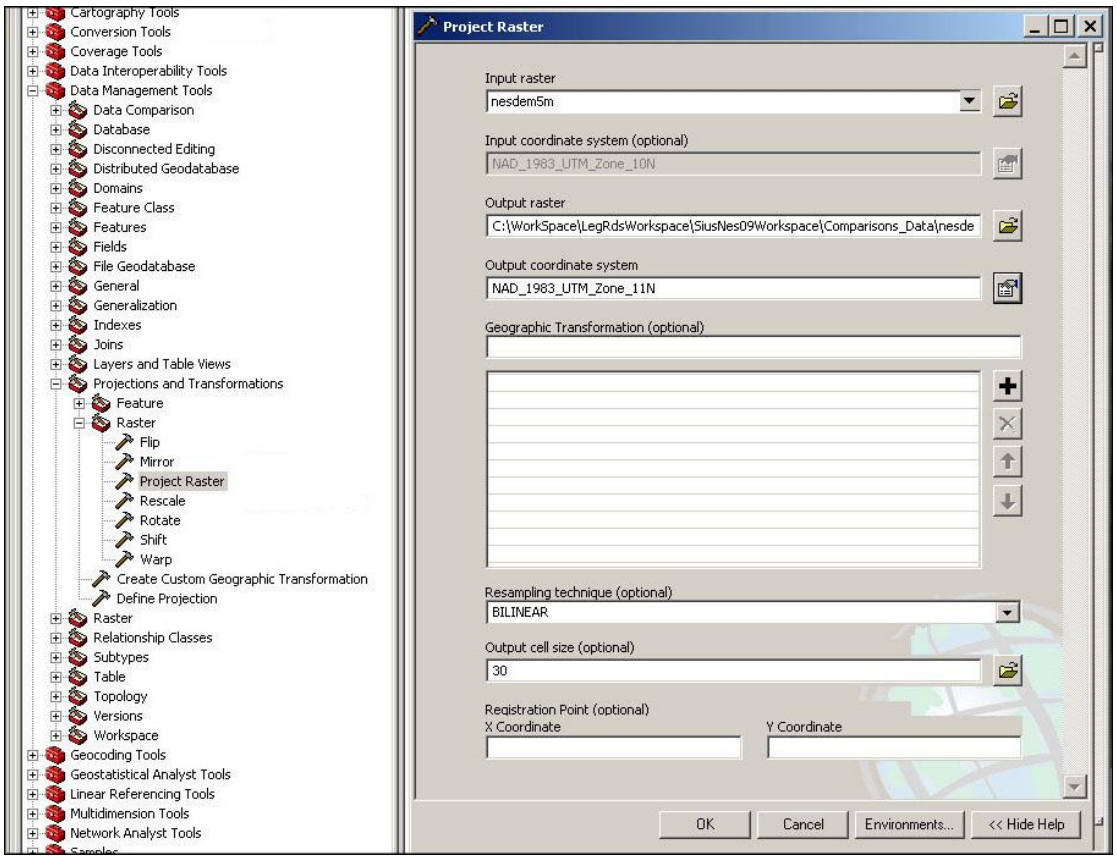
a. To project the DEM, open ArcToolbox-> *Data Management-> Projections and transformations-> Raster-> Project Raster* (see below).

i. From the *Project Raster* window,

- Under *Input raster*, click the drop-down menu and select the DEM.
- If there is nothing under *Input Coordinate System (optional)*, click the button to the right of that field-> *Select*-> navigate to the projection that you think the DEM is in-> click *Add*-> click *Apply*-> click *OK*.
- Under *Output raster*, click the button to the left of the field-> navigate to the folder in which you wish to save the new projected DEM (probably the same place as the original DEM), and type a new name (such as demproj). Click *Save*.
- Under *Output Coordinate System*, click the button to the right of the field-> click *Select*, navigate to the appropriate coordinate system (same as the

shapefiles; UTM is under *Projected Coordinate System-> Utm*)-> click *Add*-> click *Apply*-> click *OK*.

- Under *Resampling technique (optional)*, click the drop-down menu and select *BILNEAR*. *CUBIC* will also work, but do not use *NEAREST*.
- Under *Output cell size (optional)*, type "30".
- Click *OK*. A new DEM that contains the same information as the original DEM is created. Use this DEM for the rest of this section.



b. To project the HUCs or any other shapefile, open ArcToolbox-> *Data Management-> Projections and transformations-> Feature-> Project* (see below).

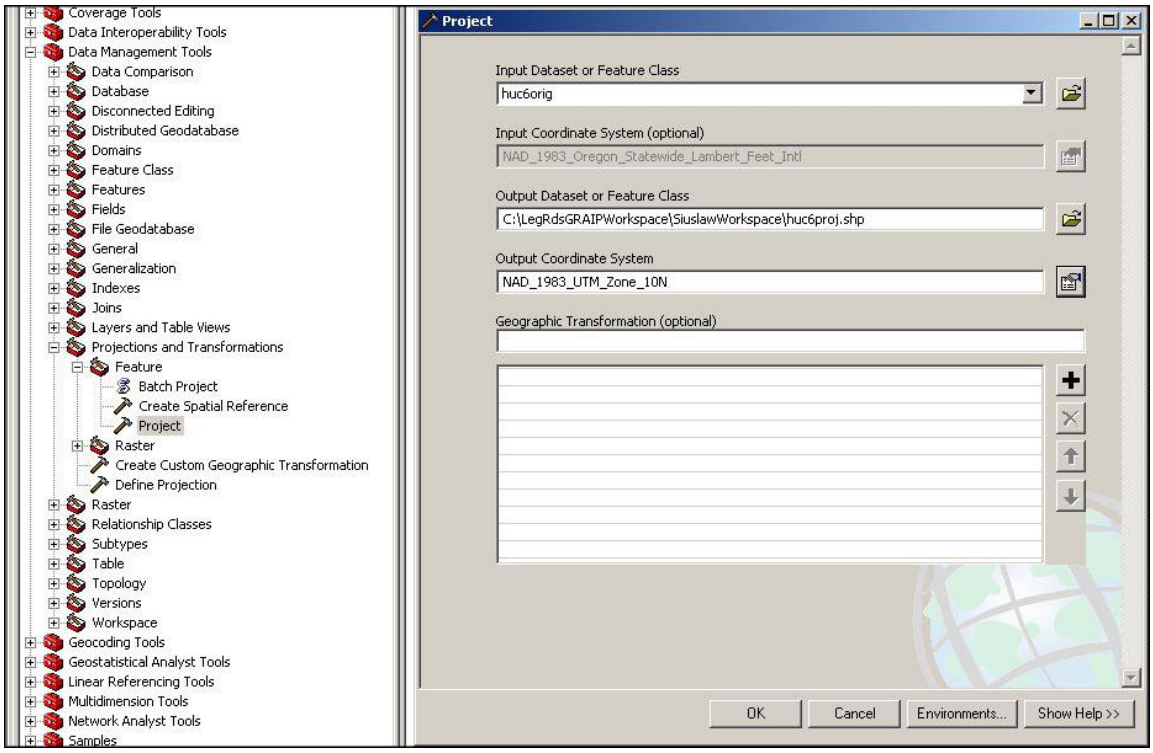
i. From the *Project* window,

- Under *Input Dataset or Feature Class*, click the drop-down menu, and select the HUCs shapefile.
- If there is nothing under *Input Coordinate System (optional)*, click the button to the right of that field-> *Select*-> navigate to the projection that you think the HUCs are in-> click *Add*-> click *Apply*-> click *OK*.

– Under *Output Dataset or Feature Class*, click the button to the left of the field-> navigate to the folder in which you wish to save the new projected HUC shapefile (probably the same place as the original HUCs), and type a new name (such as HUCproj). Click *Save*.

– Under *Output Coordinate System*, click the button to the right of the field-> click *Select*, navigate to the appropriate coordinate system (same as the shapefiles; UTM is under *Projected Coordinate System-> Utm*)-> click *Add*-> click *Apply*-> click *OK*.

– Click *OK*. A new shapefile is created that contains the HUCs and is projected the same as the other shapefiles. Use this HUC layer for the rest of this section.



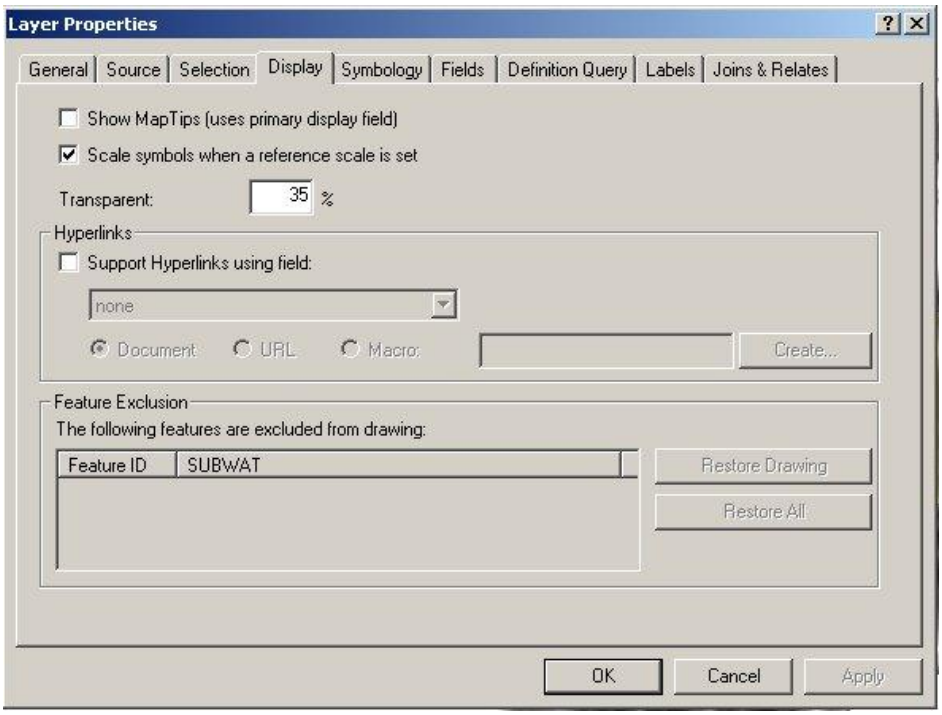
c. The projected HUCs and DEM should be overlapping properly.

4. Choose which HUCs you need.

a. Add all of the roads you will be analyzing to ArcMap, as in step 1, overtop of the HUCs (which should be over top of the DEM). If the roads are mis-registered, re-project them as you did for the HUCs in step 2, making sure to use the correct coordinate system.

b. Set the transparency of the HUCs layer to 35%. This is useful when determining the extents of each watershed and associated flow paths.

i. Right click on the HUCs layer-> *Properties*-> *Display*-> type 35 in the *Transparent* box-> click *OK*.



c. Select the HUCs that encompass the smallest full watershed that contains all of the roads (headwaters on down). Alternatively, select the only the sub-watersheds that contain the roads, along with the sub-watersheds containing runoff from these roads until all flow paths converge, as described above.

5. Delete the rest of the HUCs.

a. Go to the *Editor* toolbar-> *Editor*-> *Start editing*-> choose the folder with the HUCs if prompted.

b. Use the *Edit tool* from the *Editor* toolbar (the arrow to the immediate right of the *Editor* menu, in the red box at right) to select all of the HUCs you don't need (use the Shift key to select more than one). Go to the ArcMap Main Menu-> *Edit*-> *Delete* to delete those.

c. *Editor*-> *Save edits*.

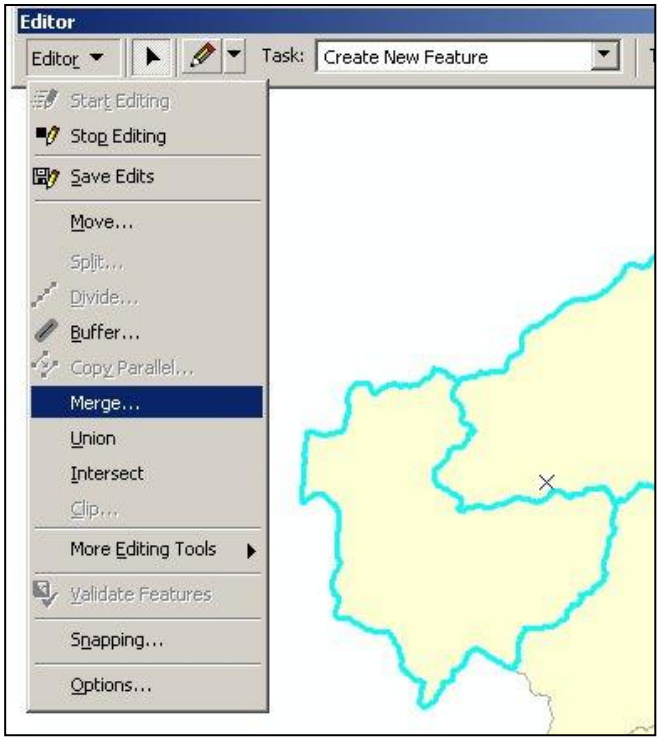
6. Merge all of the HUCs into one. This is necessary for the buffering step (step 7).

a. Use the *Edit Tool* from the *Editor* toolbar to select all the remaining HUCs at once (use Shift key; they should be the ones you want).

b. *Editor* toolbar-> *Target*-> HUCs layer.

c. *Editor*-> *Merge*-> any option will do-> click *OK*

d. *Editor*-> *Save edits*.



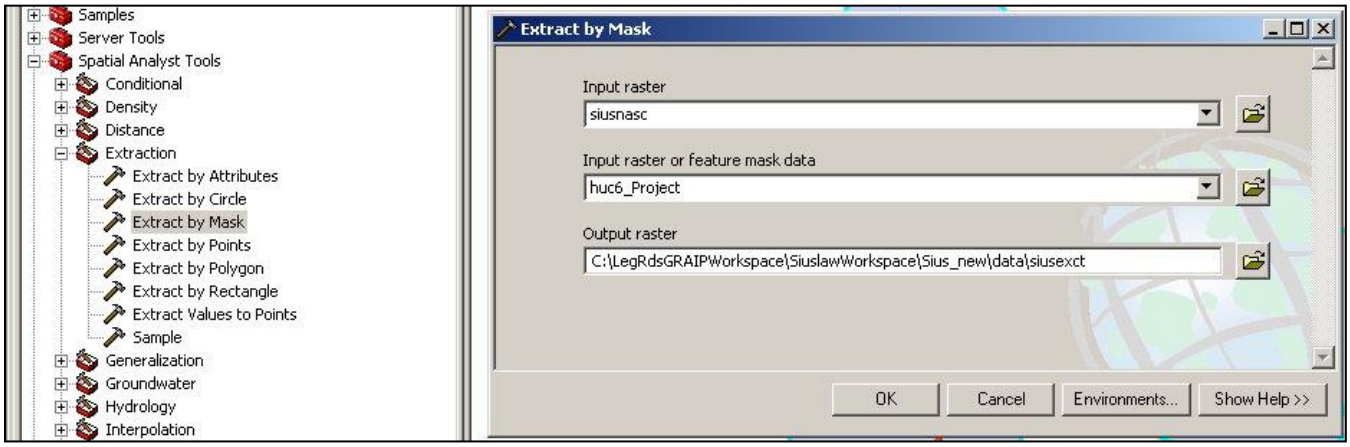
7. Buffer the new single HUC. This ensures that the end product DEM will have the entire necessary watershed. It expands the HUC feature over the ridge-tops separating the larger watershed from its neighbors.

a. Use the *Edit Tool* from the *Editor* toolbar to select the single HUC feature.

b. *Editor*-> *Buffer*…-> enter 500 m, or rough equivalent-> hit Enter key.

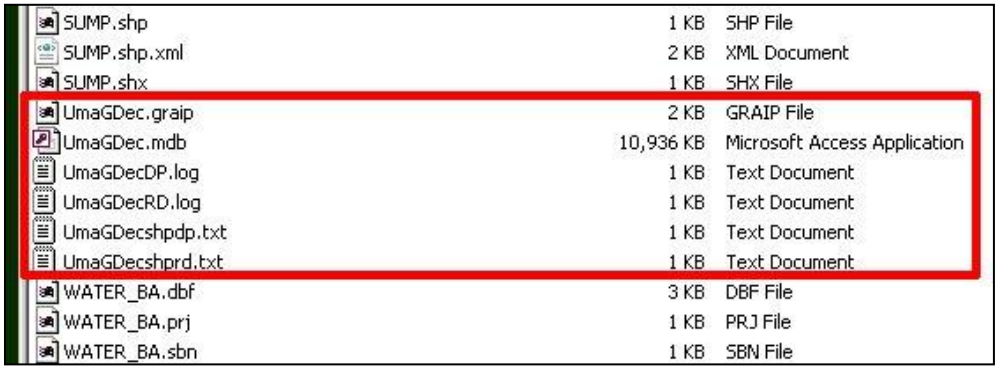
8. Extract the DEM. This final step results in a new DEM that is the shape of the HUC, ready to be processed for GRAIP.

a. ArcToolbox-> *Spatial Analyst*-> *Extraction*-> *Extract by Mask*. Enter the DEM as *Input Raster*, the now merged and buffered HUC layer as *Input raster or feature mask data*, and an appropriate location and name for the new extracted DEM (probably the same folder as the original DEM; any eight-character or fewer name will do, but it should be clear which is the extracted DEM). Click *Compute.*



Preprocessing Shapefiles

The Preprocessor has two functions. It creates the GRAIP file structure, and it checks the incoming data for the most common errors. Preprocessing creates a single shapefile with all of the drain points, called DrainPoints, and one with all of the road segments, called RoadLines. It also creates a single database with all of the data, and relates the correct DEM, DrainPoints, RoadLines, the database, and, later, the stream network shapefile to each other under a new file with a .graip extension. This .graip can only be opened with the GRAIP toolbar in ArcMap. In total, eight files are created, not including the multiple files that make up one shapefile (FileName.graip, DrainPoints.shp, RoadLines.shp, FileNameDP.log, FileNameRD.log, FileName.mdb, FileNameshpdp.txt, and FileNameshprd.txt; see Figure 14). The log files are created to identify RoadLines and DrainPoints that may have insufficient or erroneous data values.



SUMP.shp	1 KB	SHP File
SUMP.shp.xml	2 KB	XML Document
SUMP.shx	1 KB	SHX File
UmaGDec.graip	2 KB	GRAIP File
UmaGDec.mdb	10,936 KB	Microsoft Access Application
UmaGDecDP.log	1 KB	Text Document
UmaGDecRD.log	1 KB	Text Document
UmaGDecshpdp.txt	1 KB	Text Document
UmaGDecshprd.txt	1 KB	Text Document
WATER_BA.dbf	3 KB	DBF File
WATER_BA.prj	1 KB	PRJ File
WATER_BA.sbn	1 KB	SBN File

Figure 14. The files created by the GRAIP Preprocessor, not including DrainPoints.shp and RoadLines.shp.

When the Preprocessor builds the database for the input data, it references another database file called GRAIP.mdb (located in C:\Program Files\GRAIP\graip db), which has attributes that must match up with the attributes in the drain point and road lines shapefiles. The attributes in those shapefiles are originally input in the field GPS unit based on a particular data dictionary. Essentially, in order for everything to match up correctly at this step, the data dictionary used for field collection and the GRAIP.mdb file must match. There are three main data dictionary-GRAIP.mdb pairs currently used, all of which are available on the GRAIP website (http://www.fs.fed.us/GRAIP/downloads.shtml). The data dictionaries are INVENT4_2, INVENT5_0, and INVENT5_0_W; INVENT 5_0 is best for most purposes, as of December 2010.

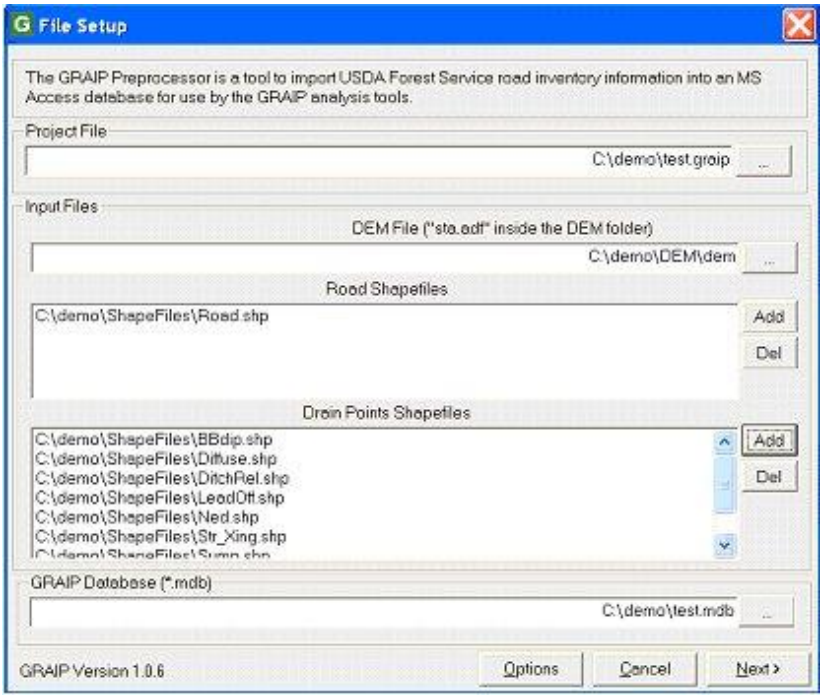
When you download the *GRAIP Database Update* from the above website, you will have a set of database files (extension .mdb) all in one zip file. Unzip the contents to *C:\\Program Files\GRAIP*. It should replace the *\graip db* folder. This will leave GRAIP set up with its original database, ready to work with current data. There is a backup of this original database in the *\Original* folder. The updated database for Legacy Roads projects is in *\graip db\GRAIP Update LegRds* (using INVENT5_0). The update for watershed studies (using INVENT5_0_W) is in *\graip db\GRAIP Update Wtrshd*. If you are going to be working with data collected with the updated (both INVENT5_0) data

dictionaries, then copy (don't move) the appropriate GRAIP.mdb file to the *C:\\Program Files\GRAIP\graip db* folder, replacing the file that is there. Once data is imported via the GRAIP Preprocessor, you can work with the resulting .graip files regardless of which GRAIP.mdb is in the *C:\\Program Files\GRAIP\graip db* folder.

Before you begin this step, ensure that the correct GRAIP.mdb will be used in the Preprocessor utility.

1. Open the GRAIP Preprocessor

a. This is a separate program, installed with the GRAIP Toolbar and found in the GRAIP folder under *Programs* in the *Start* menu.



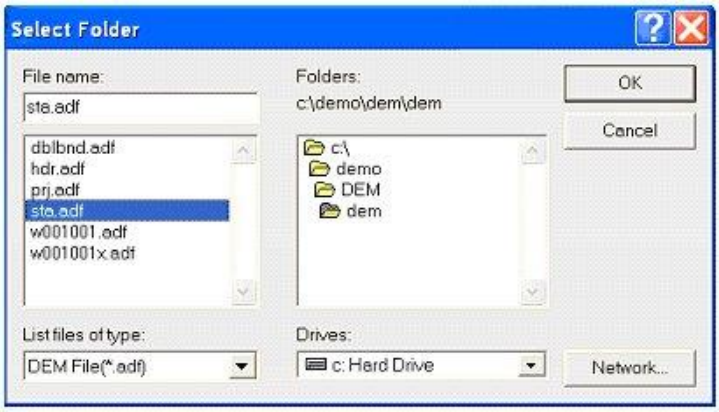
2. Create a new .graip file

a. Under *Project File*, click the {…} button, navigate to the folder with your shapefiles or wherever you want to save the .graip and other created files.

b. Name the file with something relevant. Do not use spaces. Click *OK*. FileName is used here to refer to the .graip, etc.

3. Select the DEM

a. Under *DEM File*, click {…}, navigate to the desired clipped DEM, referred to here as just "dem" (it should be in the same folder in which you intend to save the TauDEM-created files, discussed previously). Double-click dem, select sta.adf, and click *OK*.



b. If you don't have the DEM, you can still correct errors. For this step, use a dummy DEM (any DEM). You will have to re-preprocess the data with the correct DEM before running GRAIP.

4. Add the road shapefile(s), and the drain point shapefiles.

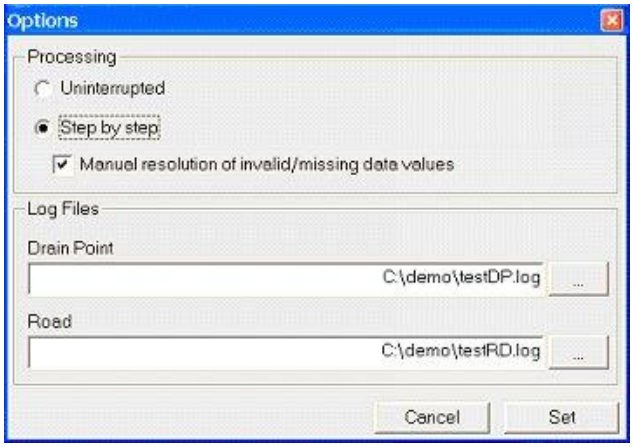
a. Under *Road Shapefiles*, click *Add*. Navigate to the location of the ROAD shapefile(s), select them, and click *OK*.

b. Under *Drain Points Shapefiles*, click *Add*, Navigate to the location of the drain point shapefiles, select all of the drain point shapefiles, and click *OK*. There are nine possible drain point shapefiles, but not every study will have them all. They are BBASE_DI, DIFF_DRA, DTCH_REL, EXCAV_ST, LEAD_OFF, NON_ENGI, STRM_CRO, SUMP, and WATER_BA.

c. You can add more than one shapefile with the same name, as if you imported, corrected, and exported the shapefiles in two batches. In this case, the second (or even third or fourth) set of shapefiles should be in a separate sub-workspace in the same workspace as the rest of the shapefiles.

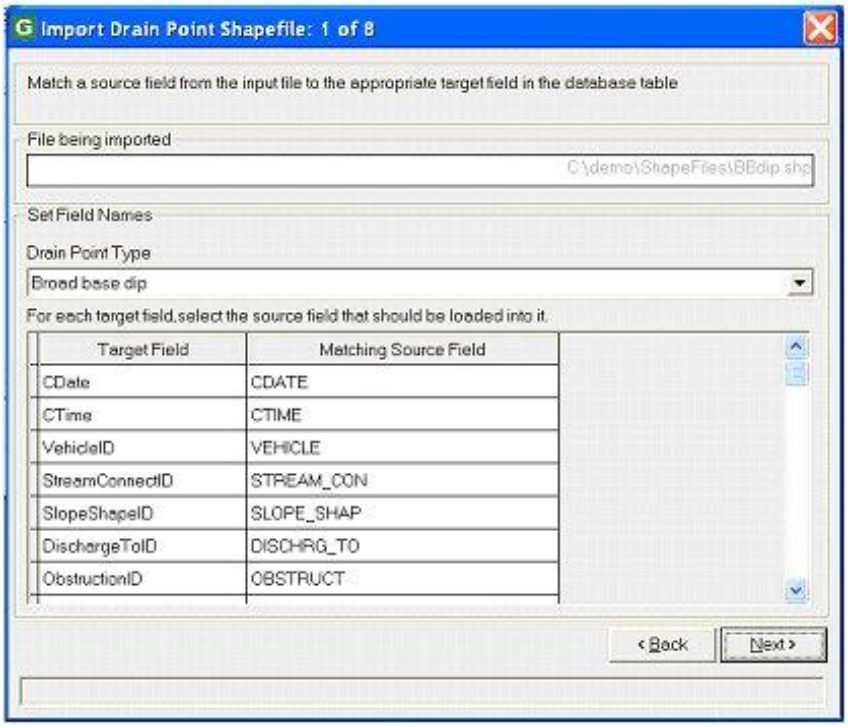
5. Click *Options*, ensure *Step by step* and *Manual resolution of invalid/missing data values* are selected in the *Processing* field, and click *OK*. These options ensure that you will catch any errors in the next step. You may also change the location of the error log files in this step, but that is not generally necessary.

a. If you choose *Uninterrupted* in the *Processing* field, all defaults will be used, and you will have no opportunity to specify what actions to take, where appropriate. This is rarely a good idea.



6. Click *Next*. At this point, all of the files that are created by the preprocessor have been created, except DrainPoints.shp and RoadLines.shp. The next steps import the drain points and road shapefiles.

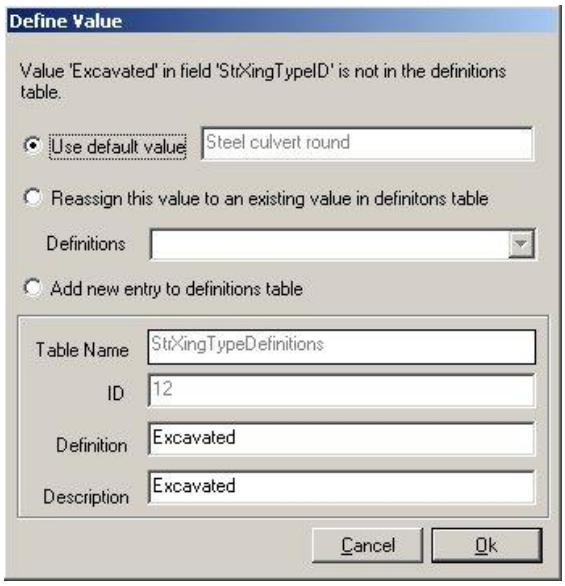
7. A screen appears with the heading *Import Drain Point Shapefile: 1 of X* (*X* is the total number of drain point shapefiles that you are importing). You can see which file is being imported, which *Drain Point Type* the preprocessor thinks it is, and the *Target* and *Source* fields that go with that drain point type. Generally, these are all correct, and no input is needed. However, it is a good idea to check to make sure all of the target and source fields match up properly. If they don't, you can select a match from



the drop-down menu that appears under the *Matching Source Field* when you click on a property. If you have the latest version of GRAIP and the latest data dictionary in the field, this should not occur. If the data dictionary has been modified, the incoming data will have unexpected values, and the Preprocessor will not be able to automatically import the data into the GRAIP geodatabase structure. When you are sure everything matches, click *Next*. Repeat this process for all drain points.

a. The road lines are similar.

b. If there is an undefined value in a drain point or road line, such as if a property exists in the data dictionary in the field, but not in GRAIP, the *Define Value* dialog appears. For example, before the last update, in the STRM_CRO shapefile, the ChannelAngleID > 75 degrees did not match that in the GRAIP data dictionary, because the GRAIP data dictionary did not have a space (so it is >75 degrees), and this produces an error. If you are using the wrong version of GRAIP.mdb, this dialog box will appear a lot.



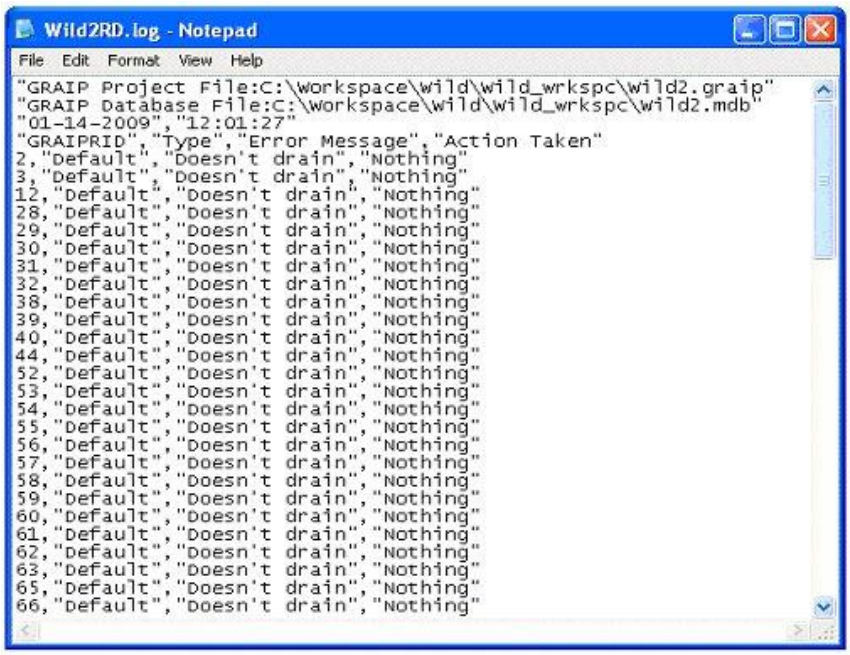
i. You have three options, *Use default value*, *Reassign this value in definitions table*, and *Add new entry to definitions table*. Select the appropriate choice and click *Ok*. Generally, *Add new entry to the definitions table* is most appropriate.

c. If there are CTime fields in the ROAD shapefile that have anything entered in them that is not a valid 24-hour time with four digits (e.g. 0745, 0959, 1919, etc.)

or 999, then the Preprocessor will freeze during the *Import Road Lines Shapefile* step. Examples of invalid CTime entries include: 9999, 9130, 930, 34, blank cell.

i. If this happens, you must find the errant CTimes and edit them so that they are valid. Add the ROAD shapefile in which the error occurs to ArcMap, and use the layer's attribute table to find and edit the errors. See the instructions for Editing Data Errors for more information.

8. Preprocessing is now complete. The FileNameDP.log and FileNameRD.log files, located in the same folder as FileName.graip, contain the errors that the preprocessor found, used in the next step.



9. In the next step, you will locate and fix any errors. When you re-preprocess the data, after the errors are corrected, and any time the DEM used does not change (including if you change which shapefiles are used, so long as the DEM remains the same), you can just select the already created *Project File* (FileName.graip) on the first screen, and click *Next*. Click *OK* when asked if you want to delete the DrainPoints, RoadLines, and FileName.mdb files. Proceed as before. You will have to go through any *Define Value* dialogs again. If you change the DEM, you must use a new .graip (e.g. FileName2.graip). Again, click *OK* when asked if you want to delete the DrainPoints, RoadLines, and FileName.mdb files. If no points have been added or

deleted from the original shapefiles, the preprocessor assigns the same GRAIPDID/GRAIPRID number to each point as it did the first time.

Editing Data Errors

The error logs generated by the GRAIP Preprocessor (FileNameDP.log and FileNameRD.log) contain the drain points and road lines that are not associated with a valid CTime/CDate/VehicleID combination. An error is logged for a drain point if its CTime/CDate/VehicleID combination is not referenced to any road segment. An error is logged for a road line segment if *none* of the entered CTime/CDate/VehicleID combinations correspond to a drain point (i.e. if there are two flow paths, and only one is entered incorrectly, there will not be an error in the road line, though the associated drain point may generate an error). These errors must be corrected before running GRAIP.

There are four main kinds of errors. The first are data entry errors, where the CTime/CDate/VehicleID in the road line does not match those in the desired drain point. Drain point data are generally correct, because their CTime/CDate/VehicleID combination is automatically generated. These errors occur because the CTime/CDate/VehicleID combination in the road line was incorrectly entered in the field, and are usually rounding errors (e.g. the CTime was rounded from 01:34:32 to 1334 instead of 1335, which is correct).

The second main kind of errors are real orphan drain point errors, where the drain point in the field was collected, but was not used to route water. This is intentional; some "drain points" do not actually drain any water anymore. Water bars on diffuse roads, completely blocked ditch relief culverts, and stream crossings that do not directly drain water are all examples of this. Nothing is done to correct these errors because they are intentional.

There are computer and program errors. These are relatively rare. There is a known error in the program that causes it to improperly round off the last minute of the hour from the drain point CTime to a 60 instead of 00 (so 12:59:45 becomes 1260 instead of 1300). Another example of a computer/program error is the -6 or -7 hours error, where the CTimes in a certain drain points shapefile will all be behind by 6 or 7 hours (so 10:45:20 becomes 4:45:20 or 3:45:20). This is rare.

Finally, there are point or road segment collection errors, where a drain point or road line was unintentionally collected, or collected twice, and then not deleted, in the field. This is uncommon.

In order to check and fix these errors, the ROAD and various original drain points shapefiles must be edited so that every road has a matching CTime/CDate/VehicleID, and every drain point that routes water in the field is matched to a segment of road. Note that the shapefiles generated by the GRAIP Preprocessor (DrainPoints.shp and RoadLines.shp) are *not* edited. In order to make those files match the edited originals, you have to re-run the GRAIP Preprocessor on the corrected original shapefiles.

Note that CTimes in the ROAD layer are in 24-hour format, rounded to the nearest minute, and without colons (so, 1537 means 03:37:25, 03:36:48, 03:37:30 etc.). Note that xx:xx:30 rounds down, while xx:xx:31 rounds up. The CTimes in the original drain point are in 12-hour format, with seconds. The CTimes in the original drain point must be in the format xx:xx:xx, or GRAIP won't know what the CTime means.

There are four columns in each error log (Figure 15). "GRAIPDID" contains the GRAIPDID number that corresponds to that feature in the DrainPoints table, and "GRAIPRID" contains the GRAIPRID number that corresponds to that feature in the

RoadLines table. “Type” or “Drain Type” is the feature type (i.e. Water Bar, Stream Crossing, Road Line, etc.). “Error Message” describes what the problem is (such as “Orphan drain point;” this does not mean the drain point is an intentional orphan!). “Action Taken” describes what the Preprocessor did to fix the problem. This field usually says “Nothing,” unless the *Define Value* dialog corrected an error in that point. If that is the case, no further action is needed for that point.

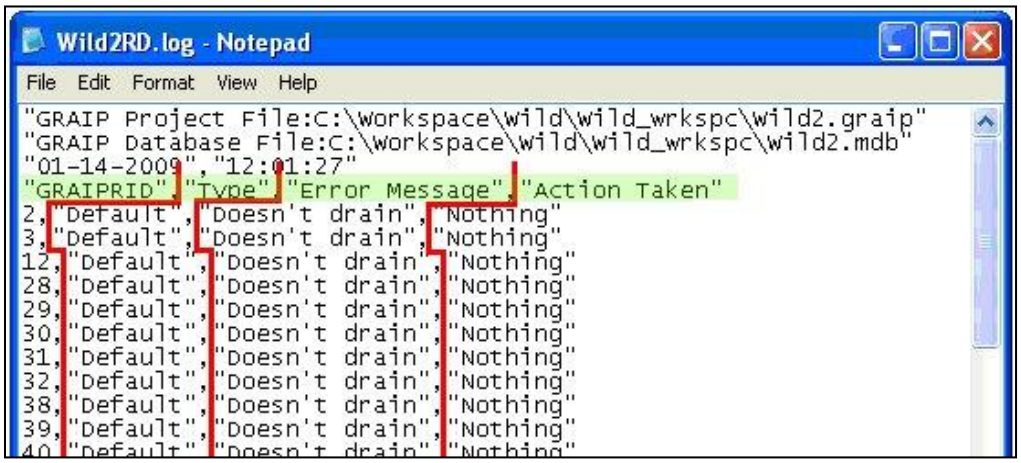
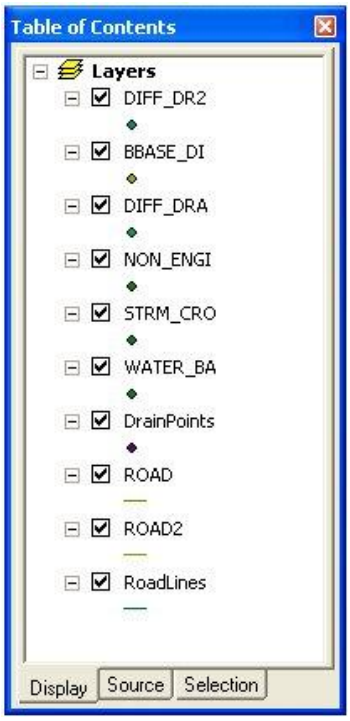


Figure 15. The error log for the RoadLines table with each of the four columns noted.

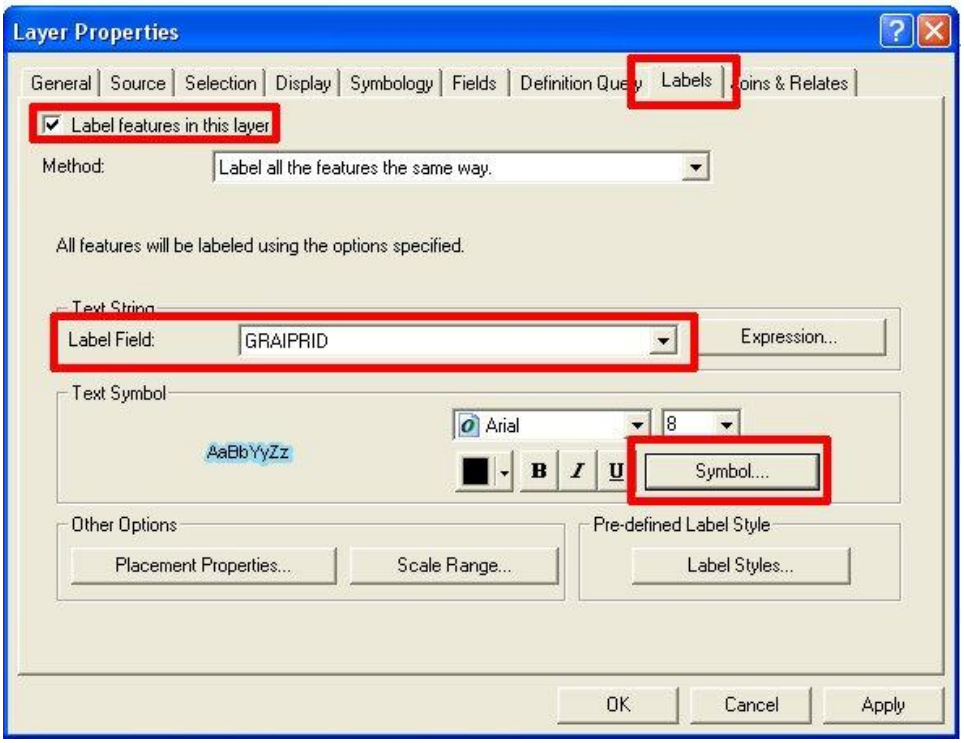
The fundamental goal of error checking is to ensure that each flow path on each road segment drains to the appropriate and valid drain point. Fixing the errors from the error logs is a bit like being a detective. You have to use the clues in the data to figure out what is happening on the ground. Clues include the comments made by field crews, the type of drain and flow path, photos, the direction the flow path is moving (discernable from the DEM and by which end of a road segment the associated drain point is located on), etc. Sometimes, a solution for one drain point or road line error solves more than one problem. Often, fixing a drain point also fixes a road segment. This might seem pretty complicated, but it gets much easier once you do it once or twice.



1. Use the Windows text editor to view the error log files (FileNameDP.log and FileNameRD.log). Print them for easier reference (they can be combined into one page, but don’t save them that way).
2. Open ArcMap-> *File*-> *Add Data…*-> navigate to the folder with the original shapefiles (ROAD, DIFF_DRA, etc.)-> select all original road lines files and drain points files (but not non-drain point or road line files, such as END_RD)-> click *Add*. Also add the RoadLines and DrainPoints shapefiles generated by the GRAIP Preprocessor and the PHOTO shapefile; these are used for

reference. Arrange the RoadLines and DrainPoints layers under the rest of the layers in the *Table of Contents* window.

a. Label the RoadLines and DrainPoints layers for easier reference. Right-click the layer-> *Properties*-> *Labels* tab-> check *Label features in this layer*-> make sure GRAIPDID or GRAIPRID is selected in the *Label Field* drop-down menu-> click *Symbol*-> *Properties…*-> *Mask* tab-> select *Halo*-> Click *Symbol* to change the color of the halo-> click *OK* until you are out of the *Properties* window. Labeling makes it easier to see when there are multiple drain points close together or on top of one another.



3. Right-click the DrainPoints layer in the *Table of Contents*-> *Open Attribute Table*. The GRAIPDID and FID columns correspond to the "GRAIPDID" column in the error log. This also applies to the RoadLines Attribute Table and error log.

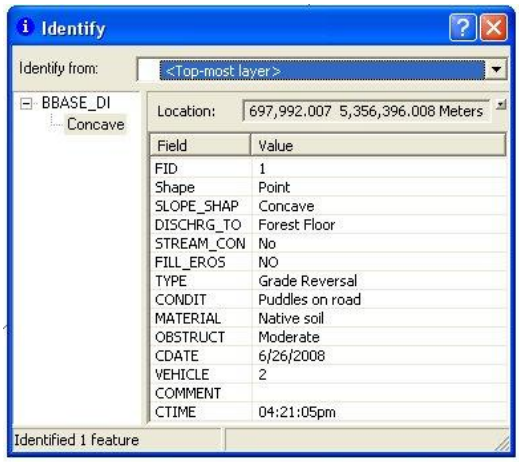
4. For each point in the drain points error log, find the corresponding point in the Attribute Table (same GRAIPDID number).

a. Look at the GRAIPDID number on the error log. Find it in the Attribute Table and click the grey box to the left of the FID column to select that point.

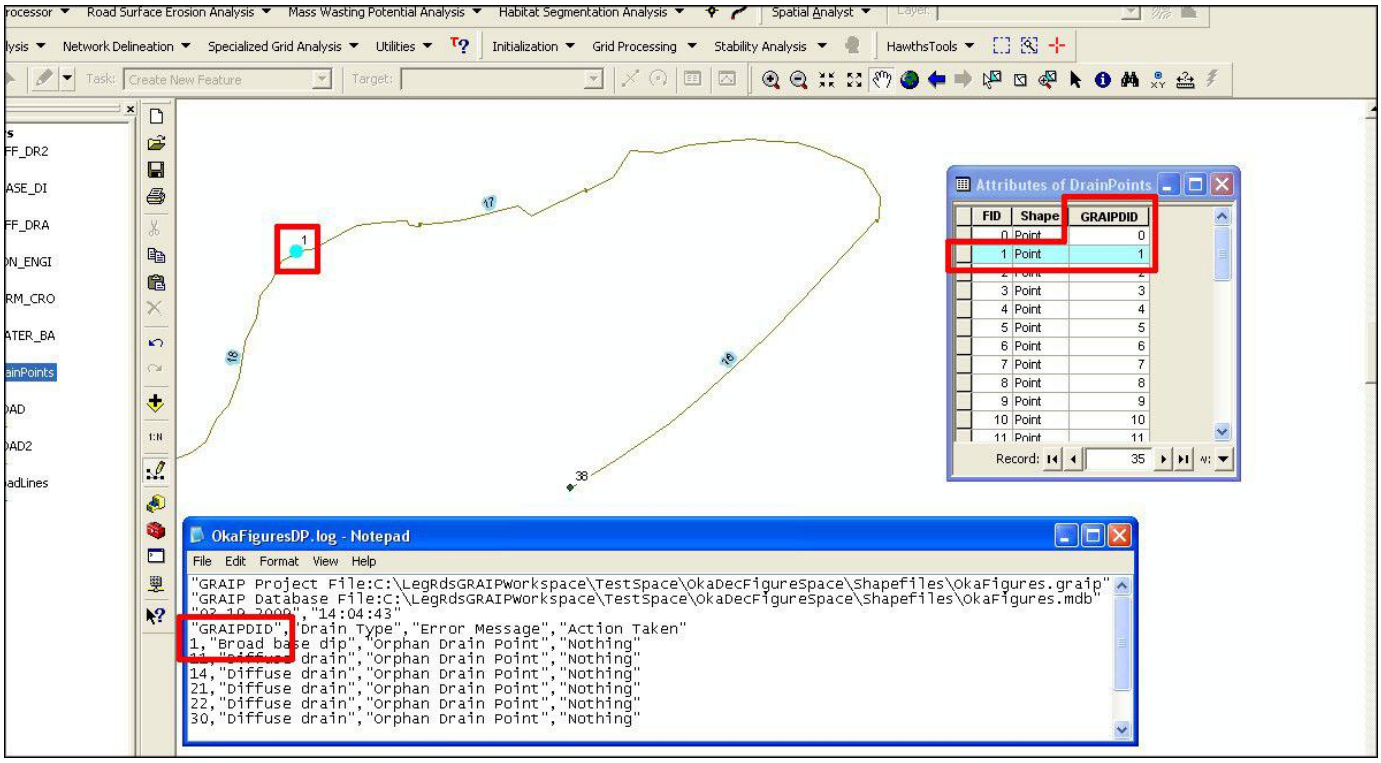
b. Zoom in on the selected point.

i. There are two ways to do this. Either use the *Zoom In* tool from the ArcMap Tools toolbar, or go to the ArcMap Main menu-> *Selection-> Zoom To Selected Features*. You may have to use the *Fixed Zoom In* button from the Tools toolbar to get closer. *Zoom To Selected Features* is available as a button in the Tools toolbar (see the Introduction). Once zoomed into the extent that you want, you may want to use *Pan To Selected Features*.

c. Use the *Identify* tool from the ArcMap Tools toolbar to select the drain point from the original shapefile (e.g. SUMP) that directly overlays the selected (and labeled) point from the DrainPoints layer.



i. Click the *Identify* tool, and click the selected point (which is from the DrainPoints layer). Since the point from the DrainPoints layer is directly underneath the point from the original shapefile, and the *Identify* tool selects the top-most layer by default, the original shapefile is selected. This also applies to the RoadLines and its corresponding original shapefile (ROAD).



d. Alternatively, you may find it easier to use the *Attributes* window from the Editor toolbar.

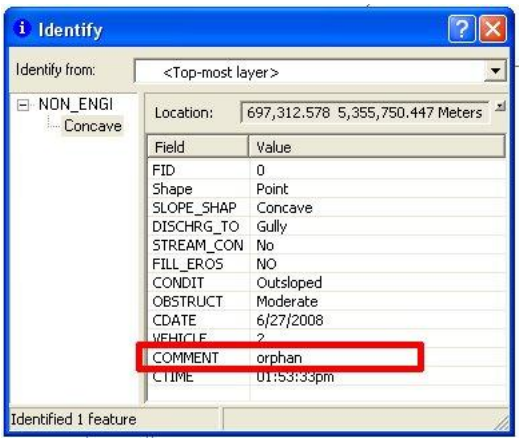
i. After you have begun your editing session, go to the Editor toolbar-> click the *Attributes* button-> pick the *Edit Tool* from the Editor toolbar (the arrow to the immediate right of the *Editor* menu)-> click on a feature (drain point or road line shapefile).

ii. The attributes of that feature appear in the *Attributes* window. You can edit the attributes by clicking in the *Value* column and typing.

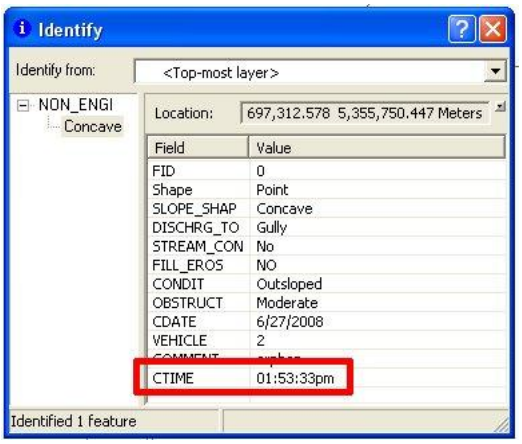
iii. Remember to continue to save your edits.

5. Now you must decide which type of error is occurring at this point and how to fix it.

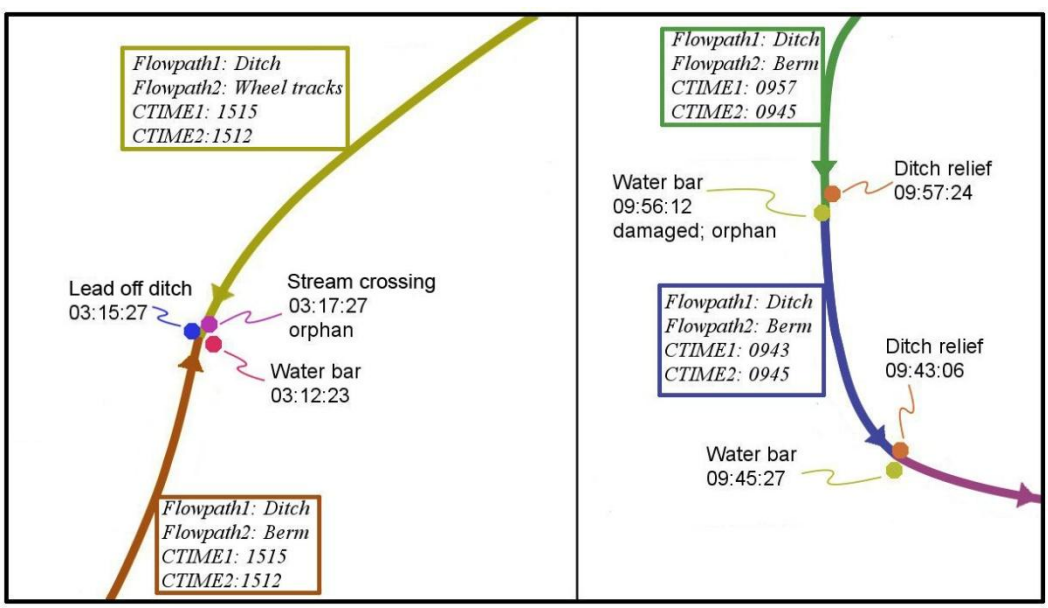
a. In the *Identify* box, look next to the *COMMENTS* field (you may have to scroll down). If the comment says “orphan,” “orph,” “doesn’t drain,” etc., this is most likely an intentionally orphaned point. The latest version of the data dictionary includes a new field in each applicable drain point where crews specify whether that drain point is an orphan. This makes it easier and faster to find intentional orphans in the office. Note this on the error log hard copy, and move on to the next point in the log.



b. Note the *CTIME* in the *Identify* box of the original drain point shapefile. Use the *Identify* tool in the same way to look at the surrounding road segments (in the original shapefile; ROAD). Remember that each road segment has two flow paths.

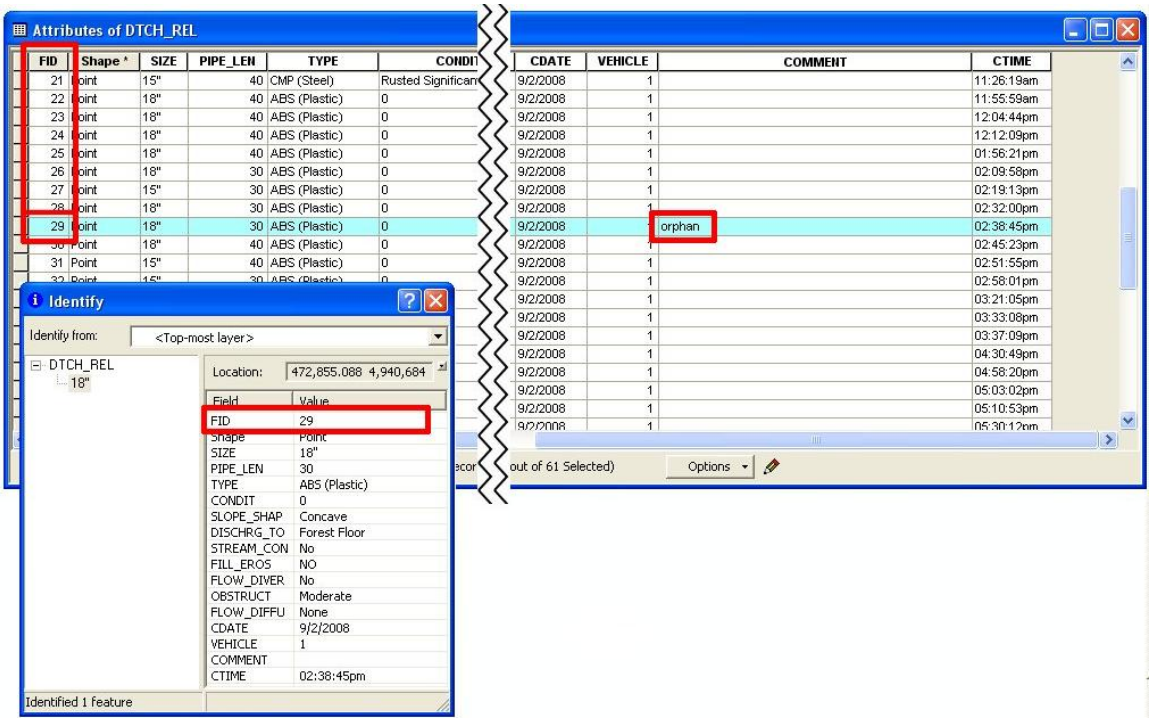


i. If both surrounding road segments have CTimes in both flow paths, check the next drain points down the road on both sides of the problem drain point to



see if those drain points have the same CTimes as those listed in the road segment. You may have to check more than one set of CTimes to be sure. If all road CTimes are accounted for (i.e. all flow paths drain somewhere that is not the drain point in question), the drain point error is probably an unlabeled intentional orphan.

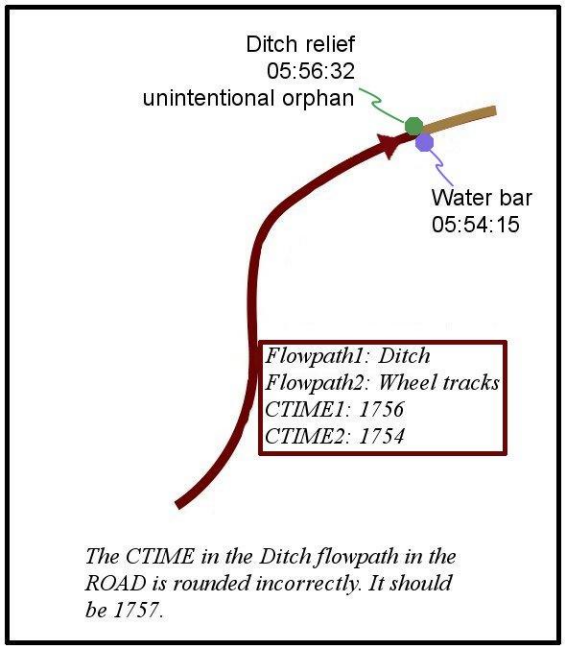
– Label the orphan. Look in the *Identify* box of the drain point in question and note its *FID*. Editor toolbar-> *Editor*-> *Start Editing*. Open the attribute table for that drain point type, scroll to that FID. Select that row and scroll over to the *COMMENT* column. Click that field, and type "true orphan," "unlabeled in field orphan," "orphan," "orph," etc. Go to *Editor*-> *Save Edits*.

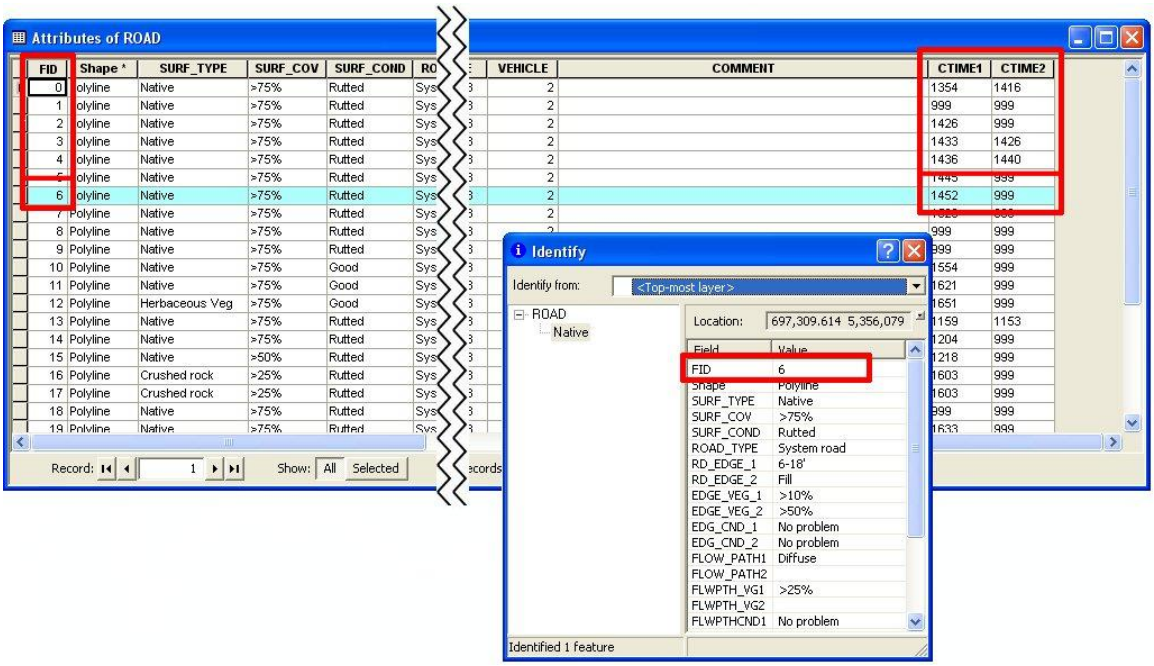


ii. If both surrounding road segments have CTimes in all used flow paths, but not all CTimes are accounted for in nearby drain points, the errant CTime is probably supposed to be the CTime from the problem drain point. Since this is usually a rounding error, the CTime in the road and that in the drain point will probably be within a minute of each other (e.g. 1756 and 05:56:32). One common rounding issue is mentioned above (the 00 = 60 error). Another is the

rounding of drain point CTimes that end in 30 (i.e. 03:15:30pm rounded up instead of down).

– Similar to above, use *Identify* to find the FID of the road, find that FID in the Attribute Table for ROAD, and select it. Scroll over to the CTime columns and enter the correctly rounded CTime from the drain point into the cell with the incorrectly rounded CTime. Save the edit.



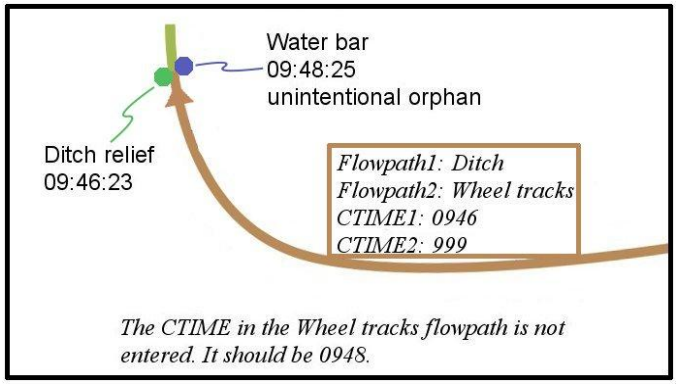


– This is where you might notice the rare - 6 or -7 hours error. If this is the case, check the rest of the drain points of that type. The easiest way to deal with this error is to verify that all drain points in a particular shapefile are affected (they usually are), and then change them in the drain point attribute table all at once using the same method as above. A side effect of this error can be that there are duplicate drain points, which will be noted in the error log. As such, if this error is discovered, it is best to fix it, and

then re-run the GRAIP Preprocessor, so that a new error log is generated without duplicates or the many -6 or -7 hours drain points.

- Rember that CTimes in the ROAD layer are in 24-hour format, and that xx:xx:30 rounds down, while xx:xx:31 rounds up. Remember that the original drain point must be in the format xx:xx:xx, or GRAIP won't know what the CTime means.

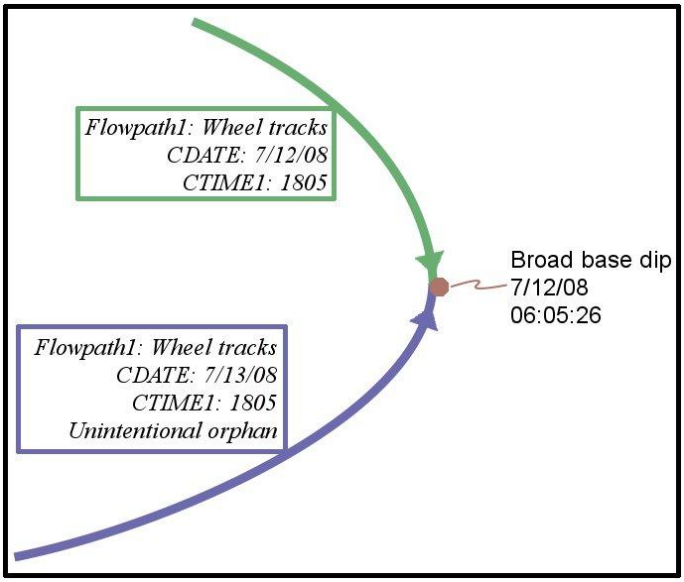
iii. If both surrounding road segments do not have CTimes in all used flow paths, the problem drain point is probably the missing CTime in the ROAD. Check to see that the drain point type makes sense with the flow path. For example, a flow path of ditch would probably drain to a ditch relief culvert or stream crossing, but not a diffuse drain. There are exceptions to any rule like that, but there should be a comment in the road or drain point to describe those situations.



- If the drain point in error appears to be the missing CTime from the road line, enter the correct CTime into the ROAD Attribute Table. As above, use *Identify* to find the FID of the road, find that FID in the Attribute Table, and select it. Scroll over to the CTime columns and enter the correct CTime from the drain point into the missing space. Save the edit.
- If some other drain point appears to be the missing CTime from the road line, enter it in the missing place in ROAD. The errant drain point may be an intentional orphan, described above. The other drain may or may not be in the error log on its own (if it drains another road segment, it won't be in the error log).

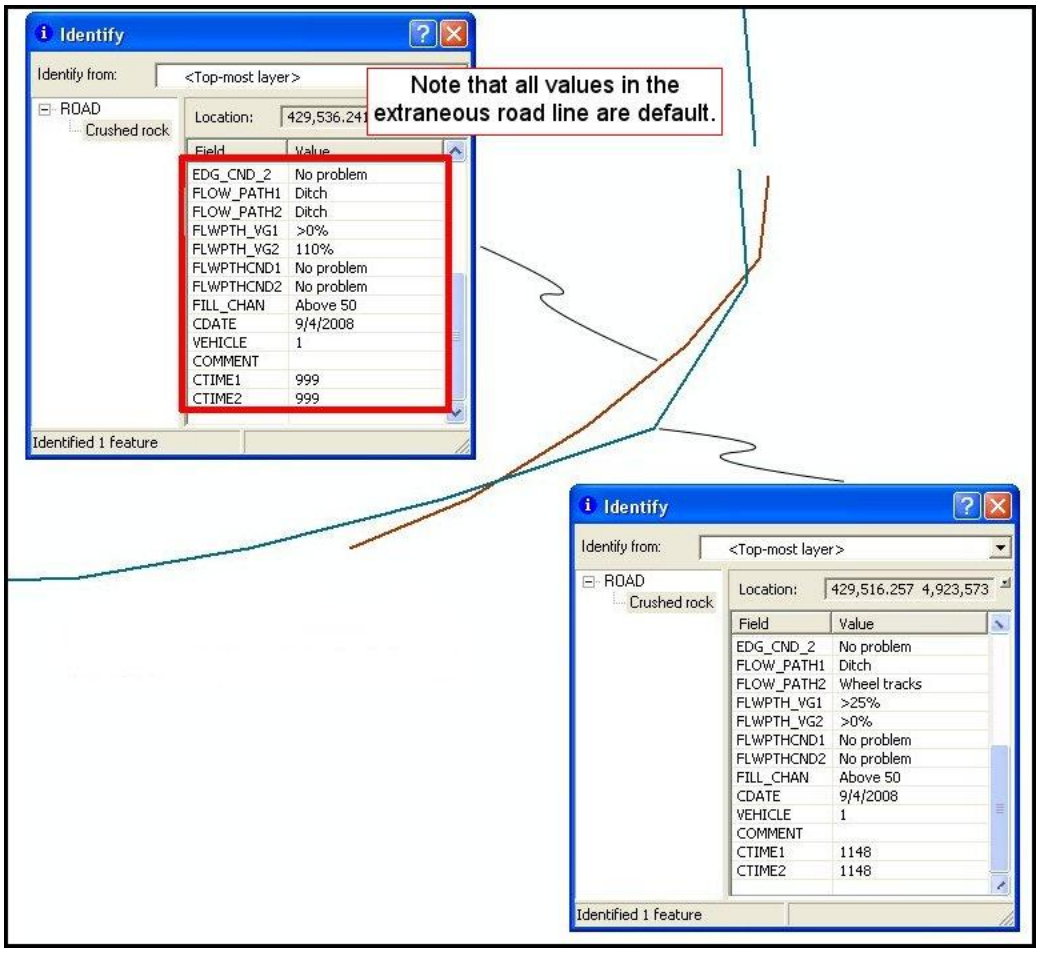
c. Some other errors include those in CDate and VehicleID. These are fairly rare, since neither of those fields are usually changed from default in the field. If it is not clear why an error is occurring from looking at the CTimes, check these fields, and edit as above the incorrect entry. Both fields are in the *Identify* box.

i. CDate errors can occur when a drain point from one day is referenced the next day. Change the CDate in either the road segment or the drain point, whichever is easier. This can get messy if more than one road segment drains to that point, or the road segment has two flow paths, because all drain points associated with the road segment must have the same CTime/CDate/VehicleID combination.



ii. VehicleID errors can result in "Duplicate DrainID: xxxxxxxxx" (where the x's are numbers) errors in the data log. This happens if two crews collected a point at the same time on the same day, but one of the crews accidentally entered the VehicleID of the other crew.

d. The last kind of error will present itself as a drain point or road line with all default properties, as a drain point of the same type, in the same location, and with the same properties as another (except CTime/CDate/VehicleID, which are automatically generated), or as a road line in the same place and with the same properties as another. A field crew may have began to collect the wrong drain point or road line, and then not deleted it, or they may have collected the same drain point or road line on two different days. There is a possibility that this was intentional, but duplicates should be deleted in any case, and resulting errors fixed. If the same point or line was collected on two different days, there is a possibility of generating CTime/CDate/VehicleID errors.



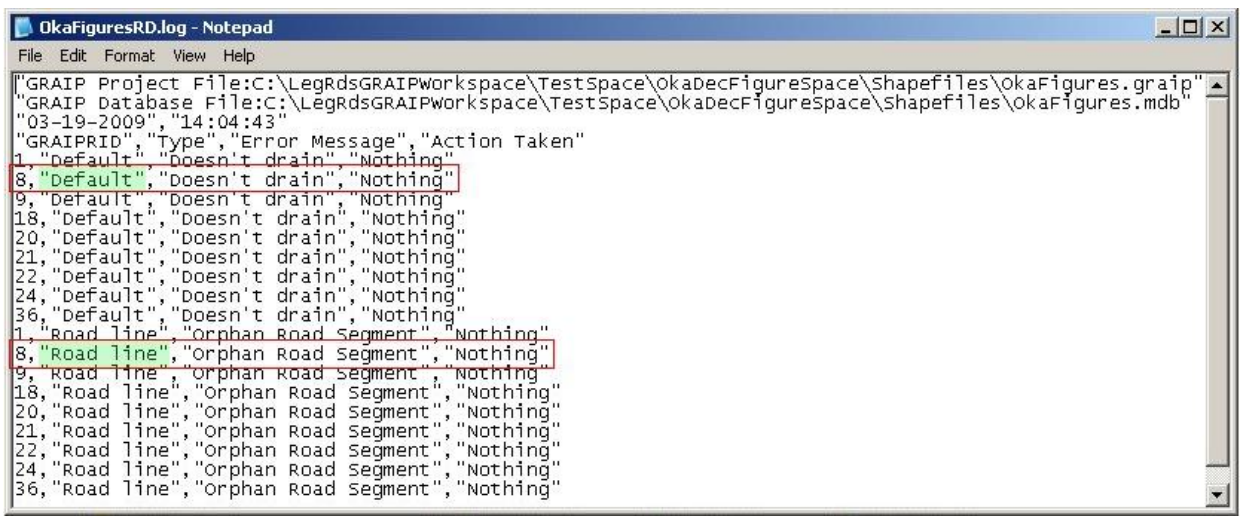
i. Delete duplicate or unintentional drain points. Use the *Edit Tool* from the Editor toolbar to select the erroneous point or line, being sure that you have selected the correct point or line, and then, from the Main Menu-> *Edit*-> *Delete*. Save the edits

ii. Be sure to correct any further errors generated by deleting duplicate points, as above.

6. Repeat the above steps for the rest of the errors in the log, noting in the error log hard copy what has been done to fix the problem (or if the point is an intentional orphan), and saving the edits.

7. Repeat the above steps 3-6 for the ROAD and RoadLines layer. There are no real differences in technique. Often, fixing a drain point error also fixes a road error. Be sure to edit the ROAD layer or the original drain points layer.

a. Note that in the road lines error log, there are two "Types" The first is "Default" and the second is "Road Line." Note that the "GRAIPRID" is the same for each. There is no real difference between the two; for example, GRAIPRID 8 next to "Default" refers to the same road line and error as GRAIPRID 8 next to "Road Line." This does not mean that there are two errors.


OkaFiguresRD.log - Notepad

File Edit Format View Help

```
"GRAIP Project File:C:\LegRdsGRAIPWorkspace\TestSpace\OkaDecFigureSpace\Shapefiles\OkaFigures.graip"
"GRAIP Database File:C:\LegRdsGRAIPWorkspace\TestSpace\OkaDecFigureSpace\Shapefiles\OkaFigures.mdb"
"03-19-2009","14:04:43"
"GRAIPRID","Type","Error Message","Action Taken"
1,"Default","Doesn't drain","Nothing"
8,"Default","Doesn't drain","Nothing"
9,"Default","Doesn't drain","Nothing"
18,"Default","Doesn't drain","Nothing"
20,"Default","Doesn't drain","Nothing"
21,"Default","Doesn't drain","Nothing"
22,"Default","Doesn't drain","Nothing"
24,"Default","Doesn't drain","Nothing"
36,"Default","Doesn't drain","Nothing"
1,"Road line","Orphan Road Segment","Nothing"
8,"Road line","Orphan Road Segment","Nothing"
9,"Road line","Orphan Road Segment","Nothing"
18,"Road line","Orphan Road Segment","Nothing"
20,"Road line","Orphan Road Segment","Nothing"
21,"Road line","Orphan Road Segment","Nothing"
22,"Road line","Orphan Road Segment","Nothing"
24,"Road line","Orphan Road Segment","Nothing"
36,"Road line","Orphan Road Segment","Nothing"
```

8. If only one flow path in a road line does not have a CTime (i.e. the CTime is entered as 999), GRAIP will assign to it the CTime of the other flow path that does have a CTime. This can cause water to be routed to the wrong drain point. Do a final check on the ROAD shapefile to ensure that there are no single orphan flow paths.

a. Open the Attribute Table for the ROAD shapefile-> right-click the column heading to the *CTIME1* column-> click *Sort Descending*. If there are any entries that are 999, then those rows will be moved to the top. You should figure out why

those entries are not valid CTimes, and fix them so that they are. Do the same for the *CTIME2* column. Save the edits.

9. When all errors in the error logs and ROAD shapefiles have been addressed, save the edits, and then go to *Editor-> Stop Editing*. Close ArcMap, or open a new map file (in the ArcMap Main Menu, go to *File-> New…*). There is no need to save the map file because the edits made have already been saved in each edited shapefile.

10. Re-run the GRAIP Preprocessor, as described above. Look at the new error logs to verify that the only errors generated for the drain points are intentional orphans (if any). If you did not delete any duplicate or unintentional drain points or road lines, the GRAIPDID/GRAIPRID numbers assigned to each point or line by the Preprocessor the first time will correspond to the same points or lines the second time. There should not be any errors in the road lines error log, because road line errors are only generated when the road segment has no associated drain points, which cannot happen on the ground. Print the new error log, and save both copies for future reference. If you have to re-run the Preprocessor in the future, you can compare the new error log to the error-free log to ensure that no new errors were generated.

Straightening Road Lines

Commonly low quality GPS satellite location points due to topography and canopy cover result in inaccuracies in the point and line location data. This is generally not a problem with drain point data, because each drain point is an average of 60-100 or more GPS positions. However, road lines are composed of a series of single positions (the vertices) connected in order of collection. As such, what is a fairly small error in a drain point becomes a larger error in the road line. This shows up as zig-zaggy road lines. If the crew stopped moving, but did not stop collecting data, there will be a closely knit group of vertices and road lines that are jumbled; these are referred to as rat's nests (Figure 16).

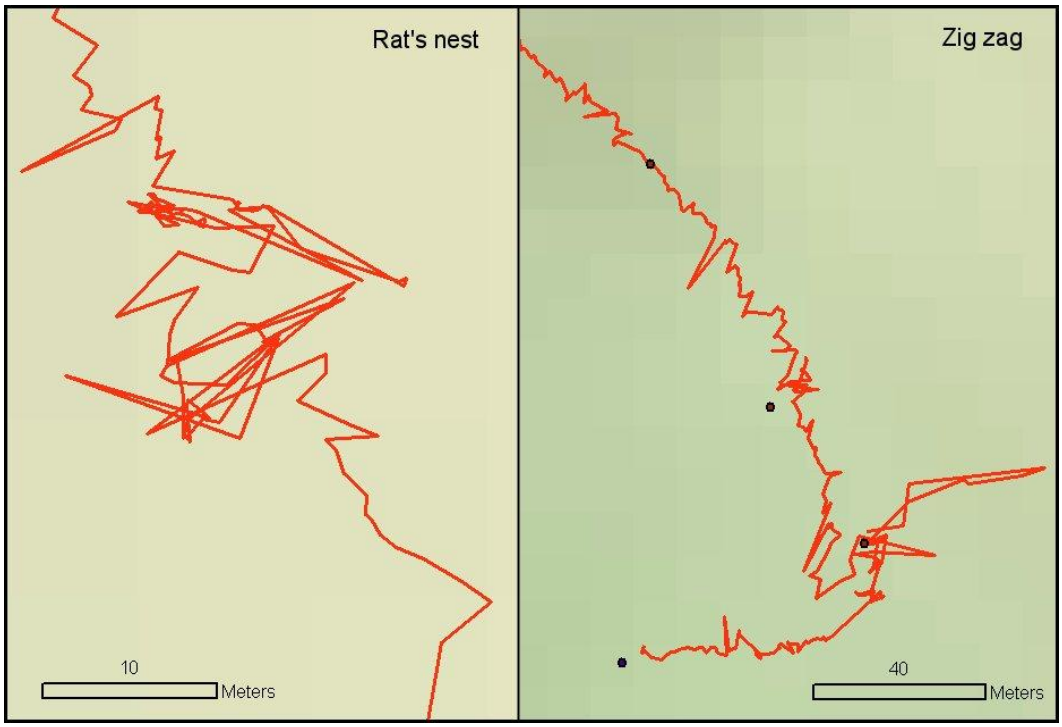


Figure 16. Examples of a rat's nest (left) and a section of very zig zaggy road (right).

Zigzags and rat's nests in the road add length to the road, resulting in inaccuracies with the final data. A rat's nest that spans a small area can contain a lot of extra length. Additionally, zigzags and rat's nests that stray outside of the road's edges can result in inaccurate road slope results. Finally, rat's nests and zigzags get in the way of seeing and easily understanding how the road drains. For these reasons, rat's nests must be eliminated, and zigzags must be straightened. After all of that, the road lines must be compared to an aerial photo to ensure all details of the road's course are included.

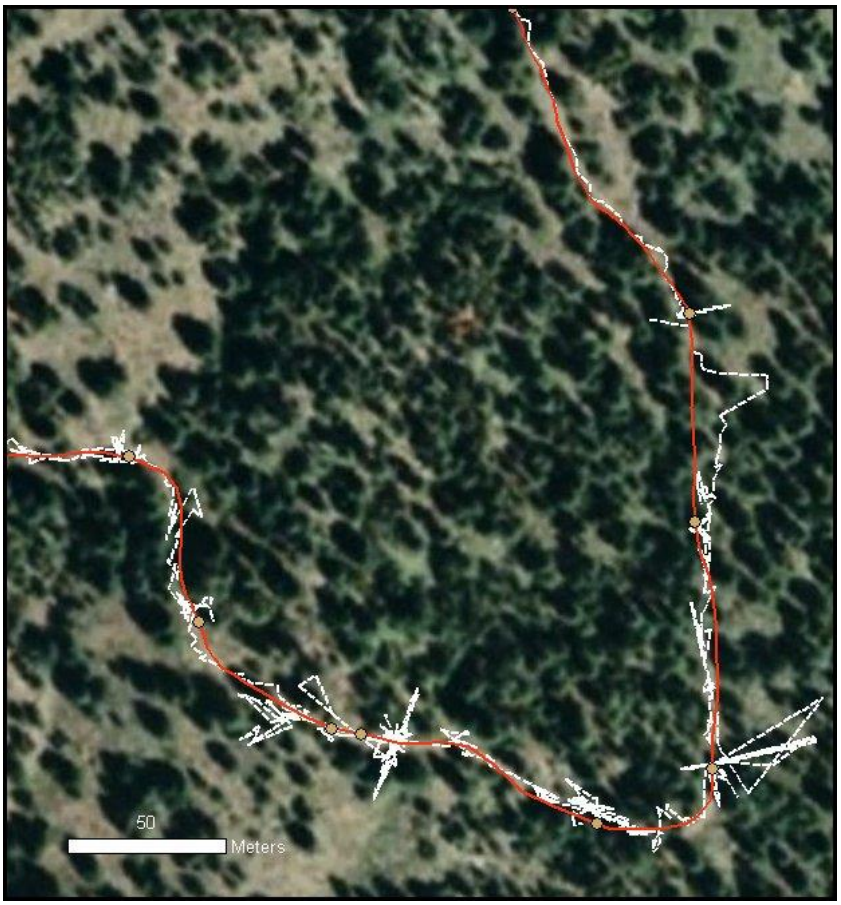


Figure 17. Before (white dashed line) and after (red solid line) the road line straightening process. Note that the straightened road line connects all drain points and is within the bounds of the road on the background image.

In order for the length data to be as accurate as possible, there should be a minimum of zigzag, and no rat's nests, at the end of the straightening process. Additionally, the mapped road lines should always be within the real road's edges (Figure 17). Roads can often be seen on aerial photos. The most important thing when straightening road lines is that they are consistent. Road lines do no need to be perfect. A good guideline for editing road lines is to try to create smoothly curving segments that have a high frequency amplitude of less than six meters. Most forest travel surfaces are about six meters wide. Remember that roads are generally smoothly changing features.

If you use a U.S. Forest Service computer, you can access background aerial photos from the USFS Image Server, which can be found on the web, with instructions, at http://fsweb.rsac.fs.fed.us/imageserver/imageserver.html. Registration problems with the Image Server are often the result of your data not being projected. Open a new map file in ArcMap, add a piece of data that you know is correctly projected, like the DEM, add the image, and then add the rest of the data, as below. You may have to actually re-project the data, as above in step 3b of the Preparing the DEM instructions.

If the road lines are not complete or missing critical data that you cannot infer, or if drain points are likely missing, have the field crew return to the location to recollect data or otherwise clear up the confusion.

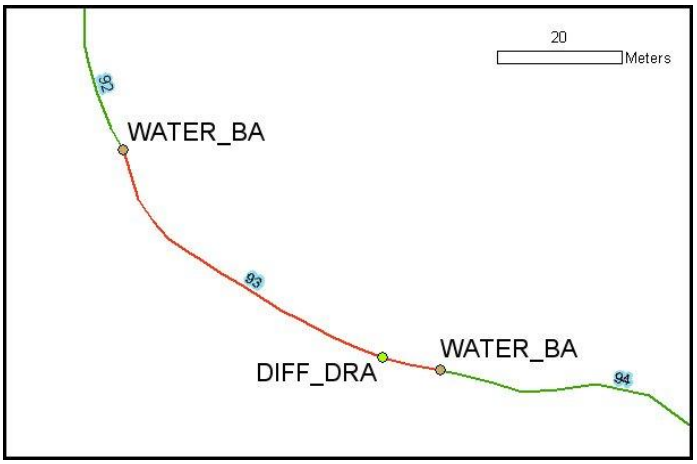
1. Open ArcMap, and add relevant data, described above in step 2 of the Editing Data Errors instructions.

a. Relevant data are all original road lines and drain points (ROAD, SUMP, etc.). If you have a previous version of the road that has already been corrected (as in pre- and post- treatment for the Legacy Roads project), add it as well.

b. A background image can be added now or later, but it will slow things down too much if the layer is left visible.

2. Start editing (Editor toolbar-> *Editor->Start Editing*). Zoom in on the end of a road (1:500 to 1:2000 are good scales for this level of editing). There are three ways to edit a line. If there is zigzag that is composed of only a few points, you can delete or move those points until the road line is straight again. If there is a rat's nest at the end of a line, you can use the *Split* tool to divide the line in two and delete the bad part and recreate the line in the correct location. If the zigzags are composed of many points, there are a series of steps you can take using the Advanced Editing tools that greatly simplify the process. See steps 3 to 6 below.

a. Remember that the drain points are usually fairly accurately located. Use them to connect one road line to another, like connect-the-dots.



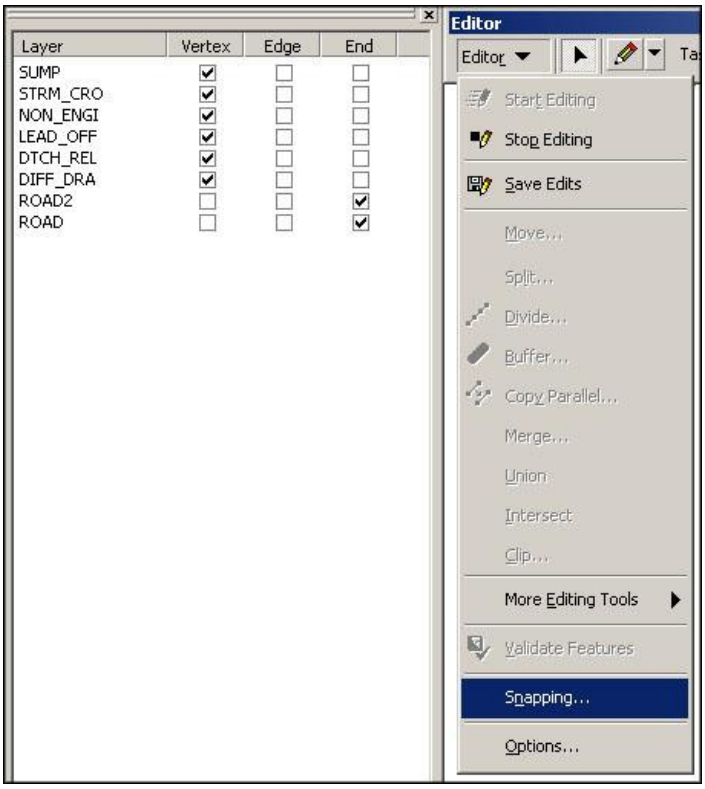
b. The ends of the road lines should be right on top of the drain point, so it is a good idea to use snapping. All drain points should be at the end of the road line, except some orphans and diffuse drain points, which may or may not be at the end of the line.

i. Snapping allows for accurate placement of feature parts relative to other feature parts. When snapping is turned on and set up for this process, road line

vertices that you are moving will jump directly on top of other drain points and the end of other road lines when you move the vertex close enough.

ii. To set up snapping for this purpose, click *Editor* in the Editor toolbar-> click *Snapping....*

– In the window that opens, check the boxes in the *Vertex* column for each of the drain points, and check the box(es) in the *End* column for all of the road line shapefiles. Close the window.

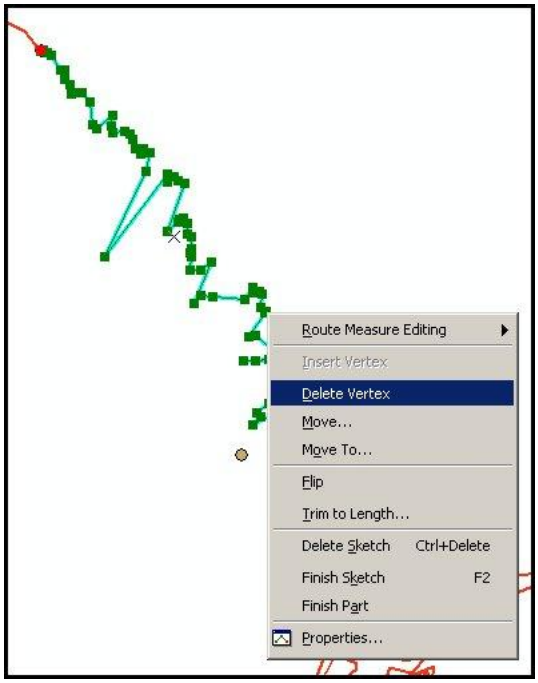


iii. As you move along a road line, be sure to snap the end points of each road line segment to an appropriate drain point or end of adjoining road line (e.g. at the top of a hill). If there are multiple drain points in the same area, you can either pick one of the drain points (not an orphan) to snap both road lines to, or snap the road lines to each other in the middle of the drain points.

3. To delete individual vertices:

a. Pick the *Edit Tool* from the Editor toolbar (the arrow to the immediate right of the *Editor* menu). Double-click the road line to display its vertices.

b. Right-click an errant vertex. This displays some options, including *Delete Vertex*. Select that option.

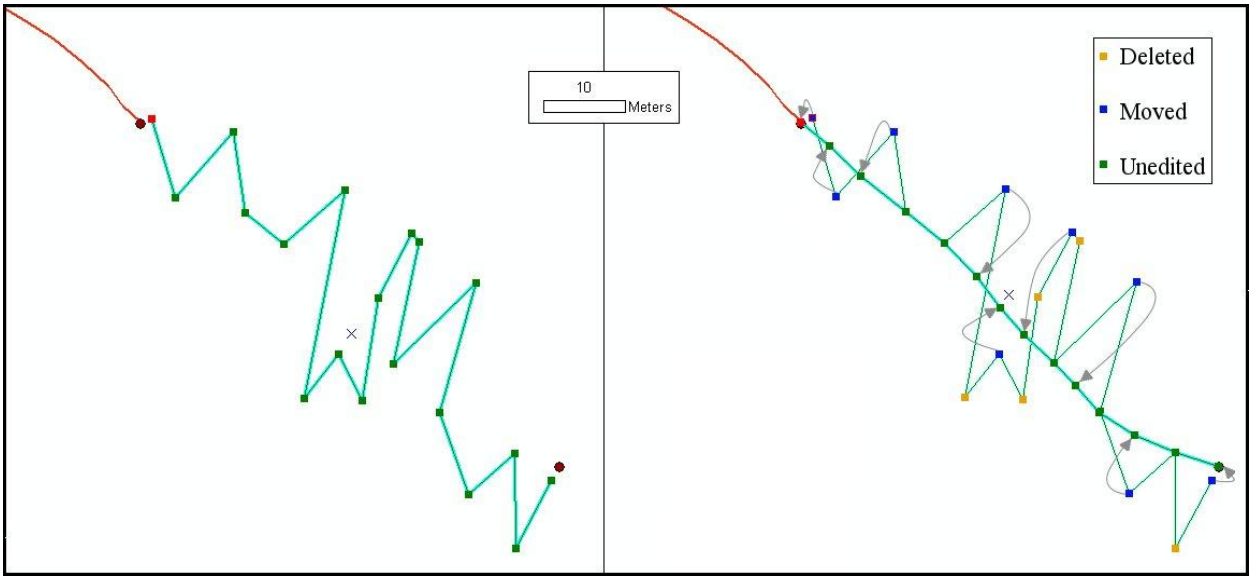


c. You can also insert a vertex on a line from the same menu if you right-click on a portion of line without a vertex.

d. It's OK to delete the red end-point vertex—the next-to-the-end-point vertex becomes the new red end point vertex.

e. A faster way to insert and delete vertices is to right-click the errant vertex or road line and press the *I* key for *Insert Vertex* or the *D* key for *Delete Vertex*.

4. To move a vertex, double-click the line with the *Edit Tool*. Move the *Edit Tool* over the vertex that needs to be moved. Click and drag it to its new location.

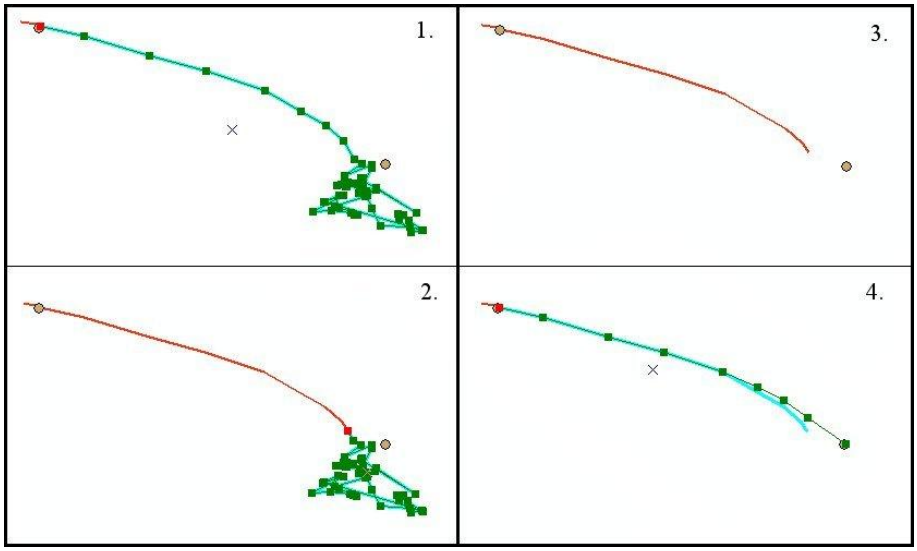


5. To use the *Split Tool* to delete a rat's nest:

a. Select the line with the *Edit Tool* (you may want to show the vertices by double-clicking the line), select the *Split Tool*, and click on the line to one side of the rat's nest or portion of very bad line. You have now divided the single line with a certain set of properties and a certain FID number in the Attribute Table into two lines with the exact same properties. One line retains the original FID number, and the other line is assigned a new number.

b. Use the *Edit Tool* to select and delete the rat's nest or portion of very bad line.

i. Click on the rat's nest or portion of very bad line to select it. In the ArcMap Main Menu, go to *Edit-> Delete*, or hit the Delete key on your keyboard.



c. After a section of road is deleted, you must re-construct that portion of the line by moving the nearest vertices to fill the gap, as in step 4.

d. Save the edits frequently.

e. In order to make sure you haven't deleted anything that shouldn't have been deleted, or left something that should have been deleted, check the Attribute Table for the ROADS layer before you begin, and note how many table entries there are (in the bottom-middle of the table window, *Records (*blank *out of total Selected)*.

Attributes of ROAD

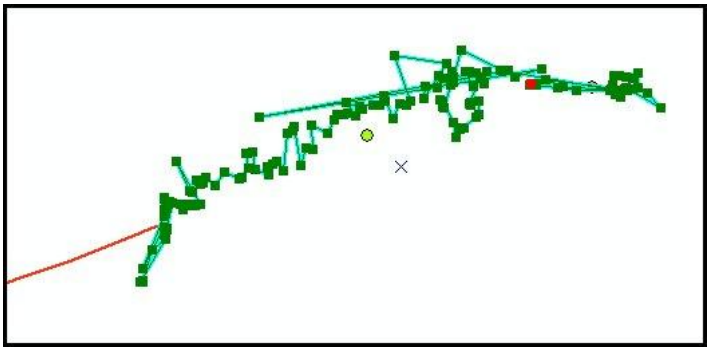
FID	Shape *	SURF_TYPE	SURF_COV	SURF_COND	ROAD_TYPE	RD_EDGE_1	RD_EDGE_2	EDGE_VEG_1	EDG
0	Polyline	Native	>75%	Rutted	System road	0 - 6'	Fill	>25%	>25%
1	Polyline	Crushed rock	>75%	Rutted	System road	0 - 6'	Fill	>25%	>25%
2	Polyline	Native	>75%	Good	System road	0 - 6'	Fill	>25%	>25%
3	Polyline	Native	>75%	Rilled/eroded	System road	0 - 6'	0' no ditch	>25%	>25%
4	Polyline	Native	>75%	Good	System road	0 - 6'	0' no ditch	>25%	>50%
5	Polyline	Native	>75%	Good	System road	6-18'	Fill	>50%	>50%
6	Polyline	Native	>75%	Good	System road	6-18'	Fill	>25%	>25%
7	Polyline	Native	>75%		System road	0 - 6'	Fill	>50%	>50%
8	Polyline	Crushed rock	>75%	Good	System road	0 - 6'	Fill	>25%	>25%
9	Polyline	Native	>75%	Rutted	System road	0 - 6'	Fill	>25%	>50%
10	Polyline	Crushed rock	>75%	Good	System road	0 - 6'	Fill	>25%	>50%

Record: 1 Show: All Selected Records (0 out of 98 Selected) Options

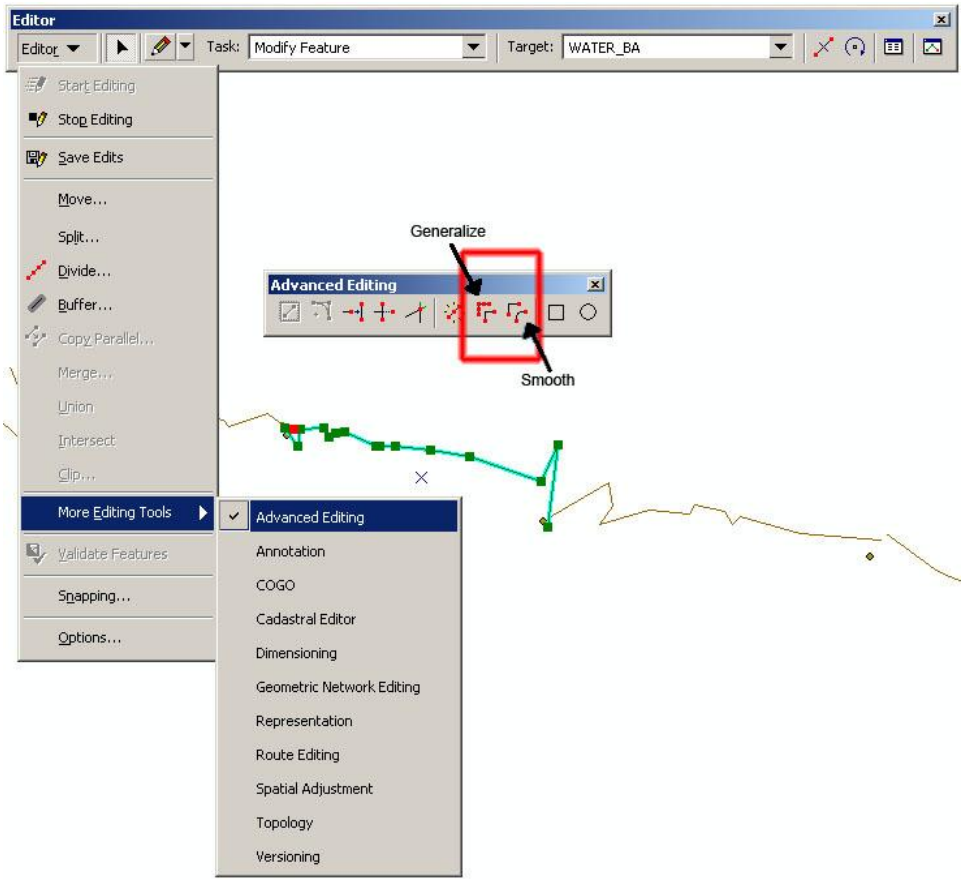
i. Don't use the largest FID number to see how many table entries there are, because these numbers get changed during the line splitting process.

ii. If there are too many records at the end of the line straightening process, sort the table by CTime and look for duplicates. If there are too few records, look for gaps in the road. Note when there are extraneous road segments already present that get deleted as you go along, because these will reduce the total number of records (this is rare; see also step 5d of the Editing Data Errors instructions).

6. If the road line is very erratic and there are many vertices, the best method requires the Advanced Editing tools.

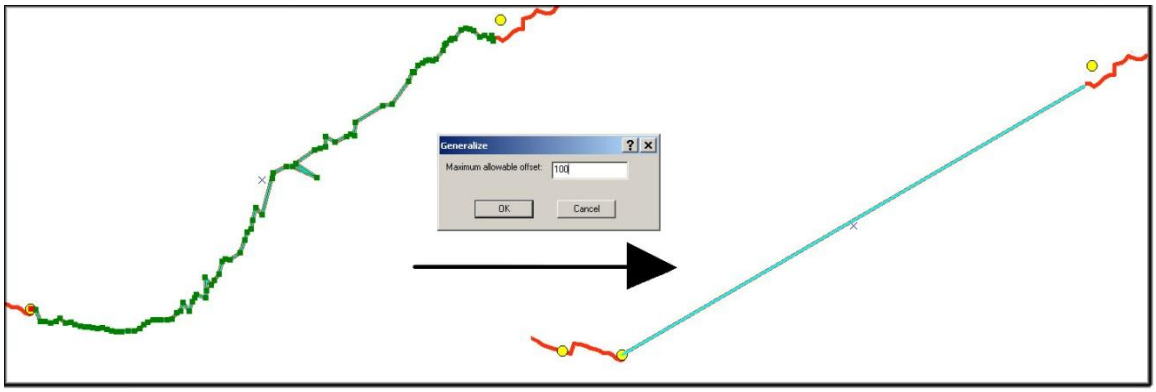


a. To turn on the Advanced Editing tools, go to the Editor toolbar-> *Editor*-> *More Editing Tools*-> click *Advanced Editing*.



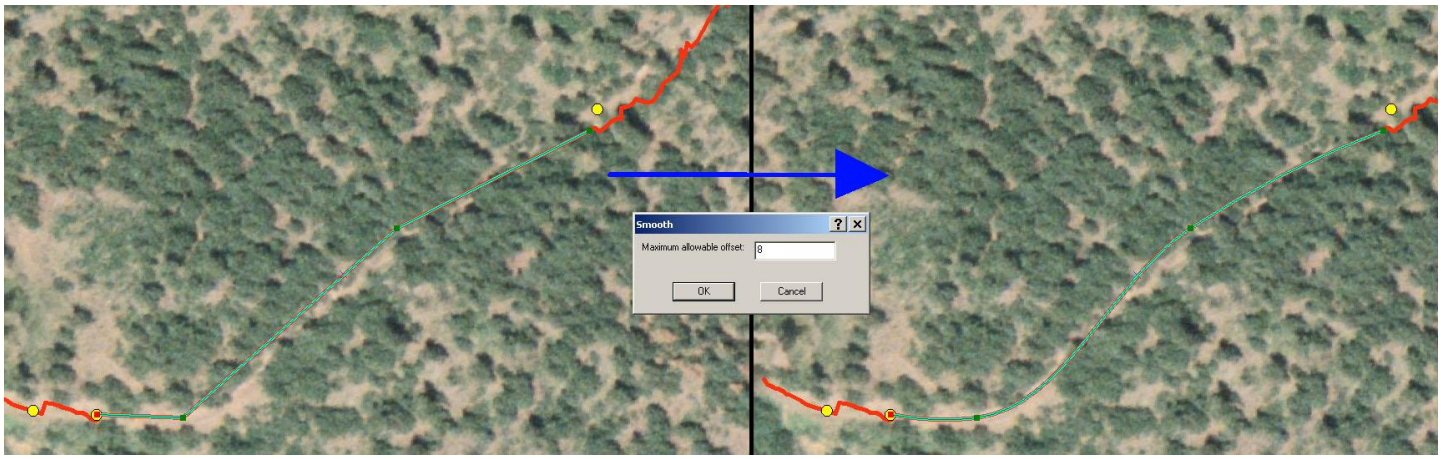
b. With the *Edit* tool, double-click the road line you wish to edit to display its vertices.

c. Go to the Advanced Editing tools-> click *Generalize*-> next to *Maximum allowable offset*, enter a very large number such as 100 -> click *OK*. The road line is reduced to two vertices.



d. Insert and move into place two to four vertices as above so that the road line very generally follows the curve you want it to. Deciding where to do this becomes easier with practice.

e. With the road line vertices displayed, go to Advanced Editing tools-> *Smooth*-> next to *Maximum allowable offset*, enter a number in the range of five to 15-> click *OK*. The road is now a smooth curve without straight connect-the-dots style segments. Deciding which number to enter becomes easier with practice.



f. With the road line vertices displayed, go to Advanced Editing tools-> *Generalize* -> next to *Maximum allowable offset*, enter a small number in the range of one to five-> click *OK*. The road line is returned to being connect-the-dots straight, which allows easier moving of vertices if necessary. Deciding which number to enter becomes easier with practice.

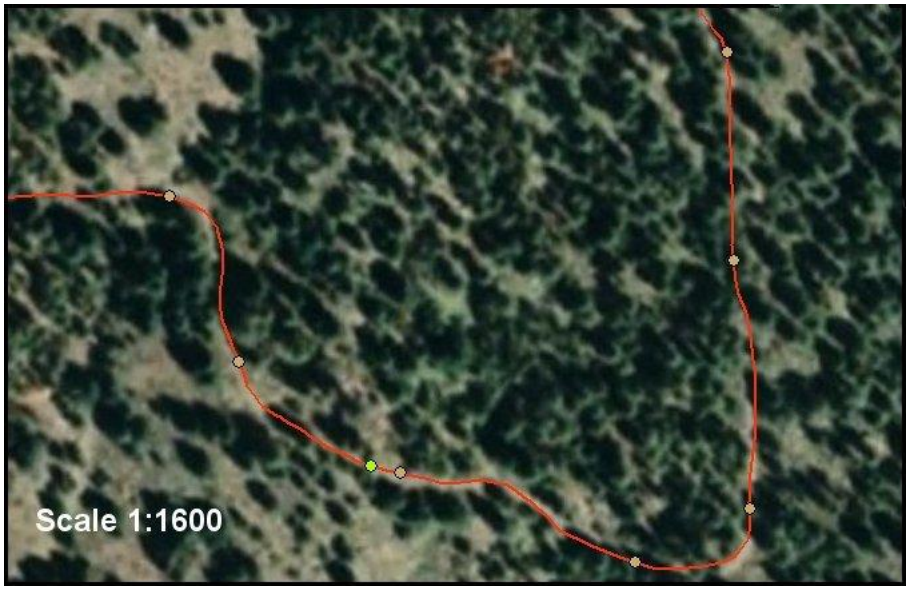
g. Save the edits frequently.

h. You may find that it is easier to do this with a background image. See the next step (step 7).

i. You may find that this method is preferable for all road lines in some areas.

7. If you haven't added a background aerial photo yet, do so now. If you have, turn the layer on.

a. If you have a 1 m resolution image, 1:1600 or so is a good scale. If you zoom in much closer than that, the image becomes blurry and you can't tell where the road is located.



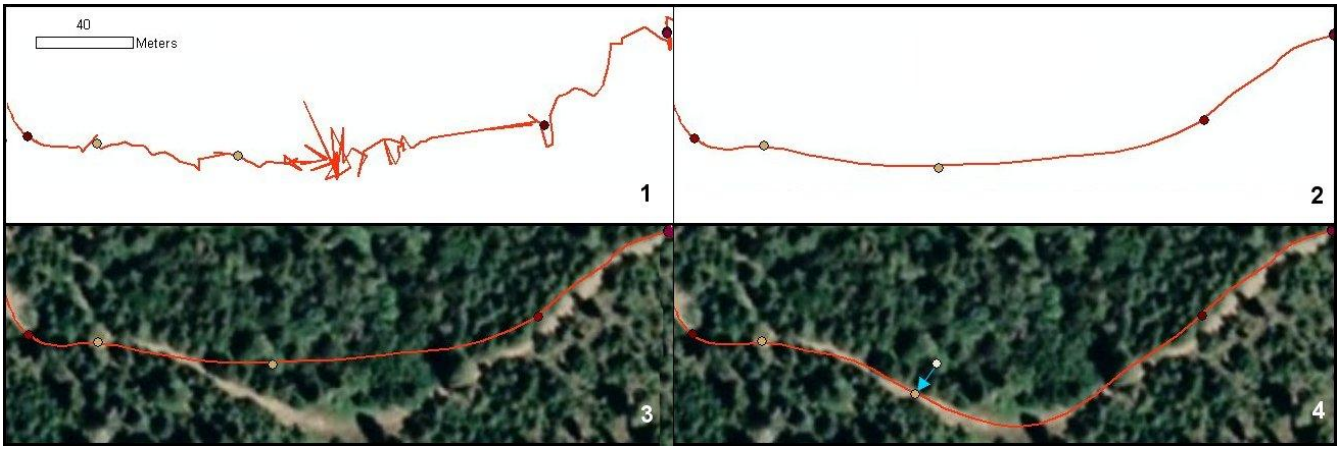
8. Check to make sure the road on the photo is registered the same as the road line from the data.

a. If the road is not registered correctly, you can still use the photo as a guide, but keep the apparent offset in mind as you go.

b. Sometimes, trees and shadows block the view of the road on the photo. Check for photos taken at a higher sun angle. You may have to interpolate and guess in those areas. Some roads are not visible at all on aerial photos.

9. Check to make sure the road line from the data follows the road on the photo, and is contained within the width of the road on the photo.

a. Start at one end of the road, and work your way along.



b. Often, a road line that has been extensively edited because of abundant zigzags and rat's nests will be off the road on the image in between drain points.

c. Sometimes, even drain points are off of the road. Usually, it's only one drain point in a group of drain points that is errant. If the drain point is more than the road width away from the road, use the *Edit Tool* to select and drag the drain point back to the road.

d. Save the edits frequently.

10. Check the number of entries in the ROAD Attribute Table, as described in step 5e above.

11. When finished, save the edits, stop editing and either close ArcMap or open a new map file, as in step 9 of the Editing Data Errors instructions, above. There is no need to save the map file, because the edits you made have already been saved to the shapefile itself.

12. Re-run the GRAIP Preprocessor, as described above. This will generate RoadLines and DrainPoints shapefiles that reflect the changes made to the road lines.

a. It is a good idea to look at the error logs once more to ensure nothing has changed.

13. The actual GRAIP analysis can now begin.

SECTION III: RUNNING THE GRAIP MODEL

This section describes the steps that are taken to run the actual GRAIP model with the GRAIP toolbar. TauDEM and SINMAP must first be run to generate files to be used by GRAIP. There are some initial steps that must be taken in the GRAIP toolbar and Hawth's Tools before true analysis can begin. There are two main parts of the GRAIP process that must be competed in order, except for the *Combined Stability Index*. There is one further step related to fish passage barriers at stream crossings that you may or may not want to run, depending on the purpose of your study.

Running TauDEM

TauDEM is used to generate a set of grids and shapefiles that are used by GRAIP, including the stream network shapefile (17 files in total). There are 13 grid files created by TauDEM (dem stands for the name of the DEM used): demfel, demsd8, demp, demang, demslp, demad8, demsca, demgord, demplen, demtlen, demsrc, demord, and demw. There are two shapefiles created by TauDEM: demnet, demw. The stream network shapefile (demnet) is associated with FileName.graip, and is added when the .graip is opened The last two files are demtree.dat and demcoord.dat.

TauDEM may take a long time to run, depending on the size of the DEM (the maximum gird size is 7000 x 7000 cells). The folder in which the DEM that is used is placed will be the folder in which all of the TauDEM-generated files are saved to. Later, this is the same folder in which SINMAP will create its folder. As such, it is a good idea to start with a fresh ArcInfo Workspace with only the DEM that you plan to use in it. TauDEM requires that the DEM name not be any longer than seven characters. The DEM should be projected to a rectangular coordinate system, such as UTM, rather than a geographic coordinate system, and should be about 30 m resolution.

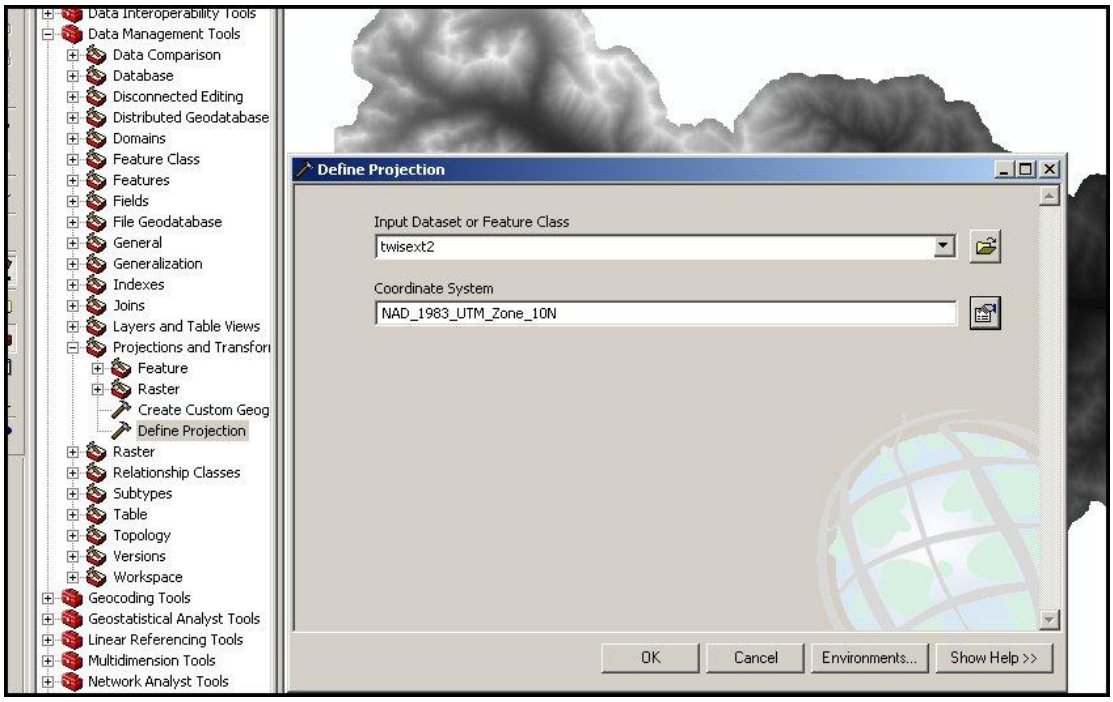
1. The projection for the DEM must be defined if it is not already. If it is defined, skip to step 2.

- **a.** Open ArcMap, add the DEM.
- **b.** Open ArcToolbox.
  - **i.** ArcMap Main Menu-> *Window-> ArcToolbox*, or the button in the Standard toolbar.
- **c.** In ArcToolbox, go to *Data Management-> Projections and Transformations-> Define Projection*.

i. Under the *Input Dataset or Feature Class*, use the drop down menu to select the DEM.

ii. Click the box to the left of the *Coordinate System* field-> *Select*-> navigate to the projection that that the DEM is in, click *Add*, then *Apply* and *OK*.

iii. Click *OK*. The projection is now defined. This works for any GIS file.

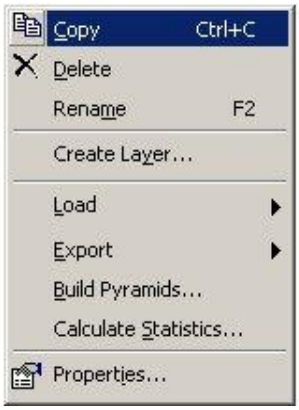


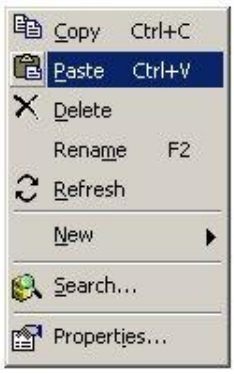
d. Close ArcMap or open a new map file. You don't have to save the map file because the changes are saved automatically. This will set the ArcMap viewer with the correct projection information before TauDEM is run.

2. If you don't have one already, create an ArcInfo workspace for the TauDEM (and later SINMAP) files. This should be done for every data set, even if multiple data sets share the same DEM. If you have done this, skip to step 3.

a. Open ArcCatalog, and navigate to your working folder (see Appendix I for an example of a file system for GRAIP).

b. Right-click-> *New*-> *ArcInfo Workspace*. Rename the new workspace with something obvious (Section I, Figure 8).





c. Navigate to the location of the clipped DEM. Copy it.

i. Right-click the DEM-> *Copy*

d. Navigate back to the new workspace and paste the DEM into it.

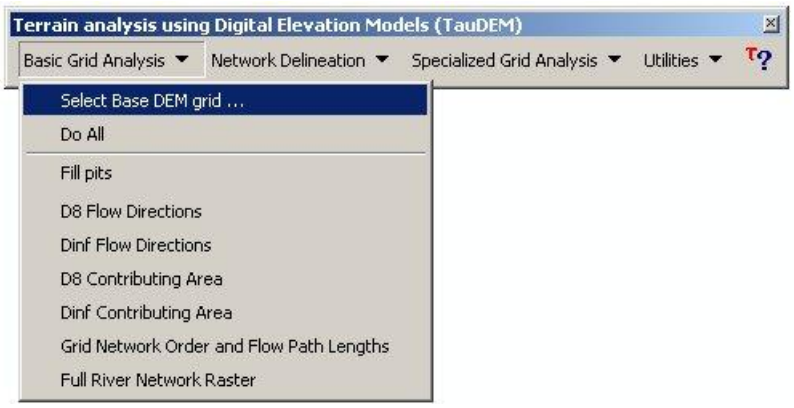
i. Open the workspace folder.

ii. Right-click anywhere in the folder-> *Paste*.

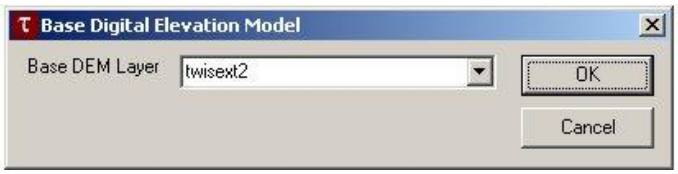
e. Close ArcCatalog or navigate away from the new workspace. TauDEM and ArcGIS might get confused if the workspace they are modifying is active (currently being viewed) in ArcCatalog at the same time.

3. Open ArcMap and add the clipped DEM with the projection defined from the TauDEM workspace to the viewer.

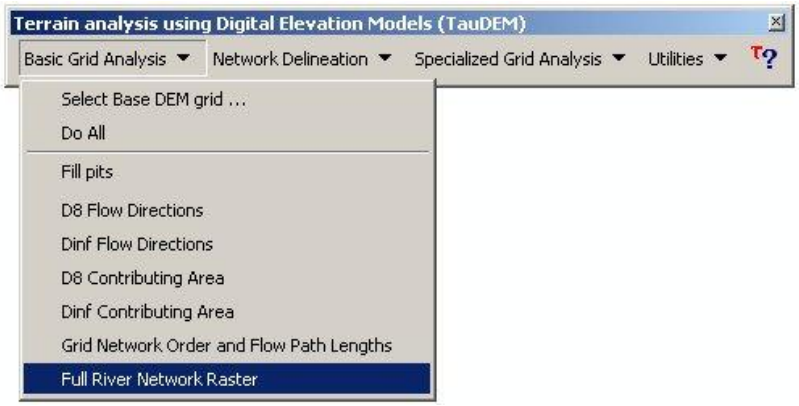
4. It is best to do the rest of these steps one immediately after another. From the TauDEM toolbar-> *Basic Grid Analysis-> Select Base DEM grid…*



a. Use the drop-down menu to select the DEM and click *OK*.



5. Go to *Basic Grid Analysis-> Full River Network Raster*. You don't want to run this step now, just adjust its parameters

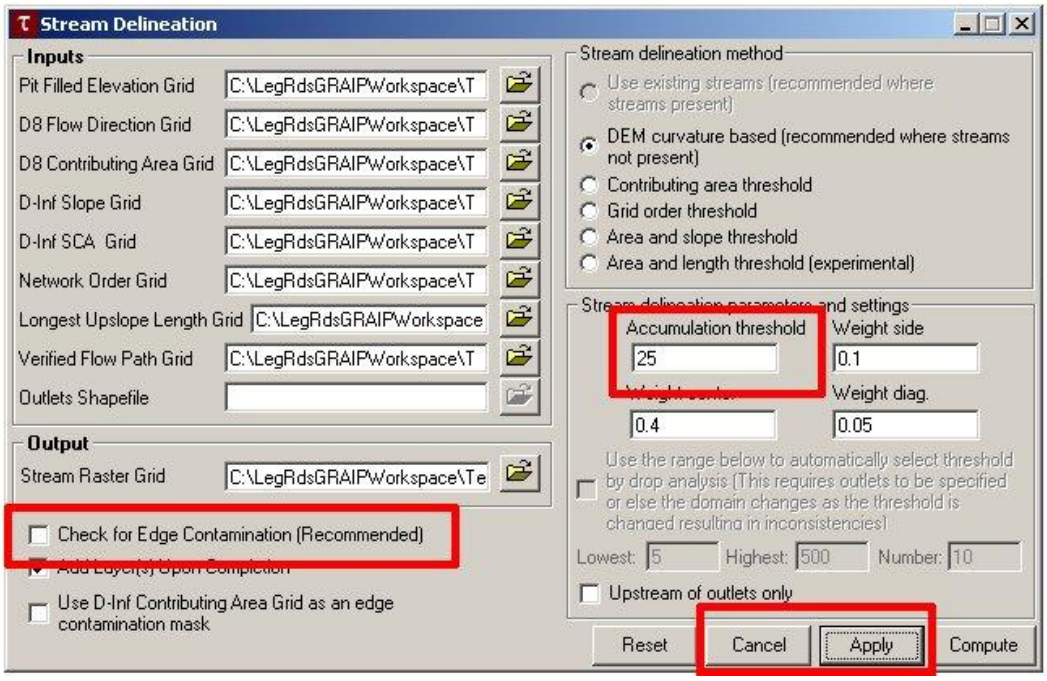


a. Uncheck *Check for Edge Contamination*

i. This will automatically uncheck *Use D-Inf Contributing Area Grid as an edge contamination mask*.

b. Change the *Threshold* to 25

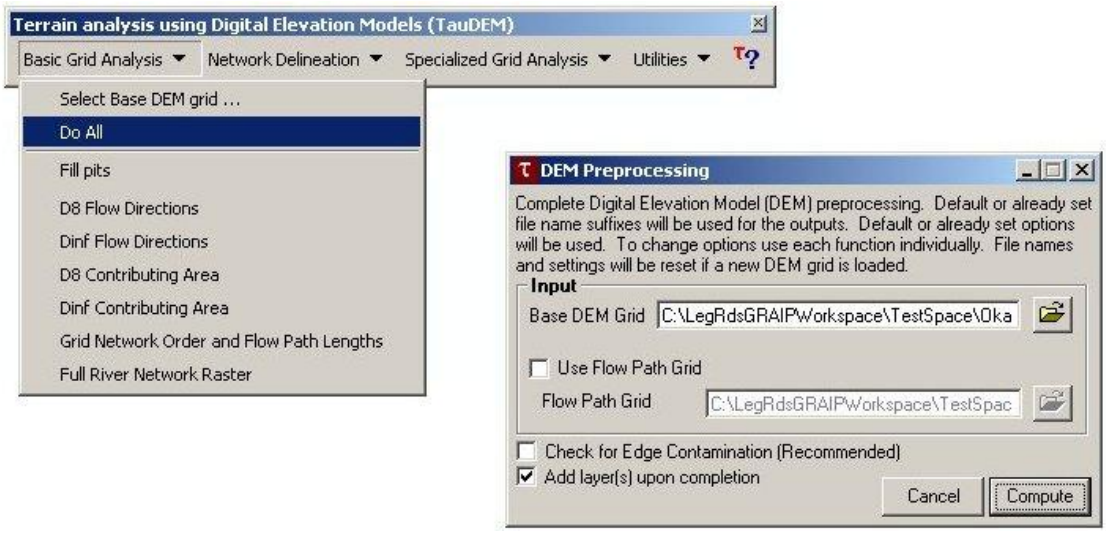
c. Click *Apply* twice (to ensure it registers), then *Cancel*.



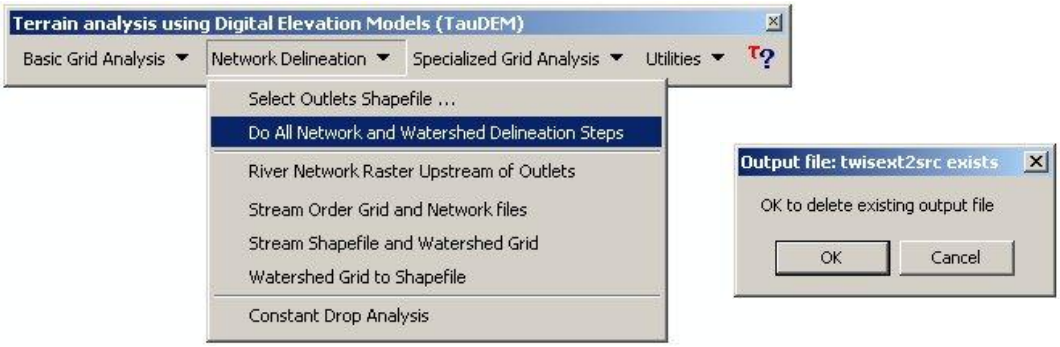
6. Go to *Basic Grid Analysis-> Do All*.

a. Double-check the default parameters and click *Compute*.

b. This step produces 11 grids (demfel, demsd8, demp, demang, demslp, demad8, demsca, demgord, demplen, demlen, demsrc).



7. Go to *Network Delineation-> Do All Network and Watershed Delineation Steps*.



a. Click *OK* when asked if it's OK to delete the existing src output file.

b. This step creates the last four grids and shapefiles (demord, demw, demnet.shp, demw.shp), recreates demsrc (which is why you are asked if the original demsrc can be deleted), and the last two files (.dat extension).

c. Do not use an outlet point.

8. Before proceeding, close ArcMap or open a new map file. This will allow for a fresh start for the next section. You don't have to save the map file because grids and shapefiles are already saved on the hard drive.

Running SINMAP

SINMAP has its basis in the infinite plane slope stability model and produces raster grids that illustrate slope stability (shallow landslide risk) based on hillslope and specific catchment area at each DEM grid cell (Pack et al. 2005). It is usually necessary to calibrate SINMAP to known locations of landslides. The maximum grid size is 7000 x 7000 cells.

SINMAP must be run before the *Mass Wasting Potential Analysis* step and it is easiest to run it before proceeding further with the GRAIP model. It is necessary to create a stability index grid that represents the inherent hillslope mass wasting risk without the roads. This is compared to the stability index grid produced by GRAIP that is modified to account for road related risk (called the combined stability index). In this way, the effect of the road on terrain stability can be determined. Additionally, SINMAP creates a calibration grid that is used by the GRAIP toolbar to determine the combined stability index.

There are seven grids created by SINMAP (demcal, demfel, demang, demslp, demsca, demsi, and demsat), and four text files (demcalp, demrtp, demlsf, and demstat). The grid demcal is the calibration region used later by the GRAIP toolbar. The grid demsi is the stability index grid.

There are three menu headings in the SINMAP toolbar: *Initialization*, *Grid Processing*, and *Stability Analysis*. The *Initialization* menu sets the parameters for the rest of the analysis, and generates the calibration grid (demcal) and a text file (demcalp). The *Grid Processing* menu prepares the DEM for analysis according to the previously determined parameters. It generates a pit-filled DEM grid (demfel), a flow direction grid (demang), a slope grid (demslp), and a contributing area grid (demsca). The *Stability Analysis* menu analyzes the terrain for stability based on the previously determined parameters and generated grids. It generates the stability index grid (demsi) and the saturation grid (demsat), as well as a series of text files (demrtp, demlsf, and demstat).

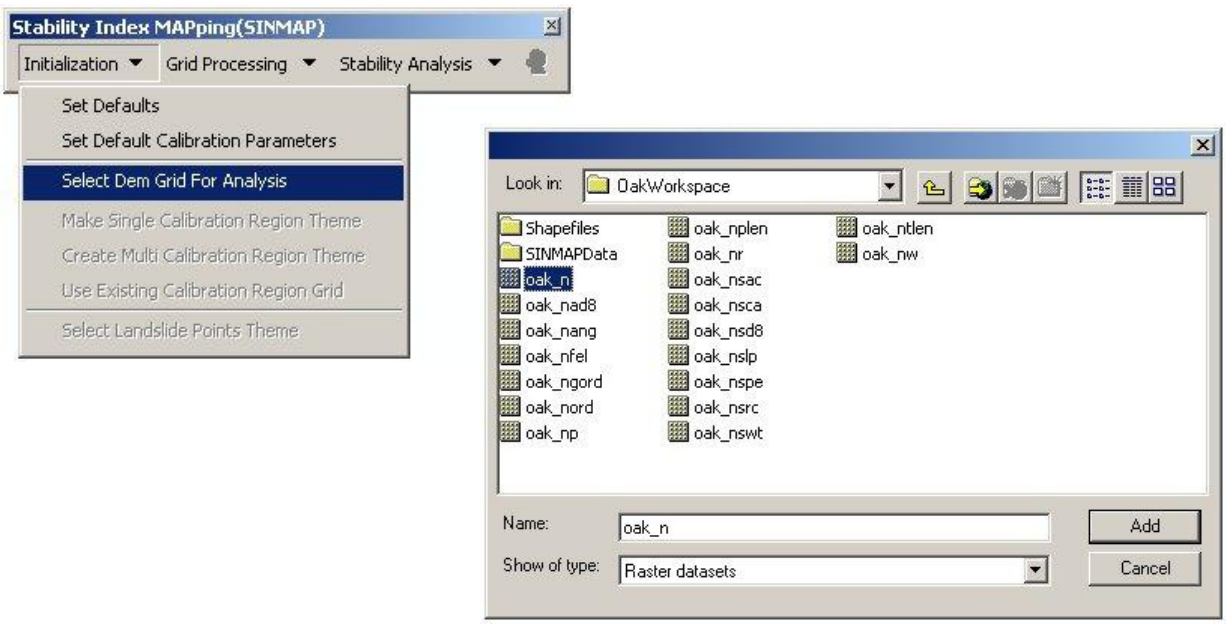
SINMAP creates a folder called SINMAPData for all of its files and grids. This is automatically located in the same directory as the DEM you base the analysis on. This should be the same DEM that has been used all along for the GRAIP process, and is therefore the DEM that is located in the folder with all of the TauDEM files and grids. It might be tempting to use the resampled 5 m DEM because it has a higher resolution, but this will create errors or it will not work at all. You should use a 30 m DEM for this process. Consult the SINMAP manual for more detailed discussion (available through the same SINMAP website as specified in the Introduction).

In order to calibrate SINMAP, you will need a point shapefile of known locations of shallow landslides that occur in similar terrain to that in which your roads are located. If the roads are located in steep country underlain by basalt and at 5000 ft elevation, then the landslides shapefile should cover similar terrain in the same or an adjacent watershed. In this case, you would not want a landslide shapefile for a nearby area that is mostly soft sandstone and is located at only 1500 ft elevation. Many landslide GIS layers are available only as polygons. If this is the case, create a new point shapefile in which you add a point at the uppermost portion of each landslide polygon. There are many ways to do this, but if you are creating or moving points, it is useful to use snapping. Landslide GIS layers may be available at a state level, at a watershed level, etc., and may be

obtained from a state GIS clearinghouse, some other state land management agency, the local or regional Forest Service or BLM website, etc. Be sure that the landslides in your layer are mostly shallow (i.e. not caused by deep underlying geological phenomena).

Calibration consists of changing the parameters that SINMAP uses so that the landslides mostly fall into areas classified as unstable. If there are few landslides in the area of the map classified as stable, and many landslides in the area classified as unstable, then it is simple to infer that the other parts of the map that are classified as unstable but do not yet have recorded landslides are at greater risk of shallow landslides than the areas that are classified as stable.

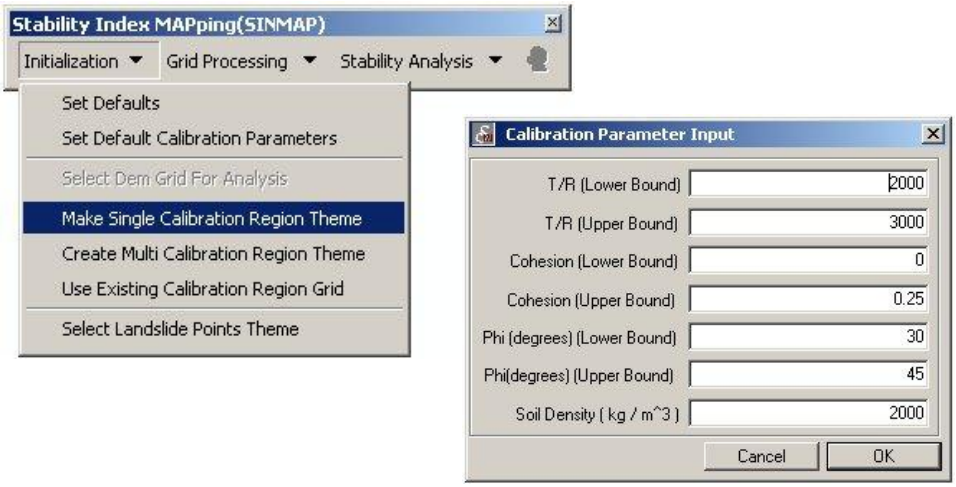
1. Open ArcMap or a new map file. SINAMP toolbar-> *Initialization-> Select DEM Grid For Analysis*.



a. Navigate to the correct DEM, select it, and click *Add*.

b. The selected DEM will be added to ArcMap, and the SINMAPData folder will be created under the same directory as the DEM.

2. SINMAP toolbar-> *Initialization-> Make Single Calibration Region Theme*



a. Various parameters can be changed so that the stability index grid is more accurate for the specific area being analyzed in this step. The defaults are fine for now. If you calibrate to known landslides, you will come back to this step to enter the calibrated parameters and then re-run the rest of SINMAP.

b. Click *OK*.

c. The calibration grid is created, added to ArcMap, and saved to the SINMAPData folder.

3. SINMAP toolbar-> *Initialization-> Select Landslide Points Theme*

a. Do this step only if you have a shallow landslide points shapefile and intend to conduct a calibration; otherwise, skip to step 4.

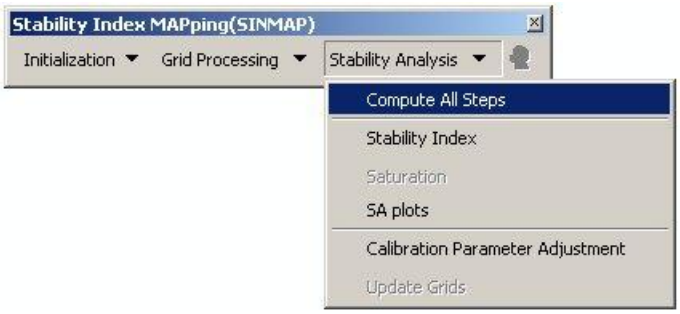
b. Navigate to your landslide points shapefile-> select it-> click *Open*.

4. SINMAP toolbar-> *Grid Processing-> Compute All Steps*

a. No further input is necessary.

b. The above described four grids are created and added to ArcMap, and are saved to the SINMAPData folder.

5. SINMAP toolbar-> *Stability Analysis-> Compute All Steps*



a. No further input is necessary.

b. The above described final two grids are created and added to ArcMap. A statistics window (*S-A Plot*) appears. The grids are saved to the SINMAPData folder.

i. The *S-A Plot* has contributing area on the Y-axis (logarithmic scale) and hillslope on the X-axis. Generally, the greater the slope and contributing area, the greater the risk of shallow landslides.

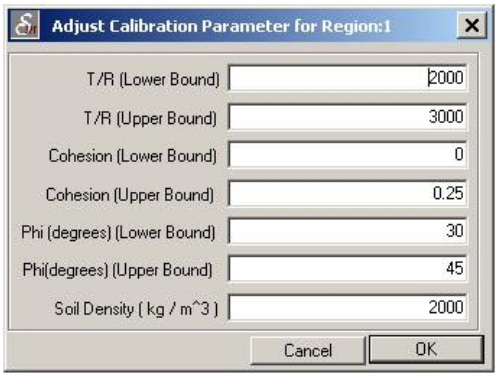
ii. The *S-A Plot* can be generated easily on its own, so you can close this window. Go to *Stability Analysis-> SA plots*.

iii. In the *S-A Plot* window, check both *Region1: -Points* and *Region1: -Lines*.

iv. This plot is used for the calibration of SINMAP to known landslides.

6. Use the *S-A Plot* to calibrate the SI grid. If you do not want to calibrate to landslides, do not do this step.

a. The *S-A Plot* has two buttons in the upper left corner of the window. The *Par Edit* button opens a window, which is where you will enter new calibration parameters. The *Statistics* button opens a window that displays statistics about the distribution of landslides among the various stability regions and how much of the land area falls into the various stability regions.

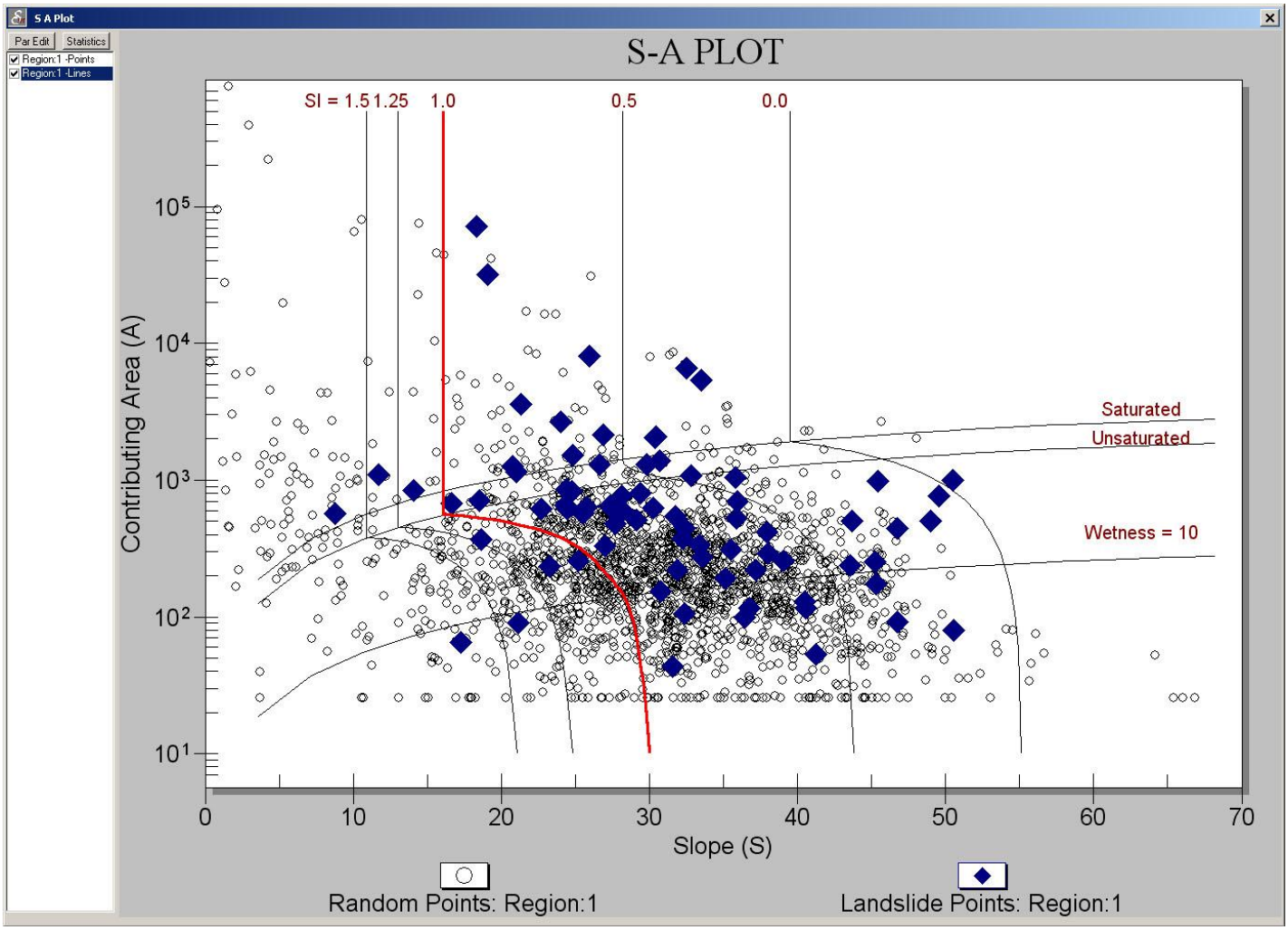


Statistics

	Region	Stable	Moderately Stable	Quasi-Stable	Lower Threshold	Upper Threshold	Defended	Total
Area(km^2)	1	6.515281	3.981777	8.913293	34.049959	6.593723	0.444076	60.498109
% of Region	1	10.769396	6.581655	14.733176	56.282683	10.899057	0.734033	100
# Landslides	1	5	2	4	49	18	1	79
% of Slides	1	6.329114	2.531646	5.063291	62.025316	22.78481	1.265823	100
LS	1	0.082647	0.033059	0.066118	0.809943	0.29753	0.016529	1.305826

b. The main *S-A Plot* shows two kinds of points in its graph. The hollow circles are random points and give a general distribution of the slope-contributing area relationship of the landscape you are working with. The large blue diamonds are where each of the landslides from your landslide points layer fall on the graph.

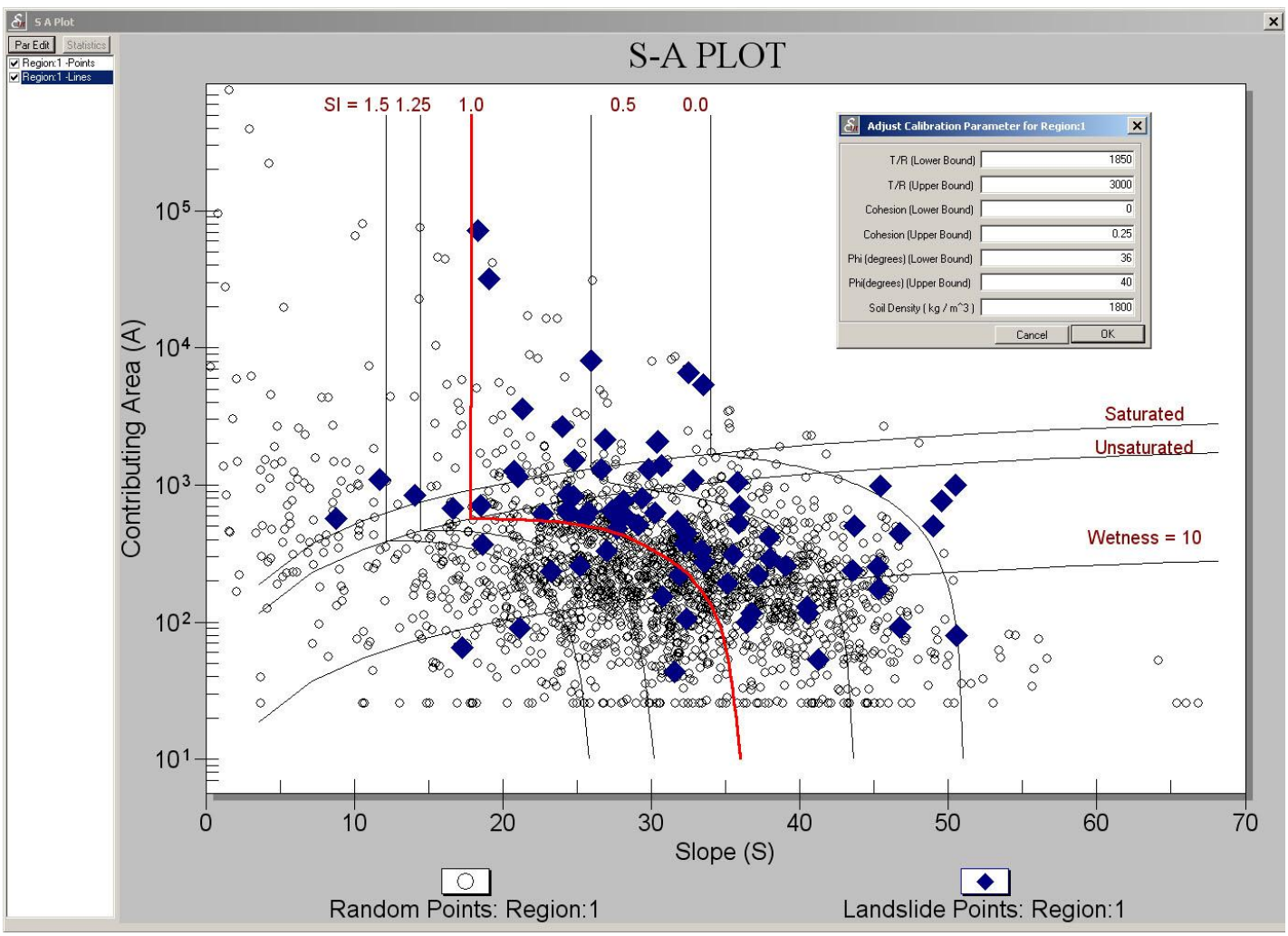
c. Each of the five vertical lines on the graph represents a break between stability index classes. The lines labeled as SI > 1 are the stable regions, and those labeled as SI < 1 are the unstable regions. You may notice that your landslides are weighted to the unstable regions already. The goal of the calibration is to move the break points (the lines) so that the stable to unstable break line (SI = 1) most closely follows the natural break in the landslide distribution. Additionally, the SI = 0.0 line should be moved so that it is on the outside edge of the point distribution (this moves the SI = 0.5 line, as well).



i. If there is no apparent pattern to the landslides (i.e. they are not weighted to one side or the other and are seemingly evenly distributed), a few things could be going on.

- Your landslide layer could cover too large of an area, and cover too much variation in geology, soil type, etc.
- Your landslides may not be driven by slope or contributing area (e.g. they are too deeply seated, such as in bedrock along a fault plane).
- Your landslide layer may not be accurate, due to inconsistencies in their mapping (multiple types of landslides mapped, points misplaced, etc.).

d. Open the *Adjust Calibration Parameter for Region 1* window by clicking on the *Par Edit* button. Each of the values in the window is editable. By changing the values, you change the location of the vertical lines. Generally, the parameters labeled as *Lower Bound* affect the location of the lines with higher SI values (left side), and the parameters labeled *Upper Bound* affect the lower SI values (right side).



i. Iteratively change these values until the lines fit as described above. After each parameter change, click *OK* to see your change take effect in the graph.

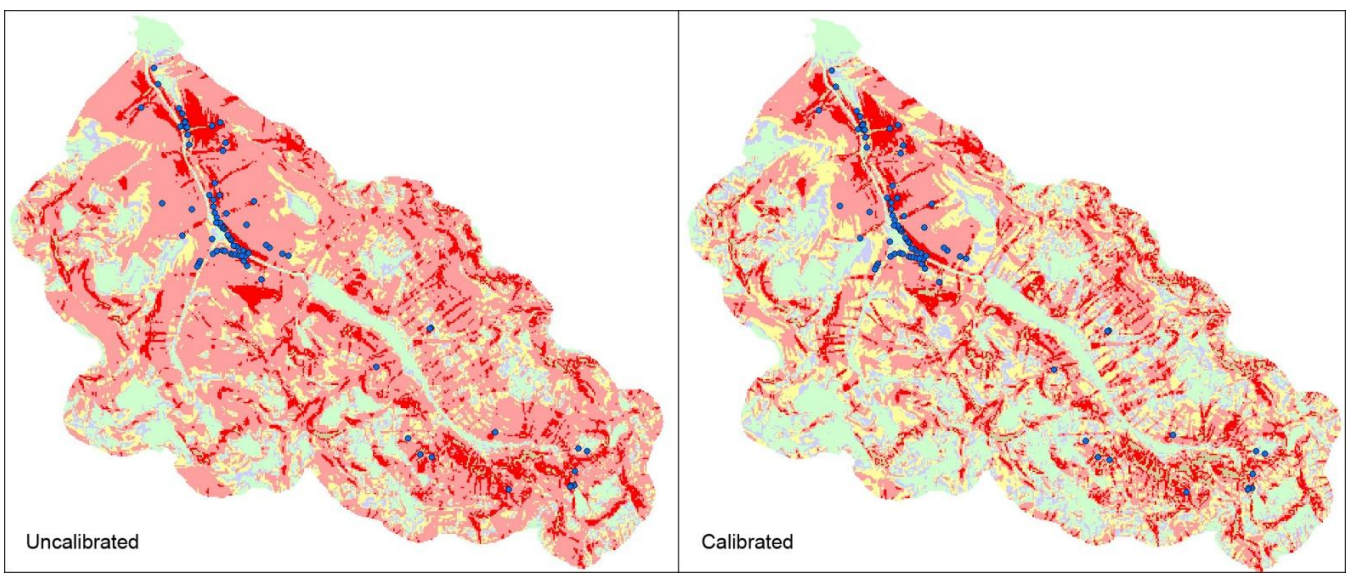
ii. This process becomes easier after you have done it a few times. It is a good idea to play with each value to see what effect it has.

iii. When you have found a good set of parameters that seem to match the landslide data, write them down.

e. Close the *S-A Plot* window, open a new map file or restart ArcMap, and delete the SINMAPData folder that was created earlier and has all of the SINMAP data in it. Do not delete the DEM. You may want to move the SI grid out of the folder so that you can compare the uncalibrated grid to the calibrated grid.

f. Go back to step 1 and run through SINMAP again, except when you create the calibration region, enter the calibrated parameter values that you determined, above. Complete the model run through step 5.

i. The SI grid that is generated is now calibrated according to your parameters. The distribution of the stability regions has changed.



ii. You can view the *Statistics* window in the *S-A Plot* to see exactly how your landslides are distributed. You should see a jump in the *% of Slides* row at the *Lower Threshold* column.

Statistics

	Region	Stable	Moderately Stable	Quasi-Stable	Lower Threshold	Upper Threshold	Defended	Total
Area(km^2)	1	10.840001	7.174588	13.99975	20.168197	6.904253	1.41132	60.498109
% of Region	1	17.917917	11.859194	23.140806	33.336905	11.412345	2.332833	100
# Landslides	1	7	4	6	40	18	4	79
% of Slides	1	8.860759	5.063291	7.594937	50.632911	22.78481	5.063291	99.999999
LS	1	0.115706	0.066118	0.099177	0.661178	0.29753	0.066118	1.305827

g. Make sure to keep a record of the values you used for each calibration parameter, as you may want to come back to rerun SINMAP later, and you will want these values later in the GRAIP analysis.

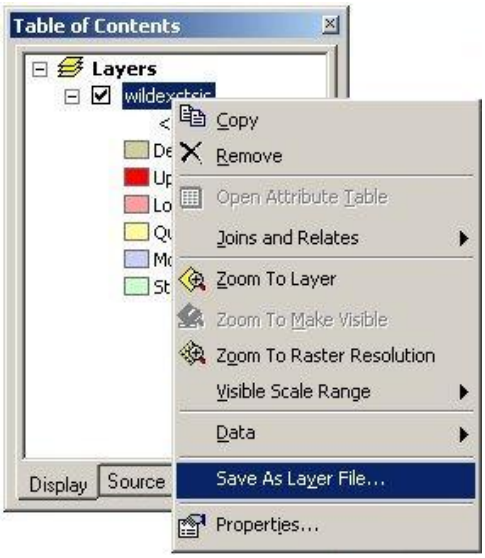
Immediately after its creation, the stability index grid has nice classified, colored, and labeled symbology (Figure 18). This same symbology is present in the combined stability index grid after it is created. If either of those grids are added to ArcMap from a file (i.e. not at the same time that they are created), that symbology is lost. There are two good ways to easily recover the pre-set symbology, without setting it all by hand. They work for both the stability index grid (demsi) and the combined stability index grid (demsic), created later in the GRAIP toolbar as well as any other GIS layer that has symbology that you want to keep.

Symbol	Range	Label
	0 - 0.001	Defended
	0.001 - 0.5	Upper Threshold
	0.5 - 1	Lower Threshold
	1 - 1.25	Quasi-Stable
	1.25 - 1.5	Moderately Stable
	1.5 - 10	Stable

Figure 18. Default symbology of the stability index layers.

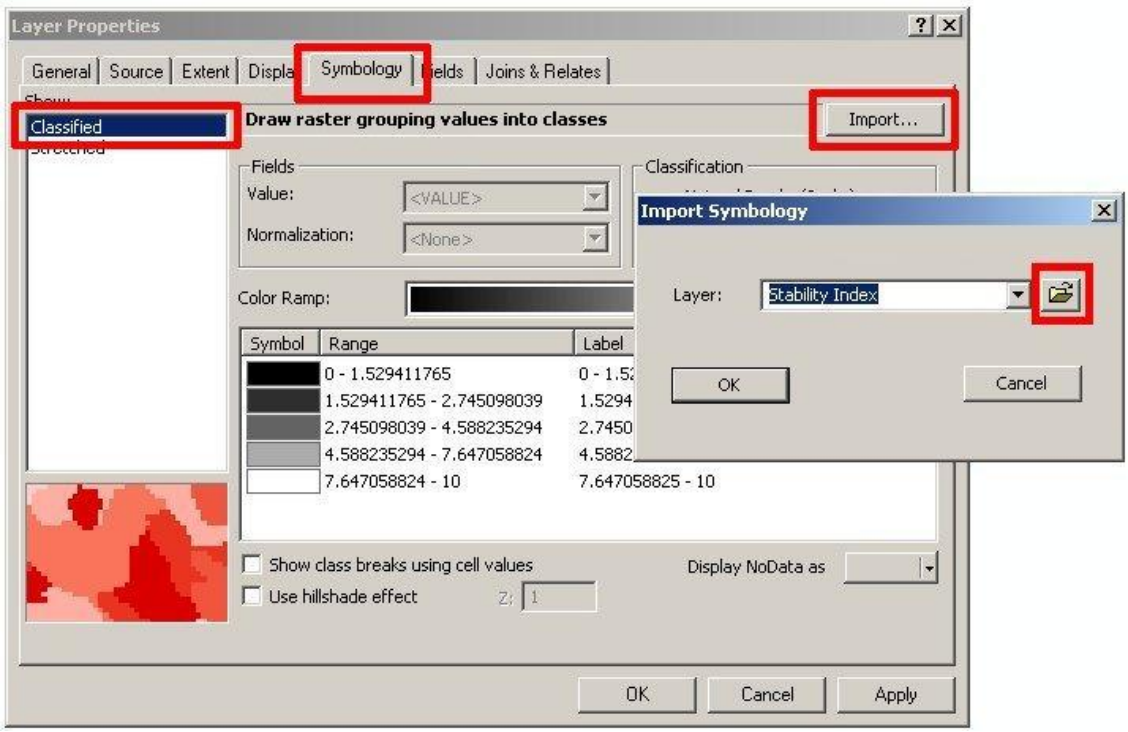
The first method; save a layer with defined symbology as a layer file:

1. After the creation of the stability index grid, go to the *Table of Contents* window-> right-click on the stability index layer name-> *Save As Layer File…*. Choose a name and location-> *Save*.



a. Notice that the file extension is .lyr.

2. To use the symbology of the saved layer file, right click the layer needing symbology in the *Table of Contents* window-> *Properties*-> *Symbology* tab-> click *Classified* in the right-hand section of the screen-> click *Import*-> click the button to the right of the *Layer* field-> navigate to and select the saved layer file-> click *Add*-> click *OK*-> click *OK* to exit the *Properties* window.

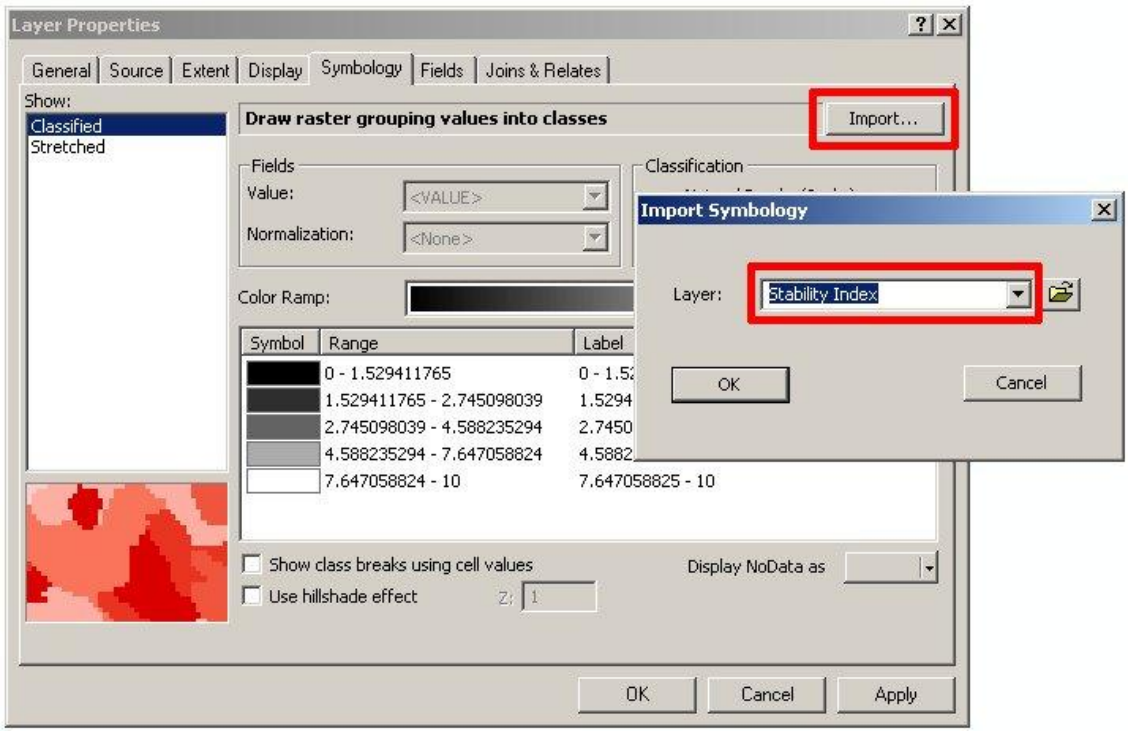


   a. The symbology shows up with the same colors, labels, and breaks as the saved layer file.

The second method; use the already defined symbology of another stability index layer to define the symbology of an undefined stability index layer:

1. Go to the *Symbology*-> *Classified* window of the layer needing symbology. Click *Import*-> use the drop-down to choose the layer that has the symbology you want-> click *OK*-> click *OK* to exit the *Properties* window. (See below).
   a. The symbology shows up with the same colors, labels, and breaks as the chosen layer.

b. Note that if this method is used, and if you change the symbology of the original layer, then the symbology of each of the layers that are based on this layer will also change



The GRAIP Toolbar Menus

There are five main menu headings and two tools in the GRAIP toolbar. The *File* menu (Figure 19) allows you to open the .graip file (Open), save the .graip file (Save and Save As…), and manage where files are saved and found (File Management). The Open

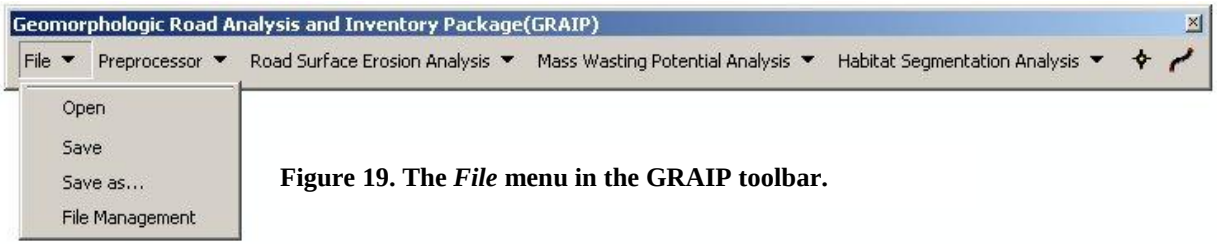


Figure 19. The *File* menu in the GRAIP toolbar.

function adds the DrainPoints, RoadLines, demnet, and DEM to the ArcMap viewer. It is necessary to use the Open function to do this so that the RoadLines and DrainPoints tables can be joined to their corresponding tables in the GRAIP Database (FileName.mdb). Generally, there won't be any reason to use the other functions of this menu. The File Management function can be useful, but it is usually easier and simpler to establish a file system that is compatible with the default parameters (Figure 20).

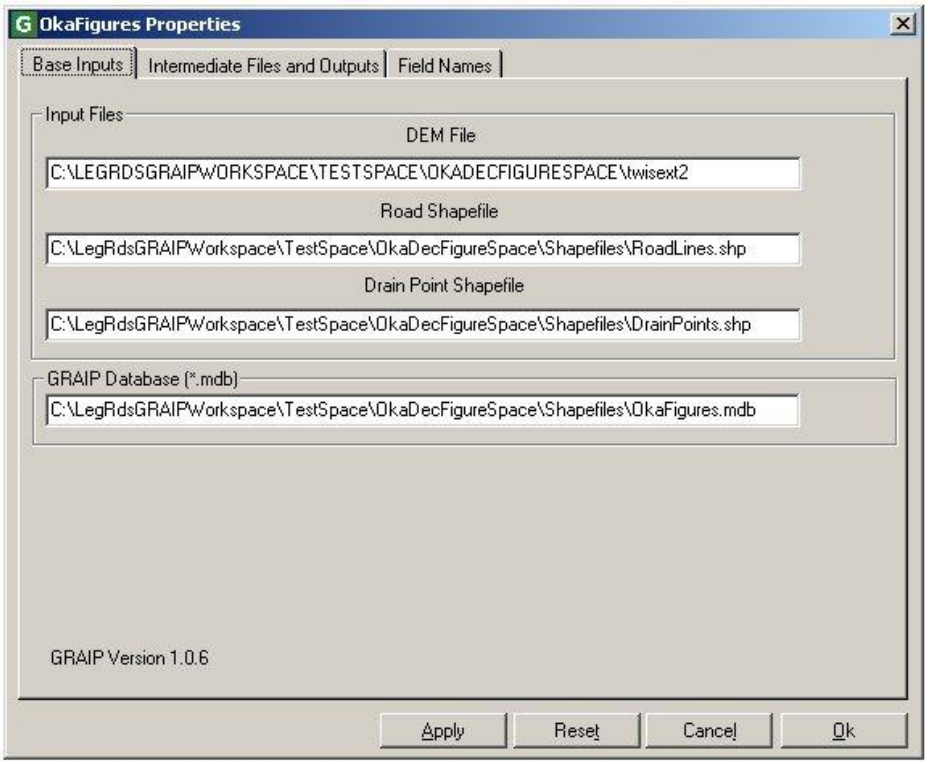


Figure 20. The *File Management* window from the File menu.

The *Preprocessor* menu (Figure 21) allows you to run the GRAIP Preprocessor (*Preprocessor Utility*) and complete a couple of steps necessary before any numbers are generated (*Create TauDEM Stream Network*, and *Resample DEM*). It is better to use the separate GRAIP

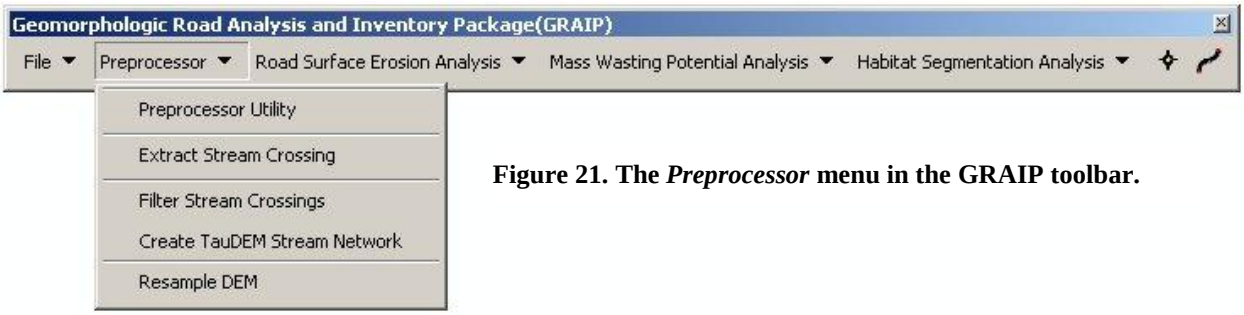


Figure 21. The *Preprocessor* menu in the GRAIP toolbar.

Preprocessor program than that included in this menu. Some of the rest of the steps may not be necessary, depending on what you intend to get from GRAIP.

The last three menus, *Road Surface Erosion Analysis* (Figure 22), *Mass Wasting Potential Analysis* (Figure 24), and *Habitat Segmentation Analysis* (Figure 23) generate the grids and data tables. If you have not done so already, it will be necessary to run SINMAP before beginning the steps under *Mass Wasting Potential Analysis*. Each process from these menus should be run from top to bottom (except the *Combined Stability Index* step, and each menu run from left to right. Often, a step requires something generated in the previous steps. The second step in the *Habitat Segmentation Analysis* menu, *Fish Habitat Segmentation*, is now defunct and non-functional. Information previously generated in this step can be found in other, more efficient ways.

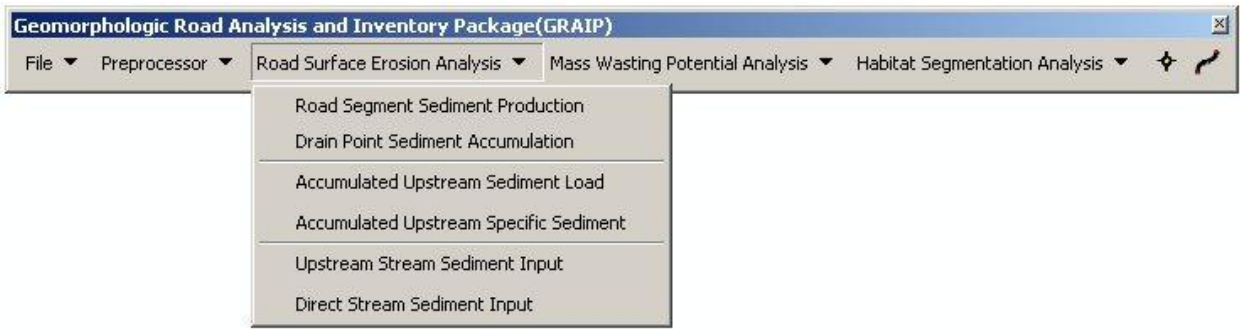


Figure 22. The Road Surface Erosion Analysis menu from the GRAIP toolbar.

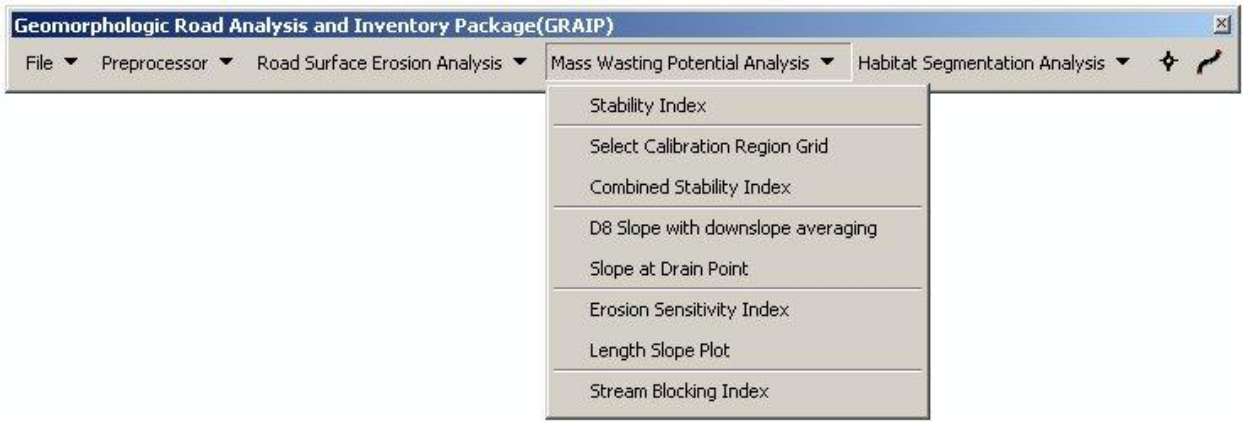


Figure 24. The *Mass Wasting Potential Analysis* menu from the GRAIP toolbar.

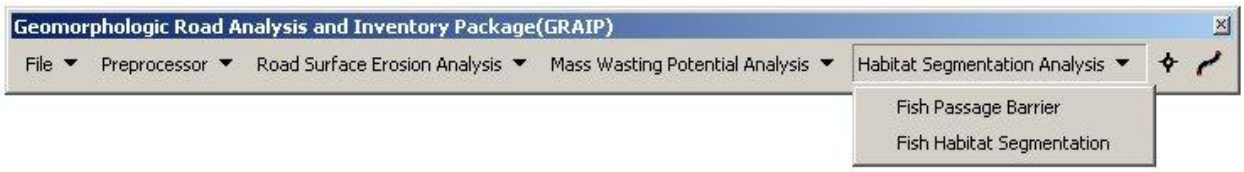


Figure 23. The Habitat Segmentation Analysis menu from the GRAIP toolbar.

The two tools are the *Drain Rex* and *Road Rex* (Figure 25). These trace the road segments that drain to a particular drain, and the drain points that drain a particular road, respectively. They do not work reliably in GRAIP v. 1.0.8 or older. To use them,

select the tool from the toolbar, and click on the drain (for the *Drain Rex*), or road (for the *Road Rex*). The associated road or drain will change color to blue and red, respectively.

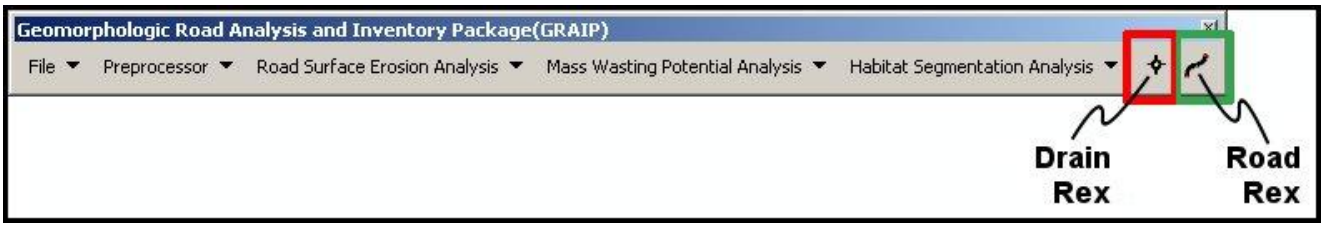


Figure 25. The *Drain Rex* and *Road Rex* tools from the GRAIP toolbar.

Preprocessing

There are five items under the *Preprocessor* menu. The *Preprocessor Utility* is discussed above. *Extract Stream Crossing*, and *Filter Stream Crossings* are related to the old *Fish Habitat Segmentation* step, and are now defunct. *Create TauDEM Stream Network* generates a new stream network shapefile that replaces that generated by TauDEM and is split at the road-stream crossings. *Resample DEM* generates a new DEM that is interpolated to be on a five meter scale for road segment slope analysis.

Additionally, Hawth's Tools is used to create a point file of the intersections of the roads and streams. Hawth's Tools is picky about projections. If the Tools don't work, define the projection of all input layers (described below), or use the alternative method presented below.

Keep in mind that not all stream crossings that have been observed and recorded in the field will show up in the stream network shapefile (Figure 26). The inverse is also true: Not all stream crossings that are in the stream network shapefile will necessarily be recorded in the field. The stream network shapefile is generated based on a set of parameters defined in TauDEM. As such, if the parameters are imperfect, as they always necessarily are, TauDEM will generate a stream network that is more or less dense than observed. The degree of error can be reduced with better stream definition parameters, but not eliminated, because there are exceptions to any rule or parameter in the field. Additionally, there can sometimes be confusion in the field about what, exactly, qualifies as a stream crossing, and so real crossings can be recorded as something else, and non-real crossings can be recorded as crossings. Generally, all of these errors apply to smaller or ephemeral streams that would be unlikely to support fish. If a recorded drain point of any kind is observed to deliver

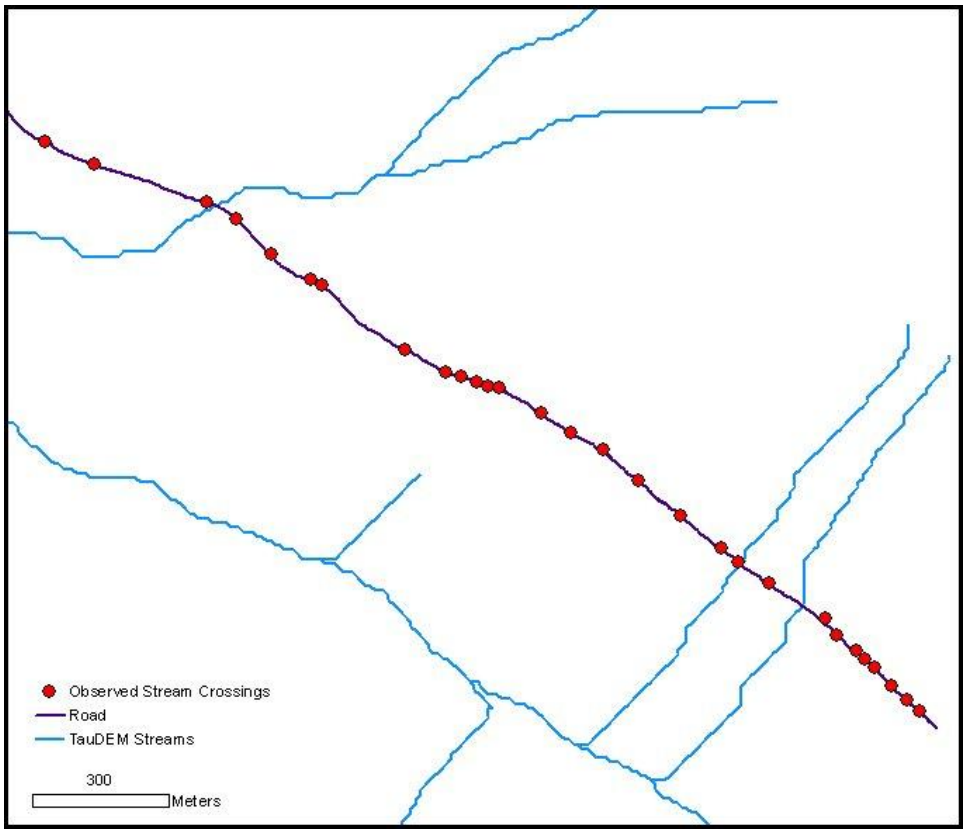
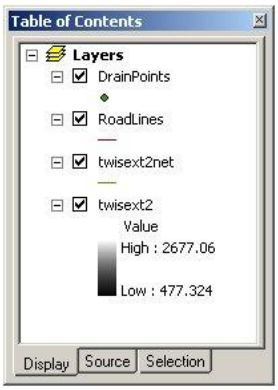


Figure 26. In this example from the Mt. Hood NF in Oregon, there are significantly more streams that were observed (red dots) than were calculated by TauDEM. In this instance, this is because of bedrock controlled springs along this particular road.

sediment to a stream, the model will properly route the sediment downhill, no matter where the stream is in the stream network shapefile. For those reasons, the above errors rarely pose a problem during the data analysis process.

You may want to make a copy of the stream network shapefile (demnet) before proceeding, so that you have an original, uncut version. Place the copy in its own workspace so that it does not get confused for the working copy.

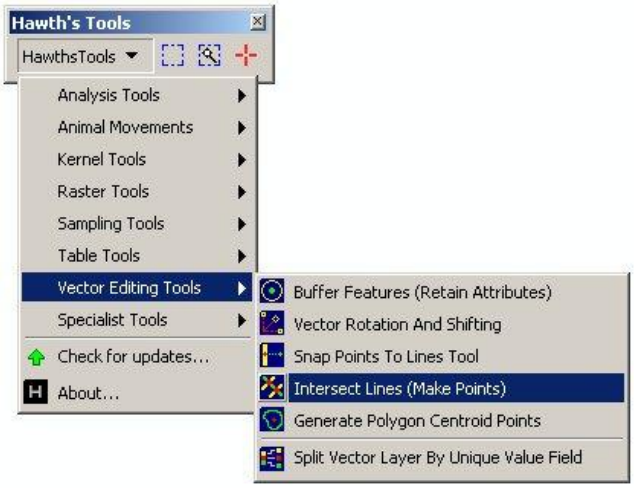


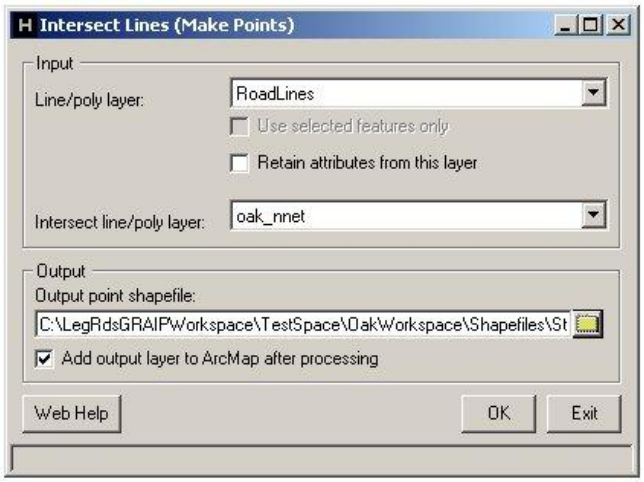
1. Open ArcMap and open the .graip.

a. GRAIP toolbar-> *File*-> *Open*-> navigate to the location of the .graip and select it-> click *OK*. DrainPoints, RoadLines, demnet, and the DEM will be added to the map.

2. Use Hawth's Tools to create points at the road-stream intersections, which make up the Outlets layer used by the GRAIP *Create TauDEM Stream Network* step.

a. Hawth's Tools toolbar-> *HawthsTools* menu-> *Vector Editing Tools*-> *Intersect Lines (make points).*





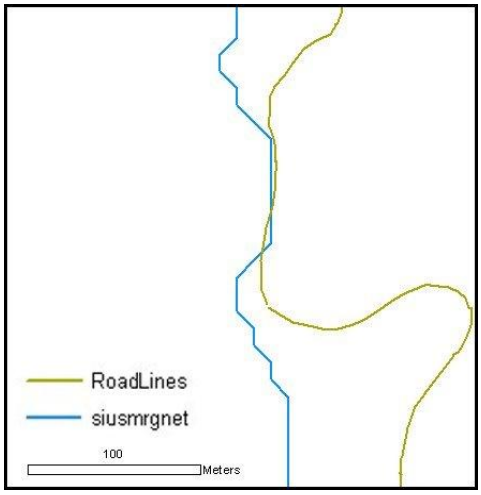
i. For *Line/poly layer*, use the drop down to select the RoadLines layer.

ii. For *Intersect line/poly layer*, select the demnet layer.

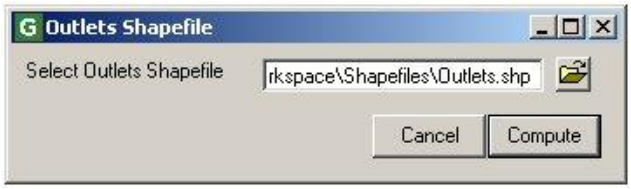
iii. For *Output*, click the button to the right of the field, navigate to the same location as the rest of the shapefiles, name the file "Outlets," click *Save*, and then *OK*.

iv. The new shapefile is added to ArcMap. It is composed of the points at which the roads intersect the stream network.

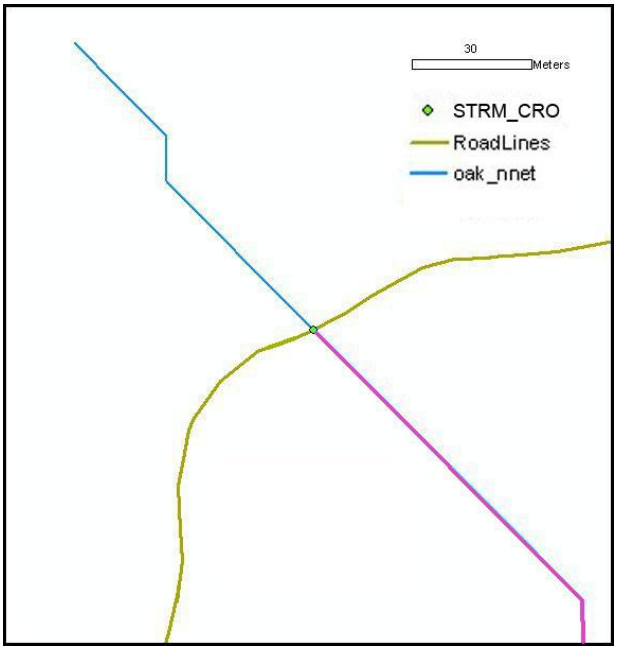
b. Make sure all of the points created are on valid road-stream intersections. If the road is mis-registered relative to the stream network shapefile, the road may cross the stream in the map when it does not cross the stream on the ground, resulting in too many points. If this is a problem, it should be fixed following the above outlined road line straightening process, including re-running the GRAIP Preprocessor.



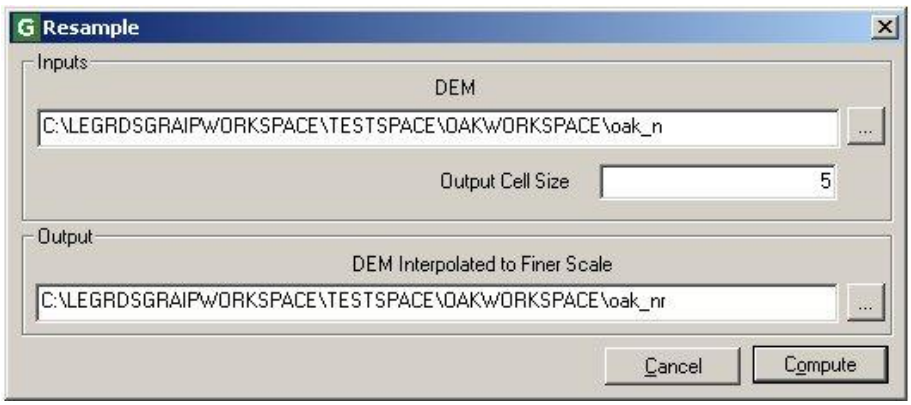
3. GRAIP toolbar-> *Preprocessor-> Create TauDEM Stream Network*. Click the box next to the field for *Select Outlets Shapefile*, and navigate to the location of the Outlets shapefile. Select it, click *Add*, then *Compute*. When asked if it is OK to overwrite files, click *Yes* (it will ask this four times).



a. The stream network shapefile that was created by TauDEM has been deleted and replaced with this new stream network shapefile that is the same, except that the streams are split at the road-stream intersections.



4. GRAIP toolbar-> *Preprocessor-> Resample DEM*.



a. Check to make sure that *DEM* (under *Input*) is correctly located.

b. Check to make sure that *DEM Interpolated to a Finer Scale* will be saved to the right place.

c. Click *Compute*. The re-interpolated DEM (demr) is added to ArcMap.

A variation on the above method, for use if Hawth's Tools does not work (this step replaces step 2, above):

2. Create an outlet file for the *Create TauDEM Stream Network* step to use by hand.

a. Open ArcCatalog and navigate to the folder with all of your shapefiles. Create a new shapefile called "Outlets."

i. Right-click in the shapefiles folder-> *New-> Shapefile…*

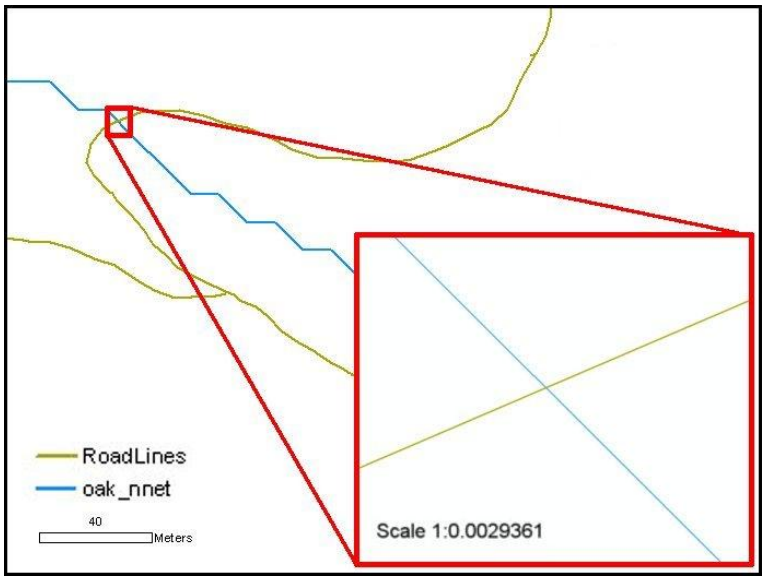
ii. Name it "Outlets," and select *Point* as *Feature Type*.

iii. Click *OK*.

b. Add the Outlets shapefile to ArcMap. Note that it does not have any points in it.

c. Editor toolbar-> *Editor-> Start Editing*. Select the folder with the Outlets shapefile. Set the *Target* to the Outlets layer.

d. Zoom in as close as possible on each road-stream intersection with the *Zoom In* tool from the Tools toolbar.



i. Select the *Sketch Tool* (to the immediate right of the *Edit Tool*). Move it directly over the road-stream intersection, and click to create a point. Save the edit and zoom out.

ii. Repeat for all other road-stream intersections.

e. Editor toolbar-> *Editor-> Stop Editing*. The Outlets shapefile is now populated with all of the necessary points for the next step.

Road Surface Erosion Analysis

The *Road Surface Erosion Analysis* menu calculates how much sediment is predicted to come off of the roads, how much of that may reach the streams, and where else the sediment is ending up. The functions in this menu require an accurate road length, so the road lines must be free of zigzag.

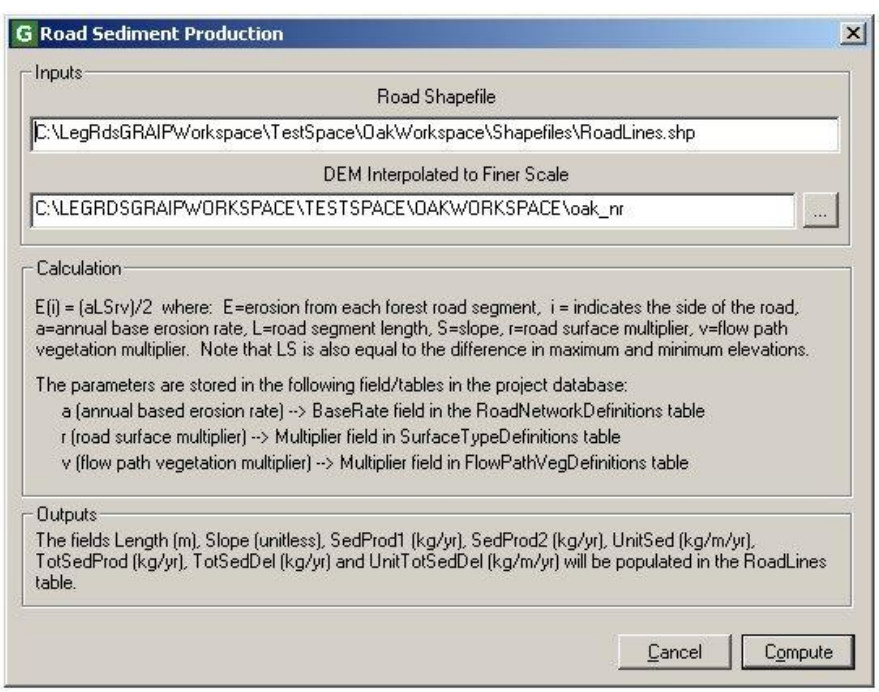
There are six tools under the *Road Surface Erosion Analysis* menu in the GRAIP toolbar, and they must be run from top to bottom. The first two steps calculate sediment production and accumulation, and delivery to streams for the road lines and drain points. These steps populate the *Length* (units meters), *Slope* (no units), *SedProd1* (kg/yr), *SedProd2* (kg/yr), *UnitSed* (kg/m/yr), *TotSedProd* (kg/yr), *TotSedDel* (kg/yr), and *UnitTotSedProd* (kg/m/yr) columns in the RoadLines table, and the *SedProd* (kg/yr), *ELength* (m), *UnitSed* (kg/m/yr), and *SedDel* (kg/yr) columns in the DrainPoints table.

The second two steps create three grids. The first two are weight grids that show sediment accumulation at drain points (demswt) and in the streams (demsac). The last grid is the upstream specific sediment grid (demspe), which shows sediment contributions from the roads directly to the stream.

The final two steps calculate sediment accumulation and direct accumulation for the stream network. Four columns are appended to the table for the stream network (demnet). These are *SedAccum* (kg/yr), *SpecSed* (Mg/km^2/yr), *SedDir* (kg/yr), and *SpecSedDir* (Mg/km^2/yr). For more information on the above described processes, see Appendix B.

1. Open ArcMap and open the GRAIP file, if they are not already open from the previous step.

2. GRAIP toolbar-> *Road Surface Erosion Analysis-> Road Segment Sediment Production*.



a. Ensure the RoadLines layer is properly located in the *Road Shapefile* field.

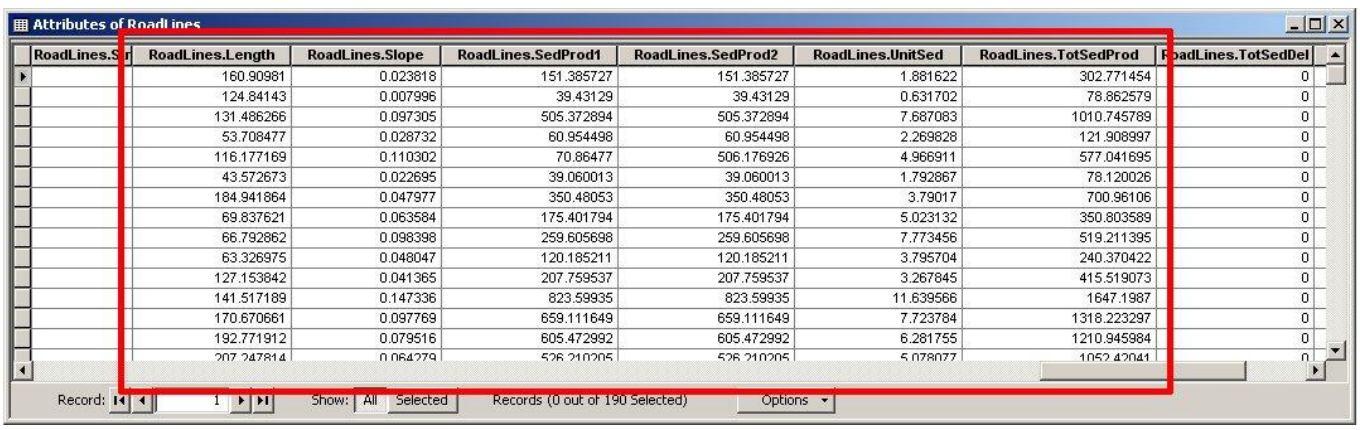
b. Ensure that demr is properly located in the *DEM Interpolated to a Finer Scale* field.

i. If this field is blank, demr has not been added to the map. Click the {…} button to the right of the field, navigate to demr, select it, and click *Add*.

ii. demr is added to the map.

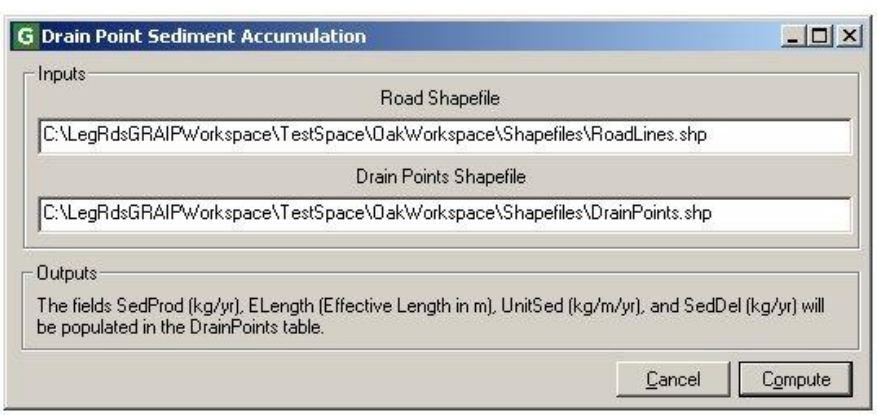
c. Click *Compute*.

d. Open the Attribute Table for the RoadLines layer to ensure that the *Length*, *Slope*, *SedProd1*, *SedProd2*, *UnitSed*, *TotSedProd*, *TotSedDel*, and *UnitTotSedProd* columns are populated. The final two columns (*TotSedDel* and *UnitTotSedProd*) may have some cells with a zero. For all steps that modify an attribute table, if all or part of the appropriate columns are zeros, close the attribute table, wait a few seconds, and reopen it. All values should be correctly populated.



RoadLines.S	RoadLines.Length	RoadLines.Slope	RoadLines.SedProd1	RoadLines.SedProd2	RoadLines.UnitSed	RoadLines.TotSedProd	RoadLines.TotSedDel
	160.90981	0.023818	151.385727	151.385727	1.881622	302.771454	0
	124.84143	0.007996	39.43129	39.43129	0.631702	78.862579	0
	131.486266	0.097305	505.372894	505.372894	7.687083	1010.745789	0
	53.708477	0.028732	60.954498	60.954498	2.269828	121.908997	0
	116.177169	0.110302	70.86477	506.176926	4.966911	577.041695	0
	43.572673	0.022695	39.060013	39.060013	1.792867	78.120026	0
	184.941864	0.047977	350.48053	350.48053	3.79017	700.96106	0
	69.837621	0.063584	175.401794	175.401794	5.023132	350.803589	0
	66.792862	0.098398	259.605698	259.605698	7.773456	519.211395	0
	63.326975	0.048047	120.185211	120.185211	3.795704	240.370422	0
	127.153842	0.041365	207.759537	207.759537	3.267845	415.519073	0
	141.517189	0.147336	823.59935	823.59935	11.639566	1647.1987	0
	170.670661	0.097769	659.111649	659.111649	7.723784	1318.223297	0
	192.771912	0.079516	605.472992	605.472992	6.281755	1210.945984	0
	207.247814	0.064279	526.210205	526.210205	5.078077	1052.42041	0

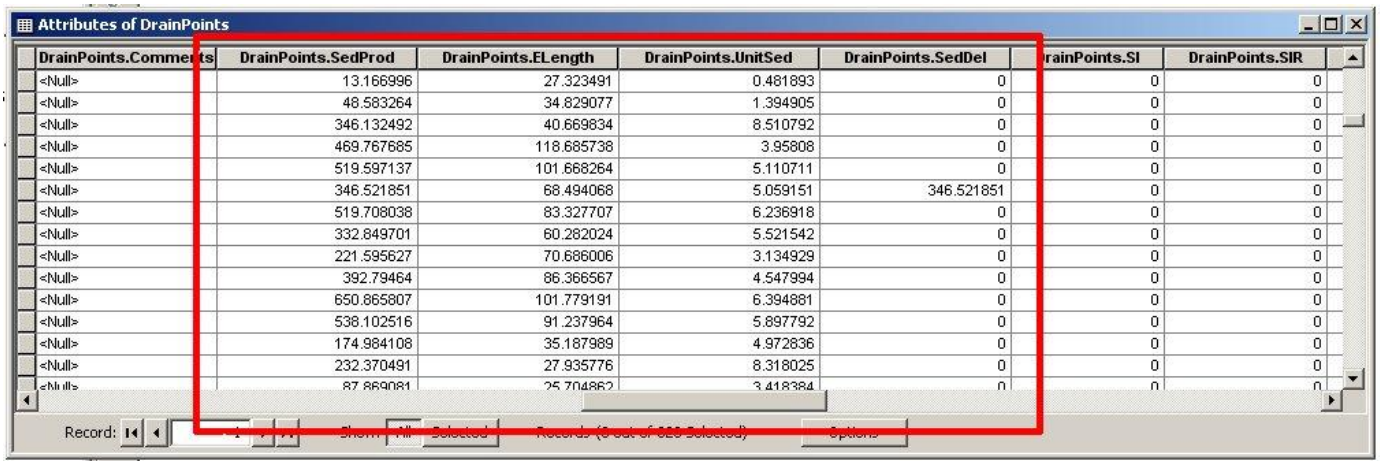
3. GRAIP toolbar-> *Road Surface Erosion Analysis-> Drain Point Sediment Accumulation*.



a. Ensure that the RoadLines and DrainPoints shapefiles are correctly located in the *Road Shapefile* and *Drain Points Shapefile* fields, respectively.

b. Click *Compute*.

c. Ensure that the *SedProd*, *ELength*, *UnitSed*, and *SedDel* columns are populated in the DrainPoints Attribute Table. The *SedDel* column may be largely zeros and other columns may have some zeros at orphan drain points.

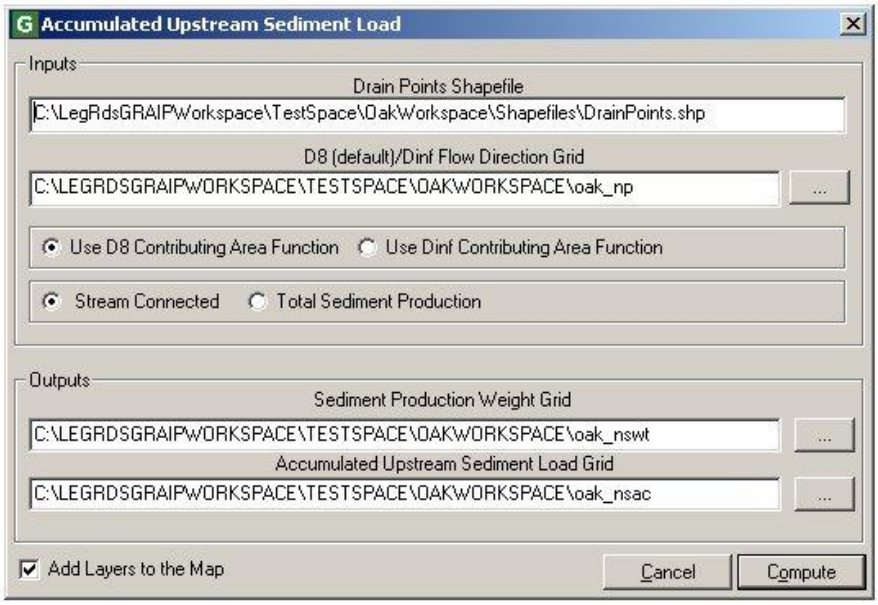


Attributes of DrainPoints

DrainPoints.Comments	DrainPoints.SedProd	DrainPoints.ELength	DrainPoints.UnitSed	DrainPoints.SedDel	rainPoints.SI	DrainPoints.SIR
<Null>	13.166996	27.323491	0.481893	0	0	0
<Null>	48.583264	34.829077	1.394905	0	0	0
<Null>	346.132492	40.669834	8.510792	0	0	0
<Null>	469.767685	118.685738	3.95808	0	0	0
<Null>	519.597137	101.668264	5.110711	0	0	0
<Null>	346.521851	68.494068	5.059151	346.521851	0	0
<Null>	519.708038	83.327707	6.236918	0	0	0
<Null>	332.849701	60.282024	5.521542	0	0	0
<Null>	221.595627	70.686006	3.134929	0	0	0
<Null>	392.79464	86.366567	4.547994	0	0	0
<Null>	650.865807	101.779191	6.394881	0	0	0
<Null>	538.102516	91.237964	5.897792	0	0	0
<Null>	174.984108	35.187989	4.972836	0	0	0
<Null>	232.370491	27.935776	8.318025	0	0	0
<Null>	87.869081	25.704862	3.418384	0	0	0

Record: Show: All Selected Options

4. GRAIP toolbar-> *Road Surface Erosion Analysis-> Accumulated Upstream Sediment Load*.



a. Ensure that the DrainPoints shapefile is correctly located in the *DrainPoints Shapefile* field, and demp is correctly located in the same folder as the TauDEM files in the *D8(default)/Dinf Flow Direction Grid* field.

b. Ensure that *Use D8 Contributing Area Function* and *Stream Connected* are selected.

c. Check to see that the two outputs (demswt and demsac) will be saved to the correct folder. If you have to change the folder, do not change their names.

d. Check *Add Layers to Map* if it is not already checked.

e. Click *Compute*.

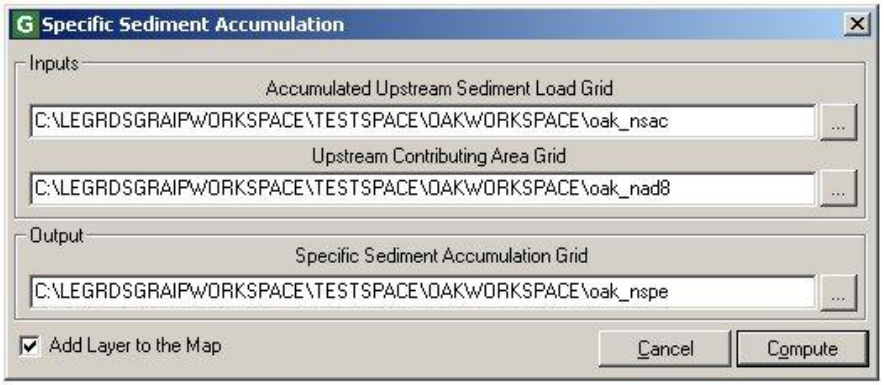
f. Make sure the two grids are reasonable.

i. Turn off the stream network and roads layers. Zoom in on the area where the roads are.

ii. The demsac layer should be on top. This layer basically traces the road sediment down stream from the point at which it enters the stream. There should be a grey to white line (color depends on amount of sediment) that follows the stream and originates at the drain points that deliver sediment to the stream. Turn the layer off when finished.

iii. Now demswt is the top-most visible layer. This layer shows the amount and location of sediment accumulation at each drain point. It should look like white dots at the drain points that do not deliver. You may have to zoom in pretty close to see this, especially if the RoadLines and DrainPoints layers are turned on. Turn this layer off when finished to keep ArcMap from slowing down as it draws it every time you change views.

5. GRAIP toolbar-> *Road Surface Erosion Analysis-> Accumulated Upstream Specific Sediment*.



a. Ensure demsac and demad8 are correctly located in the *Accumulated Upstream Sediment Load Grid* and *Upstream Contributing Area Grid* fields, respectively.

b. Ensure the *Output* grid (demspe, in the *Specific Sediment Accumulation Grid* field) will be saved to the correct folder, as above.

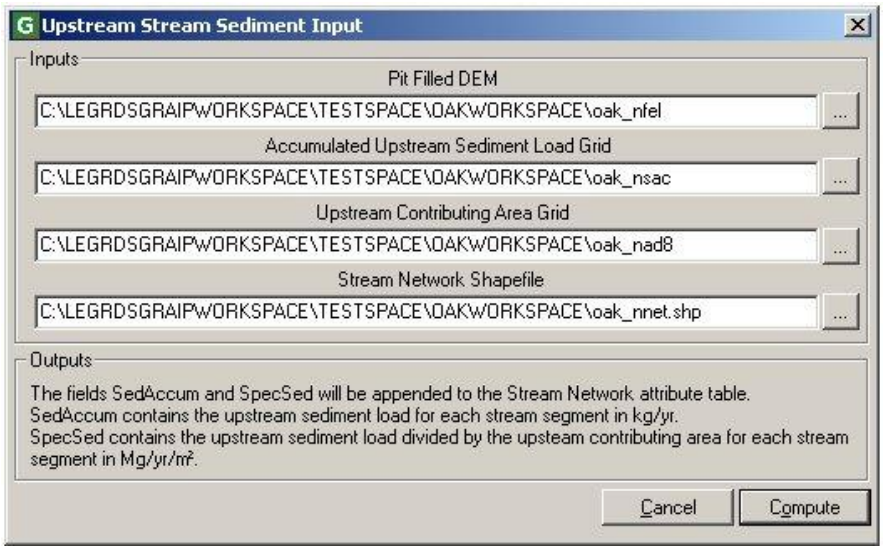
c. Make sure the layer will be added to the map and click *Compute*.

d. Ensure that the grid is reasonable.

i. Turn off the stream network layer and zoom in on the RoadLines layer.

ii. This grid resembles the demsac grid, above, but the stream-tracing line won't continue very far and will be grey instead of white. Turn off the layer when done.

6. GRAIP toolbar-> *Road Surface Erosion Analysis-> Upstream Stream Sediment Input*.



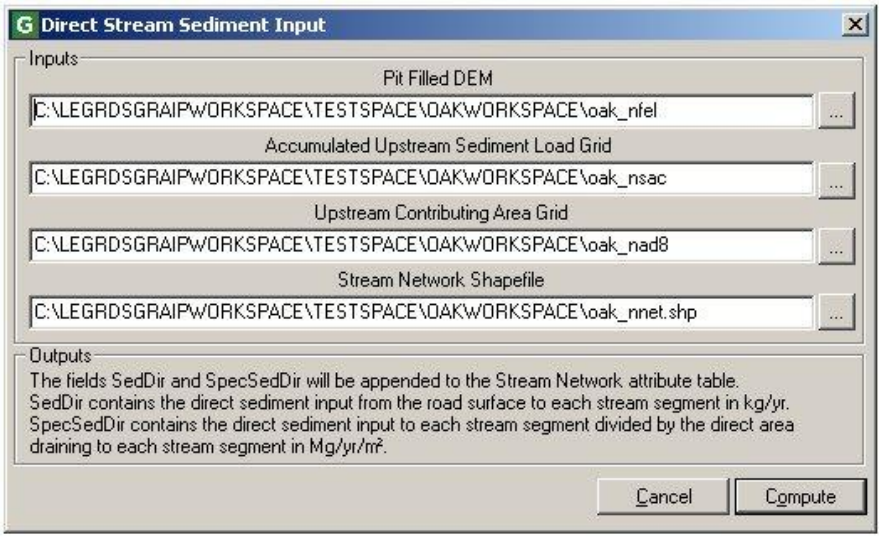
a. Ensure demfel, demsac, demad8, and demnet are properly located in their respective fields (*Pit Filled DEM*, *Accumulated Upstream Sediment Load Grid*, *Upstream Contributing Area Grid*, and *Stream Network Shapefile*, respectively).

b. Click *Compute*.

c. Ensure that the *SedAccum* and *SpecSed* columns are populated in the stream network layer (demnet) Attribute Table. Both columns may be mostly zeros, depending on how many stream network segments are affected by the roads.

d. There is a known error in GRAIP 1.0.8 and previous versions that occurs in this step. The values in the Attribute Table under the *SedAccum* column that are added by this step are erroneous in that they are too high by about a factor of ten.

7. GRAIP toolbar-> *Road Surface Erosion Analysis-> Direct Stream Sediment Input*.

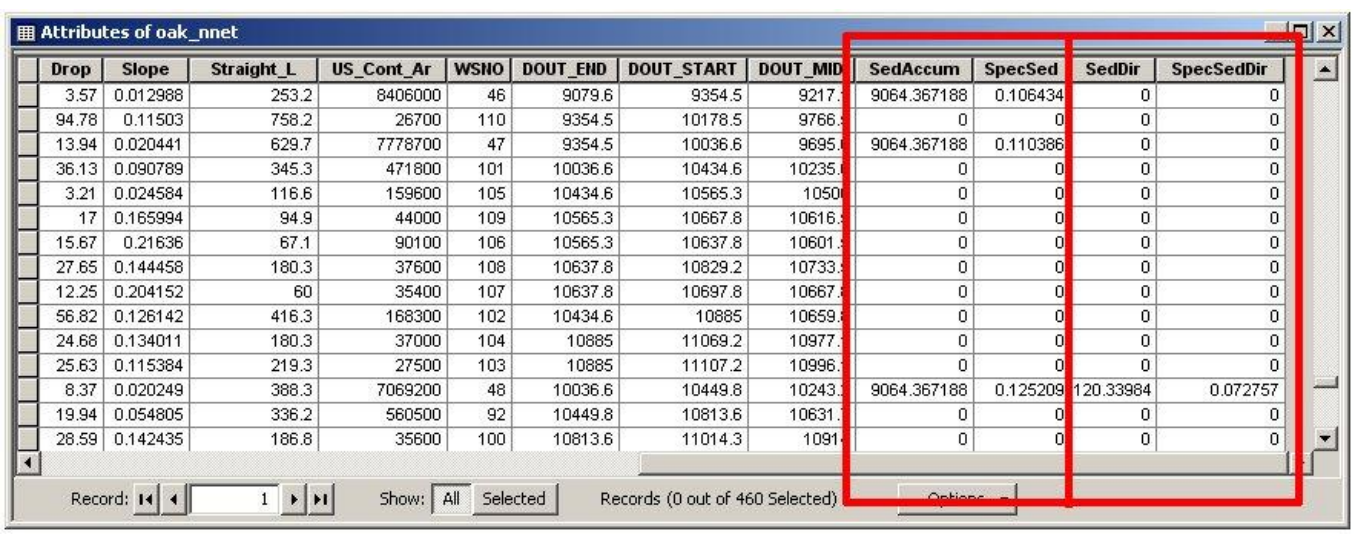


a. Ensure that the *Input* fields are correctly populated, as above in step 6a.

b. Click *Compute*.

c. Ensure that the *SedDir* and *SpecSedDir* fields are populated in the stream network Attribute Table. Both columns may be mostly zeros (even more than in step 6, above), depending on how many stream network segments are directly affected by the roads.

d. There is a known error in GRAIP 1.0.8 and previous versions that occurs in this step. The values in the Attribute Table under the *SedDel* column that are added by this step are erroneous in that they are too high by about a factor of ten.



Drop	Slope	Straight_L	US_Cont_Ar	WSNO	DOUT_END	DOUT_START	DOUT_MID	SedAccum	SpecSed	SedDir	SpecSedDir
3.57	0.012988	253.2	8406000	46	9079.6	9354.5	9217.	9064.367188	0.106434	0	0
94.78	0.11503	758.2	26700	110	9354.5	10178.5	9766.	0	0	0	0
13.94	0.020441	629.7	7778700	47	9354.5	10036.6	9695.	9064.367188	0.110386	0	0
36.13	0.090789	345.3	471800	101	10036.6	10434.6	10235.	0	0	0	0
3.21	0.024584	116.6	159600	105	10434.6	10565.3	1050	0	0	0	0
17	0.165994	94.9	44000	109	10565.3	10667.8	10616.	0	0	0	0
15.67	0.21636	67.1	90100	106	10565.3	10637.8	10601.	0	0	0	0
27.65	0.144458	180.3	37600	108	10637.8	10829.2	10733.	0	0	0	0
12.25	0.204152	60	35400	107	10637.8	10697.8	10667.	0	0	0	0
56.82	0.126142	416.3	168300	102	10434.6	10885	10659.	0	0	0	0
24.68	0.134011	180.3	37000	104	10885	11069.2	10977.	0	0	0	0
25.63	0.115384	219.3	27500	103	10885	11107.2	10996.	0	0	0	0
8.37	0.020249	388.3	7069200	48	10036.6	10449.8	10243.	9064.367188	0.125209	120.33984	0.072757
19.94	0.054805	336.2	560500	92	10449.8	10813.6	10631.	0	0	0	0
28.59	0.142435	186.8	35600	100	10813.6	11014.3	1091	0	0	0	0

Mass Wasting Potential Analysis

The functions in the *Mass Wasting Potential Analysis* menu produce data that indicate the likelihood of mass wasting events along and caused by a road. The default parameters can often be adjusted to provide more accurate results. Some of the data produced can be compared to the data produced by SINMAP for a road vs. no road comparison.

There are eight tools under the *Mass Wasting Potential Analysis* menu heading. The first tool and the last five tools must be run in order from top to bottom, and the second and third tools (*Select Calibration Grid* and *Combined Stability Index*) must be run separately due to the way certain drain points are treated by these functions. These steps can be undertaken only after SINMAP has been run. The first step finds the stability index at each drain point, and populates the *SI* column in the DrainPoints table. The second and third tools create the combined stability index grid and four other intermediary grids (demsic, demrmin, demrmax, demrdmin, and demrdmax, respectively), and one text file (demcalp.csv) that take the road water into account. The *SIR* column is also populated in the DrainPoints table. The combined stability index grid (demsic) can be compared to the stability index grid (demsi, from above) to see the affect the road has on the terrain stability.

The fourth and fifth steps create a slope grid (demslpd) and populate the *Slope* column of the DrainPoints table, which is the slope of the hillslope below each drain point. The next step addresses gully initiation risk with the erosion sensitivity index, and so populates the *ESI* column of the DrainPoints table. The seventh step creates a road length vs. hillslope plot called *L-S Plot* (note that the Y-axis is logarithmic) that can be used to calibrate the ESI threshold for increased gully risk (ESI_{crit}). The final step calculates the stream blocking index (SBI) for each stream crossing, and so populates the *PipeDiaToChanWidthRatio*, *PipeDiaToChanWidthScore*, *SkewAngle*, *SkewAngleScore*, and *SBI* columns in the DrainPoints table.

The combined stability index grid adds water from the road at each drain point to the hillslope, based on the contributing length of road and a predetermined additional road runoff rate (effectively increasing the contributing area at the cells in which the drain points lie). The overall effect is to decrease slope stability at the location of each drain point that receives road water. There are two drain point types, diffuse drains and stream crossings, that do not actually affect slope stability, but they do in the model. As such, these drain points must be removed from consideration before running the *Combined Stability Index* step, or the combined stability index grid will overestimate increases in mass wasting risk.

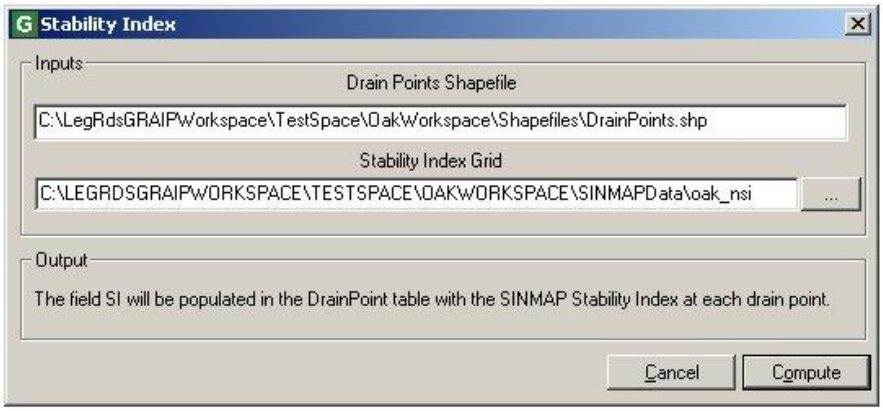
Run the *Stability Index* function, skip the next two functions, but do run *D8 Slope with downslope averaging*, *Slope at Drain Point*, *Erosion Sensitivity Index*, *Length Slope Plot*, and *Stream Blocking Index* as described below. If applicable, run the *Habitat Segmentation Analysis* menu step, as well. You will then complete a set of operations on a copy of the road and drain points shapefiles that will result in the diffuse drains and stream crossings being removed from consideration the *Combined Stability Index* function. Finally, you will run the *Select Calibration Grid* and *Combined Stability Index* functions.

Functions Requiring Standard Shapefiles

Theses functions should be completed in order, after running the *Road Surface Erosion Analysis* menu functions.

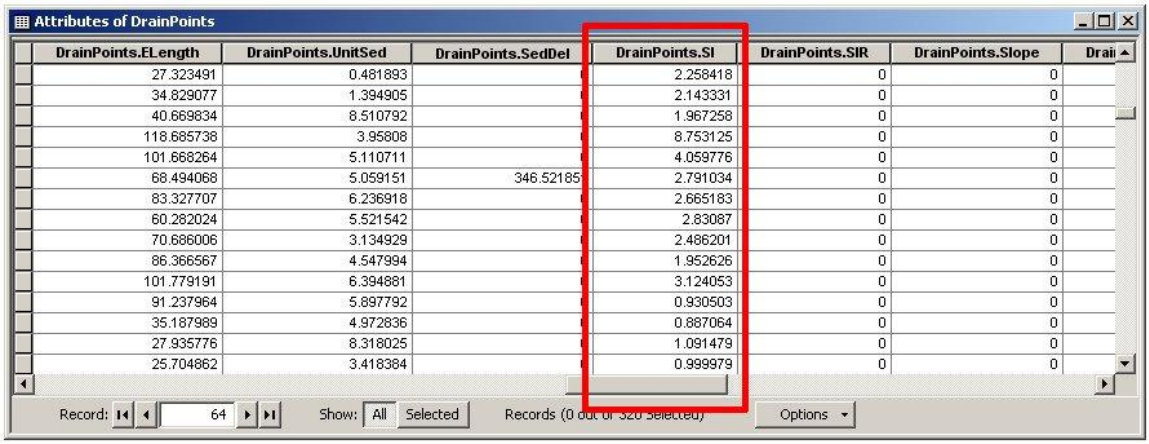
1. If not already open, open ArcMap or a new map window and open the GRAIP file (the .graip).

2. GRAIP toolbar-> *Mass Wasting Potential Analysis-> Stability Index*



a. Ensure that the DrainPoints shapefile and each of the grids are correctly located, and click *Compute*.

b. Check that the *SI* column has been populated in the DrainPoints Attribute Table. There should not be any zero values.



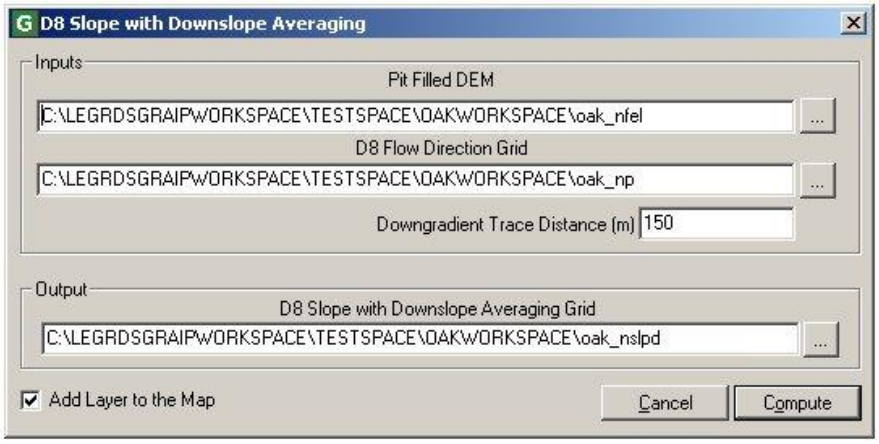
Attributes of DrainPoints

DrainPoints.ELength	DrainPoints.UnitSed	DrainPoints.SedDel	DrainPoints.SI	DrainPoints.SIR	DrainPoints.Slope	Drai
27.323491	0.481893		2.258418	0	0	
34.829077	1.394905		2.143331	0	0	
40.669834	8.510792		1.967258	0	0	
118.685738	3.95808		8.753125	0	0	
101.668264	5.110711		4.059776	0	0	
68.494068	5.059151	346.52185	2.791034	0	0	
83.327707	6.236918		2.665183	0	0	
60.282024	5.521542		2.83087	0	0	
70.686006	3.134929		2.486201	0	0	
86.366567	4.547994		1.952626	0	0	
101.779191	6.394881		3.124053	0	0	
91.237964	5.897792		0.930503	0	0	
35.187989	4.972836		0.887064	0	0	
27.935776	8.318025		1.091479	0	0	
25.704862	3.418384		0.999979	0	0	

Record: 64 Show: All Selected Records (0 out of 320 Selected) Options

3. Skip the next two functions: *Select Calibration Region Grid* and *Combined Stability Index*.

4. *Mass Wasting Potential Analysis-> D8 Slope with downslope averaging*

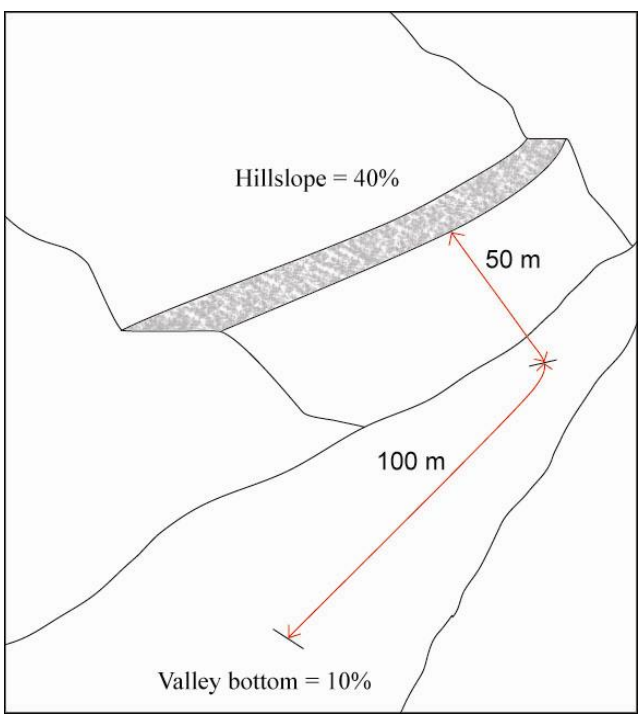


a. The purpose of this function is to generate a grid of slopes at each cell that will be used to determine the slope at each drain point, which is used to help determine the Erosion Sensitivity Index (see below). The method used estimates the slope at each cell by averaging the slope from that cell to a cell that is located a specified trace distance downhill.

b. Ensure that the *Pit Filled DEM* (demfel) and *D8 Flow Direction Grid* (demp) are correctly located.

c. The default value for the *Downgradient Trace Distance (m)* field is 150.

i. This parameter defines the trace distance that the function will use. In some locations, the slope of the hill can be underestimated, because the stream valley bottom, which has a shallower slope than the actual hillslope is



included in the downgradient trace distance. It is important that the grid's values reflect the actual hillslope at each drain point. If there are drain points in the study that are within 150 m of a stream, the *Downgradient Trace Distance (m)* may be changed to a smaller number.

ii. First, verify that there are drain points within 150 m of a stream. If there are, find an average point-to-stream distance in meters for only those drain points that are less than 150 m from the stream.

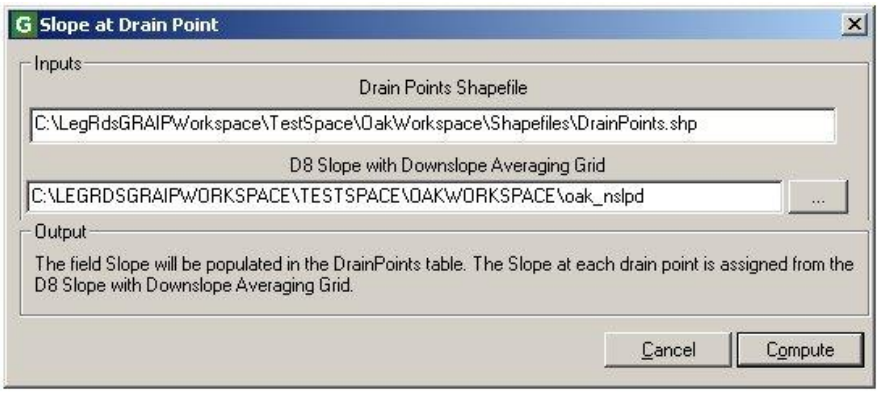
iii. Since the DEM has a resolution of 30 m, and you need two grid cell values to determine slope, you need an absolute minimum of 45 m of downslope trace distance (the length of the diagonal across a 30 m square is about 42 m). The simplest way to determine what the *Downgradient Trace Distance* should be is to take the greater of either the average point-to-stream distance or 45 m. However, the greater the specified trace distance, the more accurate the average (assuming a relatively constant slope on the hillslope). A slope calculated using only two grid cells will probably not be very accurate, due to imprecision in the 30 m DEM grid values. While 45 m might be a good distance to use for those points which are very close to the stream, it will not produce accurate results for points further away.

- It is highly recommended that you use a number higher than 90 m. This would include three grid cells at a diagonal.
- If most of the drain points that are within 150 m of the stream are within the same grid cell as the stream, then there is no way to take an accurate average hillslope, anyway, so these point-to-stream distances should be removed from consideration.
- If there is only a small percentage of points within 150 m of the stream, then you may also consider using the default 150 m. This will result in inaccurate slope values for those points within 150 m, but the majority of points will have more accurate values.

d. Ensure that the *D8 Slope with Downslope Averaging Grid* will be saved to the correct place. Do not change the name.

e. Click *Compute*. The layer will be added to the map, but can be turned off to save drawing time.

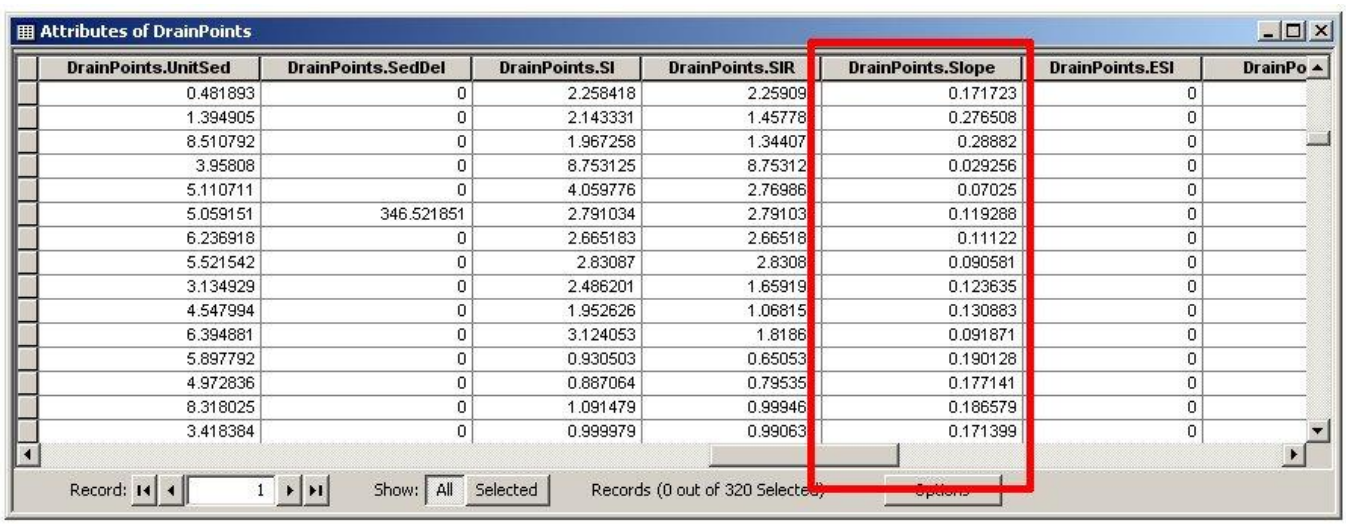
5. *Mass Wasting Potential Analysis-> Slope at Drain Point*



a. Ensure that the *Drain Points Shapefile* (DrainPoints) and the *D8 Slope with Downslope Averaging Grid* (demslpd) are correctly located.

b. Click *Compute*.

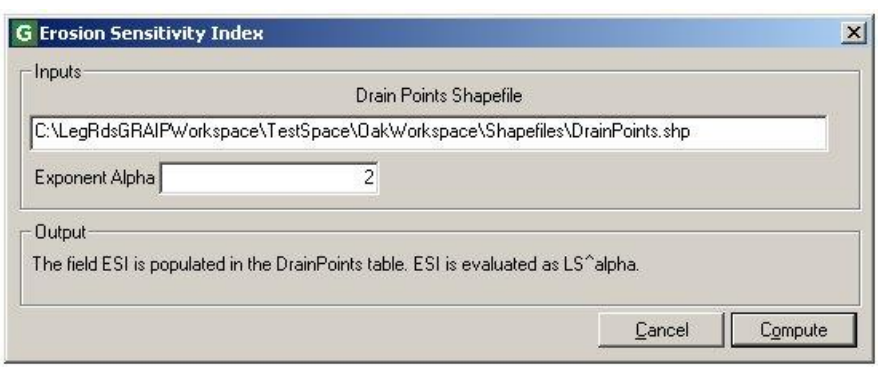
c. Check to make sure the *Slope* column is populated in the DrainPoints Attribute Table. There should not be any zero values (unless the slope below a drain point is actually totally flat).



Attributes of DrainPoints

DrainPoints.UnitSed	DrainPoints.SedDel	DrainPoints.SI	DrainPoints.SIR	DrainPoints.Slope	DrainPoints.ESI	DrainPo
0.481893	0	2.258418	2.25909	0.171723	0	
1.394905	0	2.143331	1.45778	0.276508	0	
8.510792	0	1.967258	1.34407	0.28882	0	
3.95808	0	8.753125	8.75312	0.029256	0	
5.110711	0	4.059776	2.76986	0.07025	0	
5.059151	346.521851	2.791034	2.79103	0.119288	0	
6.236918	0	2.665183	2.66518	0.11122	0	
5.521542	0	2.83087	2.8308	0.090581	0	
3.134929	0	2.486201	1.65919	0.123635	0	
4.547994	0	1.952626	1.06815	0.130883	0	
6.394881	0	3.124053	1.8186	0.091871	0	
5.897792	0	0.930503	0.65053	0.190128	0	
4.972836	0	0.887064	0.79535	0.177141	0	
8.318025	0	1.091479	0.99946	0.186579	0	
3.418384	0	0.999979	0.99063	0.171399	0	

6. *Mass Wasting Potential Analysis-> Erosion Sensitivity Index*



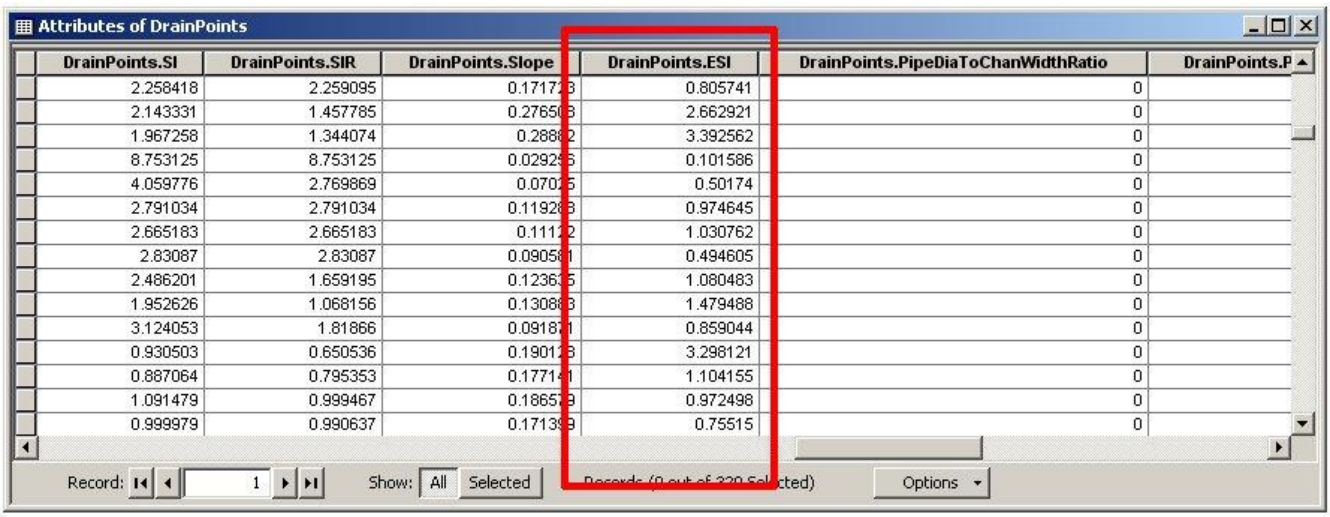
a. The Erosion Sensitivity Index (ESI) assigns a value to each drain point that corresponds to the relative risk of a gully forming below that drain point.

b. Ensure that the *Drain Points Shapefile* is correctly located.

c. The default for the *Exponent Alpha* field is 2.

d. Click *Compute*.

e. Check to make sure the *ESI* column in the DrainPoints Attribute Table is populated. There may be some zero values, which are orphan drain points. This function sometimes takes a few moments to populate the table.



Attributes of DrainPoints

DrainPoints.SI	DrainPoints.SIR	DrainPoints.Slope	DrainPoints.ESI	DrainPoints.PipeDiaToChanWidthRatio	DrainPoints.P
2.258418	2.259095	0.171723	0.805741	0	
2.143331	1.457785	0.276503	2.662921	0	
1.967258	1.344074	0.288822	3.392562	0	
8.753125	8.753125	0.029256	0.101586	0	
4.059776	2.769869	0.07025	0.50174	0	
2.791034	2.791034	0.119283	0.974645	0	
2.665183	2.665183	0.11112	1.030762	0	
2.83087	2.83087	0.090581	0.494605	0	
2.486201	1.659195	0.123635	1.080483	0	
1.952626	1.068156	0.130883	1.479488	0	
3.124053	1.81866	0.091871	0.859044	0	
0.930503	0.650536	0.190123	3.298121	0	
0.887064	0.795353	0.177141	1.104155	0	
1.091479	0.999467	0.186579	0.972498	0	
0.999979	0.990637	0.171399	0.75515	0	

Record: 1 Show: All Selected Records (0 out of 339 Selected) Options

7. *Mass Wasting Potential Analysis-> Length Slope Plot*

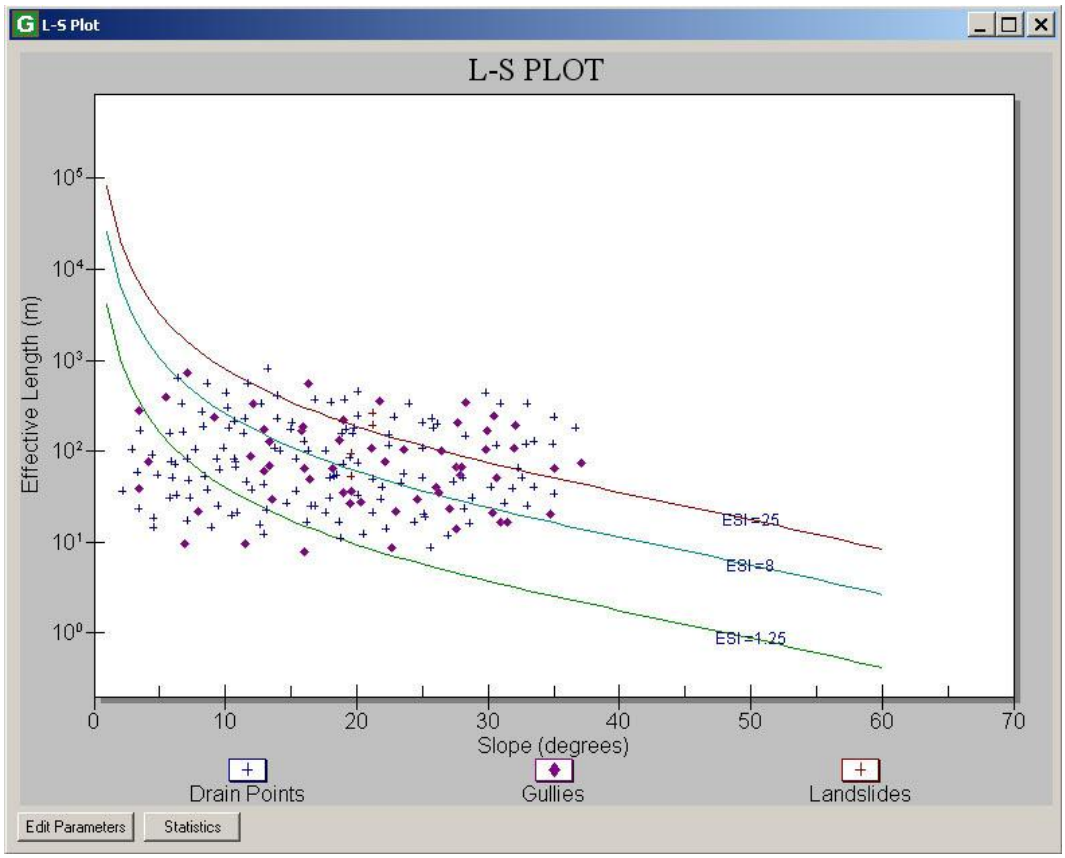
a. This generates a graph of effective length (m) vs. hillslope (degrees) of the drain points, including those drain points with gullies, with ESI isolines superimposed. Note that the Y-axis is logarithmic.

i. Effective length (or ELength) is the length of road that drains to each drain point.

ii. The ESI isolines are plotted so that a point that lies on a particular line will have the ESI value of that line.

iii. The drain points that drain to gullies are represented as diamonds, those that drain to landslides as triangles, and the other drain points, which to not drain to gullies or landslides, as plus signs.

b. This figure can be used to pick a threshold value of ESI, above which, the risk of gullying increases significantly. This threshold may be referred to as ESI_{crit}.



i. Disregard or turn off the landslide points, as landslide risks may be unrelated to gully risks, and are addressed elsewhere in the model.

- To turn off the landslide points, double-click anywhere in the chart area-> *Style* tab-> select *Landslides* from the options at right-> under *Point Type*, use the drop-down menu to select *Plus*-> click *OK*.

ii. This process only works if ELength and hillslope are the primary gully-forming factors. If other influences are more dominant, such as groundwater interception, variable soils and geology, or recent fire, then it may not be possible to determine reasonable ESI_{crit} thresholds.

iii. Generally, if there are not many gullies observed at drain points in your area, then gullying may not be of enough concern to complete this calibration process. For example, if you have a watershed with 5000 drain points, and only 25 of them have small gullies (0.5%), then the risks of further gully forming are probably not very high. However, if you have only 100 drain points, and only 5 gullies (5%), then sufficient risk probably exists to justify this calibration process. Note that, assuming your gullies fit the ELength-

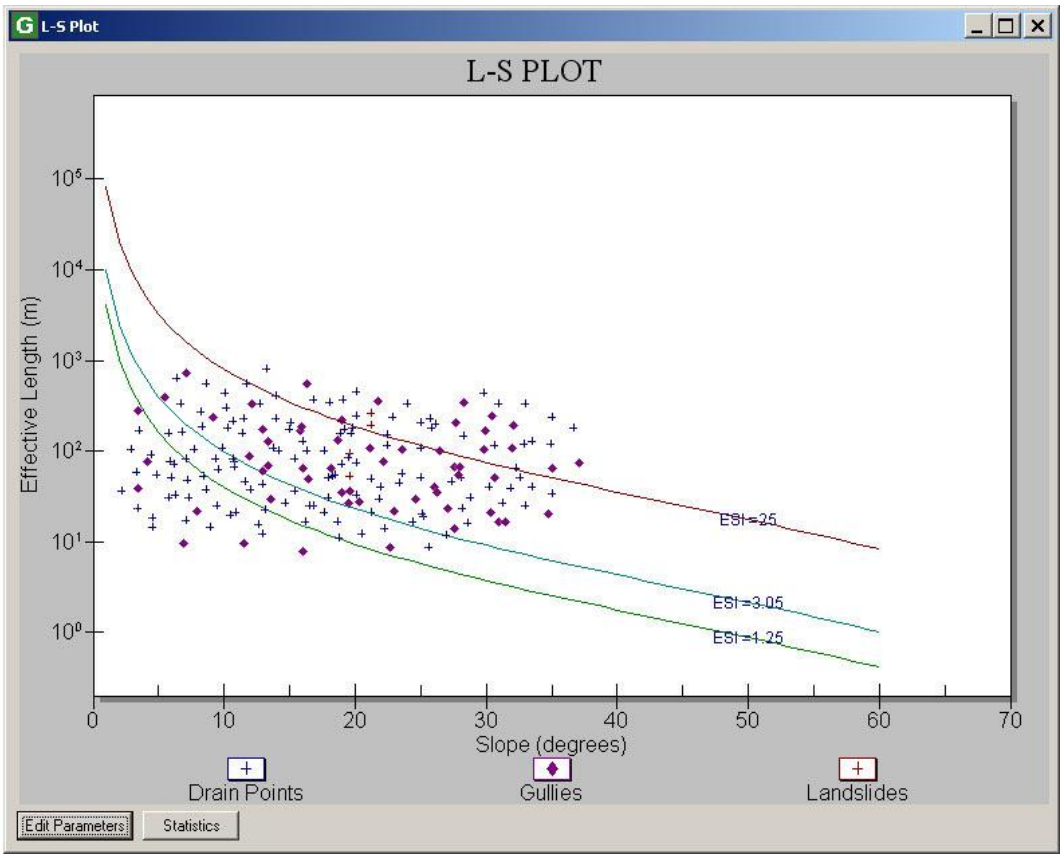
hillslope model, the more gullies you have, the easier and more accurate your calibration will be.

iv. Notice that the distribution of drain points with gullies is weighted to the regions of the graph with higher ESI (further right and up; longer ELength and steeper slope). Therefore, the higher the ESI of a drain point, the higher the risk of gullying.

- If this distribution trend is not present, then it is likely that the gullies recorded in your data have other contributors. If this is the case, you may have success if you can determine which points are affected by external factors and remove them from consideration.

v. The process here is to find the ESI isoline that most closely bounds the lower end of the cluster of drain points with gullies. This process is similar to the process used in the calibration of SINMAP. You will move the middle ESI isoline (default value of 8) until you are satisfied with its location.

- In the *L-S Plot* window, click *Edit Parameters*. From here, you can change the value of each ESI isoline, as well as the value of alpha (which you first encountered above in the *Erosion Sensitivity Index* function; generally, there is no need to change this value).
- Change the value of the *Medium ESI* field to change the location of the middle ESI isoline. Larger values move the line up and right; smaller values move it down and left. Press *Ok*.
- You can view information about the distribution of drain points with gullies among the ESI regions (i.e. the area between the ESI isolines) by clicking the *Statistics* button in the *L-S Plot* window.



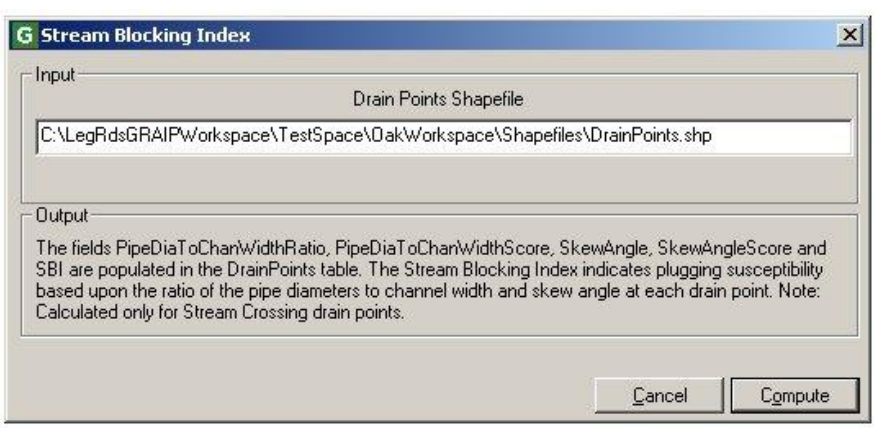
vi. The value of the middle ESI isoline when the line most closely bounds the cluster of drain points with gullies is the value of ESI_{crit}.

c. If you have more GRAIP data for the same area, you may want to incorporate it into one L-S Plot that you can use to more accurately find the ESI_{crit}. This involves exporting the Attribute Tables of each drain point type into a spreadsheet program, such as Microsoft Excel, and further combining and manipulating it there.

d. ESI_{crit} can be used to determine the distribution of drain points that have a high risk of gullying but do not yet have a gully.

e. Nothing is added to any table, created, or saved in this step.

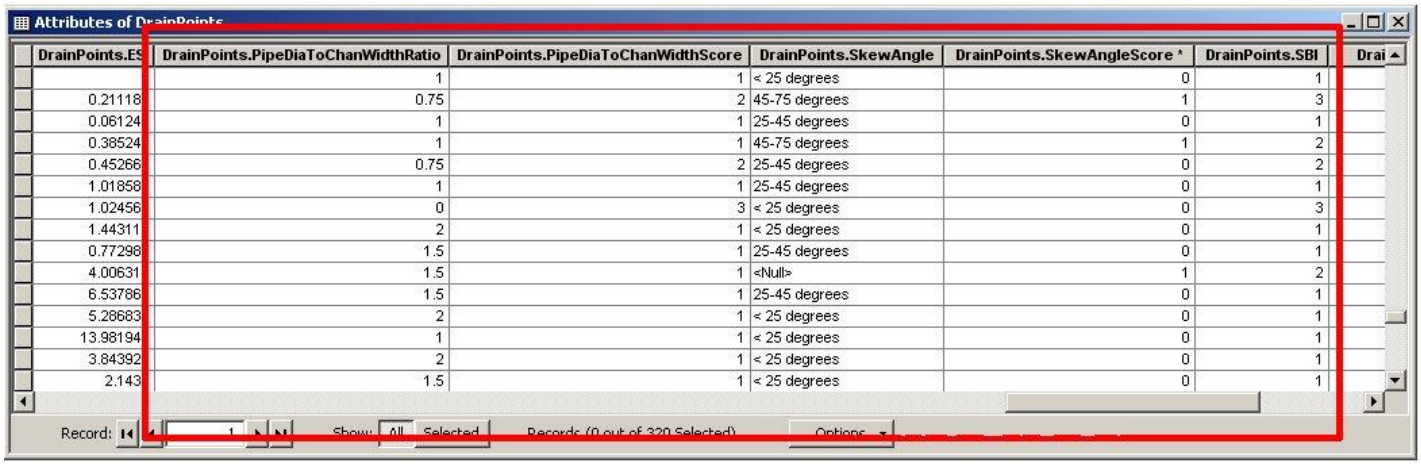
8. *Mass Wasting Potential Analysis-> Stream Blocking Index*



a. Ensure that the *Drain Points Shapefile* is correctly located.

b. Click *Compute*.

c. Ensure that the *PipeDiaToChanWidthRatio*, *PipeDiaToChanWidthScore*, *SkewAngle*, *SkewAngleScore*, and *SBI* columns in the DrainPoints table are populated at stream crossings. Most of the values will likely be zeros, because most drain points are not stream crossings.



Attributes of DrainPoints

DrainPoints.ES	DrainPoints.PipeDiaToChanWidthRatio	DrainPoints.PipeDiaToChanWidthScore	DrainPoints.SkewAngle	DrainPoints.SkewAngleScore *	DrainPoints.SBI	Drai
	1	1	< 25 degrees	0	1	
0.21118	0.75	2	45-75 degrees	1	3	
0.06124	1	1	25-45 degrees	0	1	
0.38524	1	1	45-75 degrees	1	2	
0.45266	0.75	2	25-45 degrees	0	2	
1.01858	1	1	25-45 degrees	0	1	
1.02456	0	3	< 25 degrees	0	3	
1.44311	2	1	< 25 degrees	0	1	
0.77298	1.5	1	25-45 degrees	0	1	
4.00631	1.5	1	<Null>	1	2	
6.53786	1.5	1	25-45 degrees	0	1	
5.28683	2	1	< 25 degrees	0	1	
13.98194	1	1	< 25 degrees	0	1	
3.84392	2	1	< 25 degrees	0	1	
2.143	1.5	1	< 25 degrees	0	1	

Record: 1 Show: All Selected Records (0 out of 320 Selected) Options

9. If you are planning to continue with the *Habitat Segmentation Analysis* function, do so now, and come back to this point when finished. Open a new map file for the below steps.

The Combined Stability Index Functions

In these steps, you will modify a copy of the road lines and drain points shapefiles so that the diffuse drains and stream crossings are removed from consideration by the *Combined Stability Index* function, you will re-run certain GRAIP functions on those modified shapefiles, and you will finally run the *Select Calibration Region Grid* and *Combined Stability Index* functions.

The copies of the shapefiles are modified by the addition of a dummy drain point that will route all of the water from the diffuse drains and stream crossings to a part of the DEM that is outside the area of interest. The CTimes in the ROAD shapefile that correspond to diffuse drains and stream crossings will be changed to be that of the dummy point. Once this operation has been completed, you will use the Preprocessor to make another GRAIP file (extension .graip), which gets runs through the applicable functions in the GRAIP toolbar. Note that if there are no diffuse drains or stream

crossings, you can skip to step 12, and complete steps 12 and 13 in order with the rest of the *Mass Wasting Potential Analysis* functions, above.

1. Open ArcCatalog

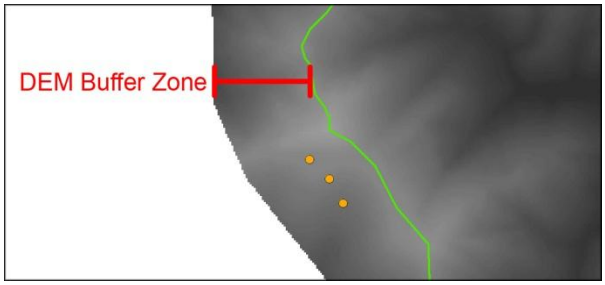
- **a.** Create a new workspace at the same level as the folder in which you have your shapefiles. Call it SICShapefiles or something similar.
- **b.** Copy and paste each of the drain point and road line shapefiles into this new workspace (BBASE_DI, DIFF_DRA, DTCH_REL, EXCAV_ST, LEAD_OFF, NON_ENGI, STRM_CRO, SUMP, WATER_BA, and ROAD). Do not copy the other shapefiles (e.g. END_RD or GULLY).

2. If you have not done so, open a new map file in ArcMap. Add each of the above road line and drain point shapefiles, as well as the DEM from the working folder (the one with the TauDEM grids, etc.).

3. Open the ROAD Attribute Table.

- **a.** Note each of the different *VEHICLE*/*CDATE* combinations.
  - **i.** *VEHICLE* "2"/*CDATE* "7/11/2009"; *VEHICLE* "2"/*CDATE* "7/12/2009"; and *VEHICLE* "1"/*CDATE* "7/11/2009" are all different combinations.

4. Start editing, and select any one of the drain points as the *Target*. Find a location on the DEM that is well outside of the area of interest (probably an area outside of the watershed in the DEM buffer zone), and use the *Sketch Tool* to create a new point for each *VEHICLE*/*CDATE* combination.



- **a.** It is easiest to choose a drain point that has as few attributes as possible, such as SUMP.
- **b.** If two crews collected data over three days, you will create six points to account for each *VEHICLE*/*CDATE* combination.

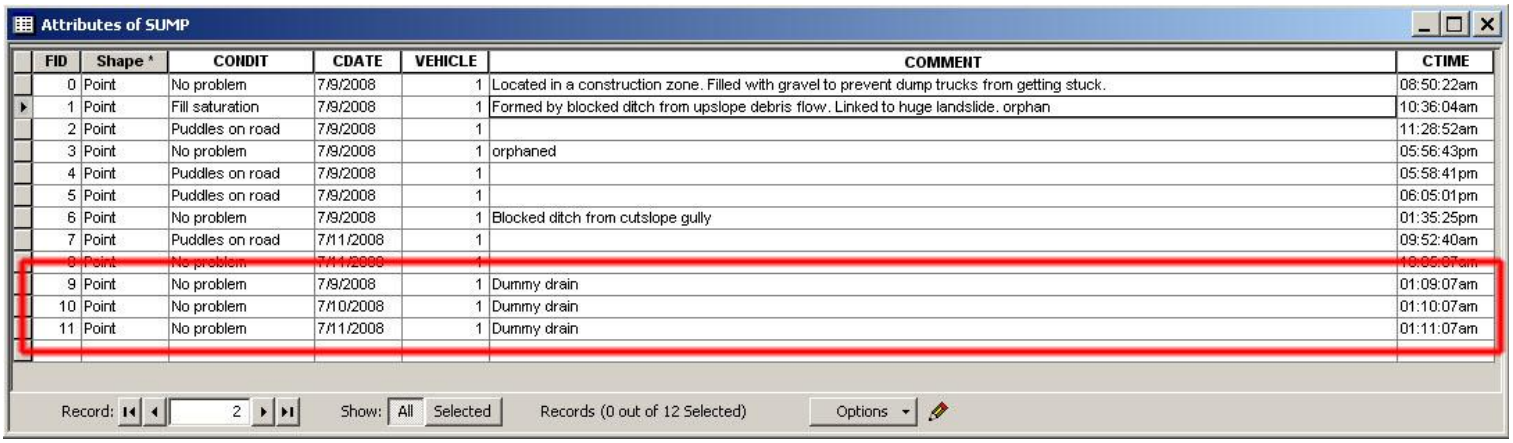
5. Open the attribute table for the drain point that has the new points.

a. Note that there are mostly blank entries for each of the points that you created.

b. Fill each of the columns in with properly formatted information.

- **i.** It is easiest to do this by copying from other rows, and then editing if necessary. This ensures that all spaces and capital letters are correct. In general, it is best to use default information.
- **ii.** In each *Comment* field, type, "DUMMY DRAIN," or similar.
- **iii.** For each new drain point, enter one of the *VEHICLE/CDATE* combinations noted above. There should be one new point for each combination. Ensure that this is formatted correctly.
- **iv.** For the *CTIME*, you want to make sure to use a number that is not yet used elsewhere in the watershed as well as make it obvious which *CTIME* refers to which *VEHICLE/CDATE* combination.
  - Since no data is collected in the middle of the night, it is safe to use any time between about 10:00 PM and 5:00 AM. You can check the range of CTimes in the ROAD Attribute Table if you are unsure.
  - An easy way to remember which *CTIME* goes with which *VEHICLE/CDATE* combination is to use the vehicle number as the hour (it will usually be between 01 and 04), and the day as the time (it will always be between 01 and 31). So, *VEHICLE* "2"/*CDATE* "7/11/2009" becomes "02:11:00am" in the attribute table.

c. Save the edits frequently.



Attributes of SUMP

FID	Shape *	CONDIT	CDATE	VEHICLE	COMMENT	CTIME
0	Point	No problem	7/9/2008	1	Located in a construction zone. Filled with gravel to prevent dump trucks from getting stuck.	08:50:22am
1	Point	Fill saturation	7/9/2008	1	Formed by blocked ditch from upslope debris flow. Linked to huge landslide. orphan	10:36:04am
2	Point	Puddles on road	7/9/2008	1		11:28:52am
3	Point	No problem	7/9/2008	1	orphaned	05:56:43pm
4	Point	Puddles on road	7/9/2008	1		05:58:41pm
5	Point	Puddles on road	7/9/2008	1		06:05:01pm
6	Point	No problem	7/9/2008	1	Blocked ditch from cutslope gully	01:35:25pm
7	Point	Puddles on road	7/11/2008	1		09:52:40am
8	Point	No problem	7/11/2008	1		10:05:07am
9	Point	No problem	7/9/2008	1	Dummy drain	01:09:07am
10	Point	No problem	7/10/2008	1	Dummy drain	01:10:07am
11	Point	No problem	7/11/2008	1	Dummy drain	01:11:07am

Record: 2 Show: All Selected Records (0 out of 12 Selected) Options

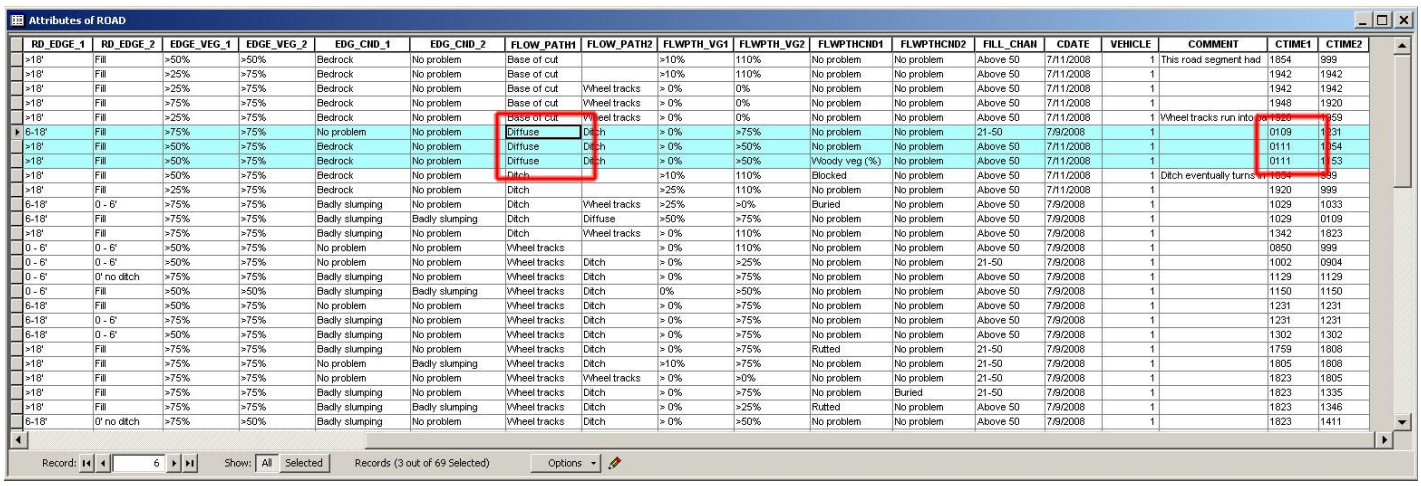
6. Open the ROAD Attribute Table. For each flow path that drains to a diffuse drain or stream crossing, change its *CTIME* to that of the appropriate dummy point (the point with the matching *VEHICLE/CDATE* combination).

a. Scroll all the way to the right, so that both *CTIME* columns as well as both *FLOW_PATH* columns are showing. You may have to make the *COMMENT* column smaller to see everything you need to.

b. Right-click the column heading for *FLOW_PATH1*-> click *Sort Ascending*. Each of the road segments that have *Diffuse* in for the primary flow path are grouped.

c. For each *Diffuse* flow path, enter the appropriate dummy CTIME.

i. Using the example above, *VEHICLE* "2"/*CDATE* "7/11/2009" becomes "0211" in the *CTIME1* column.



Attributes of ROAD

RD_EDGE_1	RD_EDGE_2	EDGE_VEG_1	EDGE_VEG_2	EDG_CND_1	EDG_CND_2	FLOW_PATH1	FLOW_PATH2	FLWPTH_VG1	FLWPTH_VG2	FLWPTHCND1	FLWPTHCND2	FILL_CHAN	CDATE	VEHICLE	COMMENT	CTIME1	CTIME2
>18'	Fill	>50%	>50%	Bedrock	No problem	Base of cut		>10%	110%	No problem	No problem	Above 50	7/11/2008	1	This road segment had	1854	999
>18'	Fill	>25%	>75%	Bedrock	No problem	Base of cut		>10%	110%	No problem	No problem	Above 50	7/11/2008	1		1942	1942
>18'	Fill	>25%	>75%	Bedrock	No problem	Base of cut	Wheel tracks	> 0%	0%	No problem	No problem	Above 50	7/11/2008	1		1942	1942
>18'	Fill	>75%	>75%	Bedrock	No problem	Base of cut	Wheel tracks	> 0%	0%	No problem	No problem	Above 50	7/11/2008	1		1948	1920
>18'	Fill	>25%	>75%	Bedrock	No problem	Base of cut	Wheel tracks	> 0%	0%	No problem	No problem	Above 50	7/11/2008	1	Wheel tracks run into a	1926	1959
6-18'	Fill	>75%	>75%	No problem	No problem	Diffuse	Ditch	> 0%	>75%	No problem	No problem	21-50	7/9/2008	1		0109	1231
>18'	Fill	>50%	>75%	Bedrock	No problem	Diffuse	Ditch	> 0%	>50%	No problem	No problem	Above 50	7/11/2008	1		0111	1054
>18'	Fill	>50%	>75%	Bedrock	No problem	Diffuse	Ditch	> 0%	>50%	Woody veg (%)	No problem	Above 50	7/11/2008	1		0111	1153
>18'	Fill	>50%	>75%	Bedrock	No problem	Ditch		>10%	110%	Blocked	No problem	Above 50	7/11/2008	1	Ditch eventually turns	1654	999
>18'	Fill	>25%	>75%	Bedrock	No problem	Ditch		>25%	110%	No problem	No problem	Above 50	7/11/2008	1		1920	999
6-18'	0 - 6'	>75%	>75%	Badly slumping	No problem	Ditch	Wheel tracks	>25%	>0%	Buried	No problem	Above 50	7/9/2008	1		1029	1033
6-18'	Fill	>75%	>75%	Badly slumping	Badly slumping	Ditch	Diffuse	>50%	>75%	No problem	No problem	Above 50	7/9/2008	1		1029	0109
>18'	Fill	>75%	>75%	Badly slumping	No problem	Ditch	Wheel tracks	> 0%	110%	No problem	No problem	Above 50	7/9/2008	1		1342	1823
0 - 6'	0 - 6'	>50%	>75%	No problem	No problem	Wheel tracks		> 0%	110%	No problem	No problem	Above 50	7/9/2008	1		0850	999
0 - 6'	0 - 6'	>50%	>75%	No problem	No problem	Wheel tracks	Ditch	> 0%	>25%	No problem	No problem	21-50	7/9/2008	1		1002	0904
0 - 6'	0' no ditch	>75%	>75%	Badly slumping	No problem	Wheel tracks	Ditch	> 0%	>75%	No problem	No problem	Above 50	7/9/2008	1		1129	1129
0 - 6'	Fill	>50%	>50%	Badly slumping	Badly slumping	Wheel tracks	Ditch	0%	>50%	No problem	No problem	Above 50	7/9/2008	1		1150	1150
6-18'	Fill	>50%	>75%	No problem	No problem	Wheel tracks	Ditch	> 0%	>75%	No problem	No problem	Above 50	7/9/2008	1		1231	1231
6-18'	0 - 6'	>75%	>75%	Badly slumping	No problem	Wheel tracks	Ditch	> 0%	>75%	No problem	No problem	Above 50	7/9/2008	1		1231	1231
6-18'	0 - 6'	>50%	>75%	Badly slumping	No problem	Wheel tracks	Ditch	> 0%	>75%	No problem	No problem	Above 50	7/9/2008	1		1302	1302
>18'	Fill	>75%	>75%	Badly slumping	No problem	Wheel tracks	Ditch	> 0%	>75%	Rutted	No problem	21-50	7/9/2008	1		1759	1808
>18'	Fill	>75%	>75%	No problem	Badly slumping	Wheel tracks	Ditch	>10%	>75%	No problem	No problem	21-50	7/9/2008	1		1805	1808
>18'	Fill	>75%	>75%	No problem	No problem	Wheel tracks	Wheel tracks	> 0%	>0%	No problem	No problem	21-50	7/9/2008	1		1823	1805
>18'	Fill	>75%	>75%	Badly slumping	No problem	Wheel tracks	Ditch	> 0%	>75%	No problem	Buried	21-50	7/9/2008	1		1823	1335
>18'	Fill	>75%	>75%	Badly slumping	Badly slumping	Wheel tracks	Ditch	> 0%	>25%	Rutted	No problem	Above 50	7/9/2008	1		1823	1346
6-18'	0' no ditch	>75%	>50%	Badly slumping	No problem	Wheel tracks	Ditch	> 0%	>50%	No problem	No problem	Above 50	7/9/2008	1		1823	1411

Record: 6 Show: All Selected Records (3 out of 69 Selected) Options

d. Repeat for the *FLOW_PATH2* and *CTIME2* columns.

e. From the DIFFUSE and STRM_CRO Attribute Tables, write down each *VEHICLE/CDATE/CTIME* combination. Be sure to round the CTime correctly.

i. Also note how many features are in each shapefile (used below).

f. In the ROAD Attribute Table, sort the *CDATE* column. For each of the *VEHICLE/CDATE/CTIME* combinations noted above, enter the appropriate dummy CTime.

i. You may find it easier to sort the *VEHICLE* column or each *CTIME* separately.

ii. Note that each *VEHICLE/CDATE/CTIME* combination may appear more than one time in the table.

iii. If a drain point is an orphan, its CTime will not appear in the ROAD Attribute Table.

iv. Remember to look in both the *CTIME1* and *CTIME2* columns.

v. Save the edits frequently.

g. At this point, no *VEHICLE/CDATE/CTIME* combination from either the DIFFUSE or the STRM_CRO shapefile should appear in the ROAD Attribute Table.

h. Stop editing and close ArcMap or open a new map file.

7. Open the GRAIP Preprocessor.

a. Create a new GRAIP file (extension .graip) using the shapefiles that you modified in the SICShapefiles workspace and the DEM from the working folder (the one with the TauDEM grids, etc.).

i. Make sure to save the new GRAIP file in the SICShapefiles folder.

8. Open each error log (FileNameDP.log and FileNameRD.log).

a. Make sure that there are no orphan road lines.

b. In the drain points error log (FileNameDP.log), ensure that every diffuse drain and stream crossing is an orphan. The easiest way to do this is to count the number of entries for each drain point type and compare that number to the total number of features in each drain point type in each shapefile, noted above. Both numbers should match.

c. If there are drain points missing from the error log, find their GRAIPDID number on the error log, go back into ArcMap with the appropriate shapefiles (ROAD, DrainPoints, and whichever drain point is missing), find that GRAIPDID's CTime (similar to the process used in the *Editing Data Errors* section), and edit the ROAD Attribute Table to change it to a dummy CTime. Re-run the Preprocessor and re-check the error logs.

9. In a new map file in ArcMap, open the GRAIP file with the SICShapefiles.

10. *Road Surface Erosion Analysis-> Road Segment Sediment Production*.

a. Under *DEM Interpolated to Finer Scale*, select the resampled DEM that you used before (demr).

b. Ensure that the *Road Shapefile* is correctly specified as that in the SICShapefiles workspace.

c. This function populates fields necessary for the *Combined Stability Index* function to run.

11. *Road Surface Erosion Analysis-> Drain Point Sediment Accumulation*.

a. Ensure that both the *Road Shapefile* and the *Drain Points Shapefile* are correctly specified as those in the SICShapefiles workspace.

b. This function populates fields necessary for the *Combined Stability Index* function to run.

12. *Mass Wasting Potential Analysis-> Select Calibration Region Grid->* navigate to the SINMAPData folder created previously-> select the calibration grid (demcal)-> click *Add*. The calibration region grid is added to ArcMap.

13. *Mass Wasting Potential Analysis-> Combined Stability Index*

a. Ensure that the DrainPoints and RoadLines shapefiles are correctly located from the SICShapefiles workspace. Ensure that the fields *Calibration Parameters Text File*, *Dinf Slope*, *Dinf Specific Catchment Area*, and *Calibration Grid* are correctly populated and located (demcalp.csv, demslp, and demsca from the TauDEM folder, and demcal from the SINMAPData folder, respectively).

b. The following are default parameters:

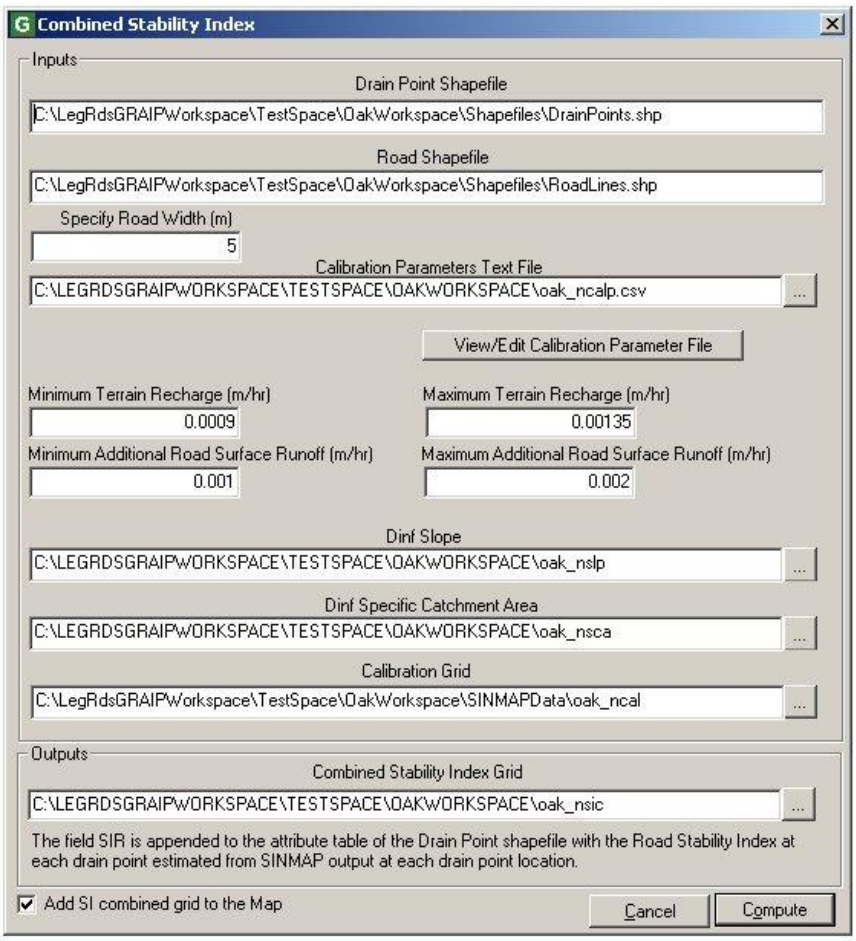
i. *Specify Road Width (m)* is 5.

ii. *Minimum Terrain Recharge (m/hr)* is 0.0009.

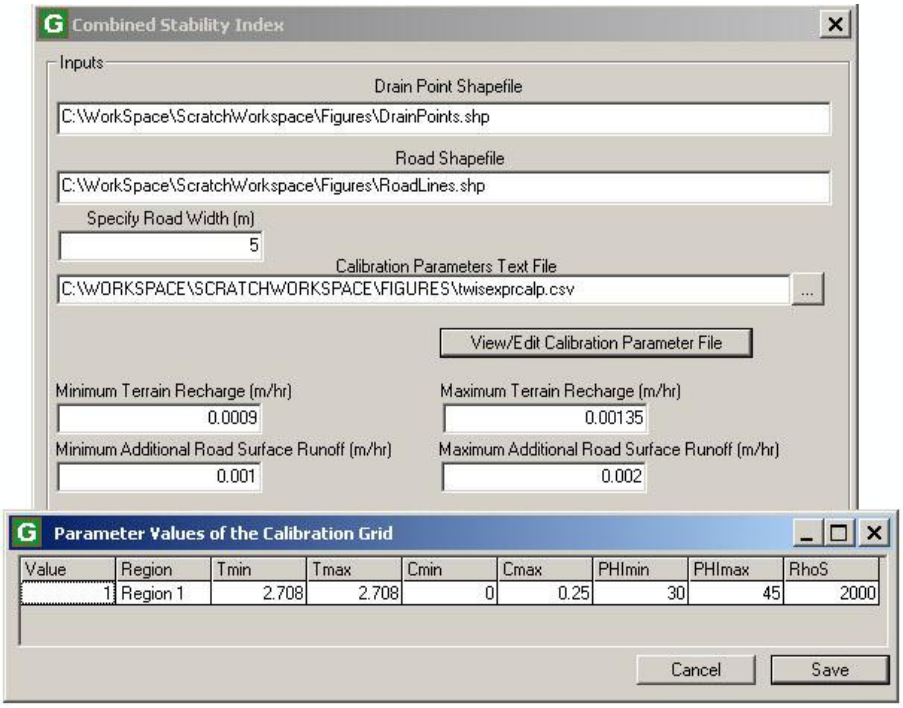
iii. *Maximum Terrain Recharge (m/hr)* is 0.00135.

iv. *Minimum Additional Road Surface Runoff (m/hr)* is 0.001.

v. *Maximum Additional Road Surface Runoff (m/hr)* is 0.002.



c. You can edit additional parameters by clicking on the *View/Edit Calibration Parameter File* button. If you have calibrated SINMAP to a landslides point layer, you will change the parameters in this step to match those from SINMAP. To do this, click the *View/Edit Calibration Parameter File* button.



i. In the *Parameter Values of the Calibration Grid* window that pops up, enter the calibrated values from SINMAP for each property in the appropriate column.

- Leave the columns labeled *Value* and *Region* alone. If you have more than one calibration region, there will be one row for each region.
- The next two columns, *Tmin* and *Tmax* stand for the transmissivity of the soil, which corresponds to the *T* in the *T/R (Lower/Upper Bound)* parameters in SINMAP. The *R* stands for terrain recharge, the value of which can be viewed and adjusted in the main *Combined Stability Index* screen (see above) in the *Minimum/Maximum Terrain Recharge (m/hr)* fields. For each of the *T* columns, calculate the value to enter, based on the appropriate value (*Minimum* or *Maximum*) already given for *R*, such that,

$$\frac{T}{R} = X$$

where X is the desired value for the *T/R (Lower/Upper Bound)* parameters in SINMAP. For example, if the SINMAP calibration parameter for *T/R (Lower Bound)* is 1850, and the value for *Minimum Terrain Recharge (m/hr)* is 0.0009 (default), then solve for *T*,

$$\frac{T}{0.0009} = 1850$$

$$T = 1.665$$

Enter this value in the *Tmin* column and then do a similar calculation to find *Tmax* (using the *Maximum Terrain Recharge (m/hr)*, which is 0.00135 by default).

- *Cmin* and *Cmax* correspond to the respective *Cohesion (Lower/Upper Bound)* parameters in SINMAP.
- *PHImin* and *PHImax* correspond to the respective *Phi(degrees) (Lower/Upper Bound)* parameters in SINMAP.
- *RhoS* corresponds to the *Soil Density (kg / m^3)* parameter in SINMAP.

ii. Click *Save*. The previously defined (in SINMAP) calibration parameters will be used to generate the Combined Stability Index grid.

d. Ensure that the *Combined Stability Index Grid* will be saved to the correct place. Do not change its name.

e. Check *Add SI combined grid to map* and click *Compute*.

f. Five grids and one text file (calibration parameters; demcalp.csv) are created:

i. The combined stability index grid (demsic) is added to ArcMap and saved wherever you specified.

ii. The minimum and maximum depth of terrain runoff grids (demrmin and demrmax) are not added to ArcMap and are saved to the same place as the TauDEM files. These files are intermediary (i.e. they are used by the *Combined Stability Index* function and nothing else)

iii. The specific discharge due to minimum and maximum runoff grids (demrdmin and demrdmax) are not added to ArcMap. These files are intermediary.

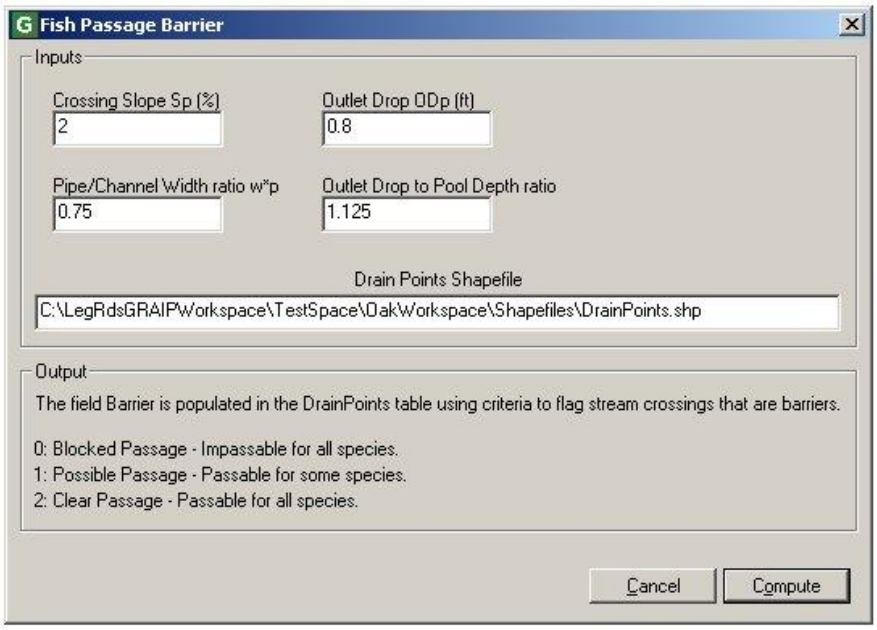
Habitat Segmentation Analysis

The function in the *Habitat Segmentation Analysis* menu produces data that identifies the stream crossings which are blocked to all fish passage, and those which are blocked to some species or life stages of fish. This function assigns a value, 0-2, to each crossing, where 0 is a blocked passage to all species, 1 is blocked to some species, and 2 is clear to all species. The *Barrier* column is populated in the DrainPoints Attribute Table. This step is usually not necessary, especially if you are not conducting a watershed-wide study, or if another more complete approach is being used. In order to complete this step, your field data must be collected using a data dictionary that has information on the pool depth and outlet drop at stream crossings (e.g. INVENT 4_2 or INVENT 5_0_W). Upon completion of this step, the GRAIP toolbar analysis is complete.

There is a second tool under the *Habitat Segmentation* menu, called *Fish Habitat Segmentation*, which is now defunct, and no longer works. This step assigned the above values to the stream network shapefile segments in the stream network shapefile table, appending the *HabPatchID* column to the stream network layer Attribute Table. This can be achieved more easily using manual methods, because this step required significant extra work earlier in the analysis process.

1. If ArcMap is not open, open it and open the appropriate .graip.

2. GRAIP toolbar-> *Habitat Segmentation Analysis-> Fish Passage Barrier*



a. Ensure that the DrainPoints shapefile is correctly located in the appropriate *Inputs* box.

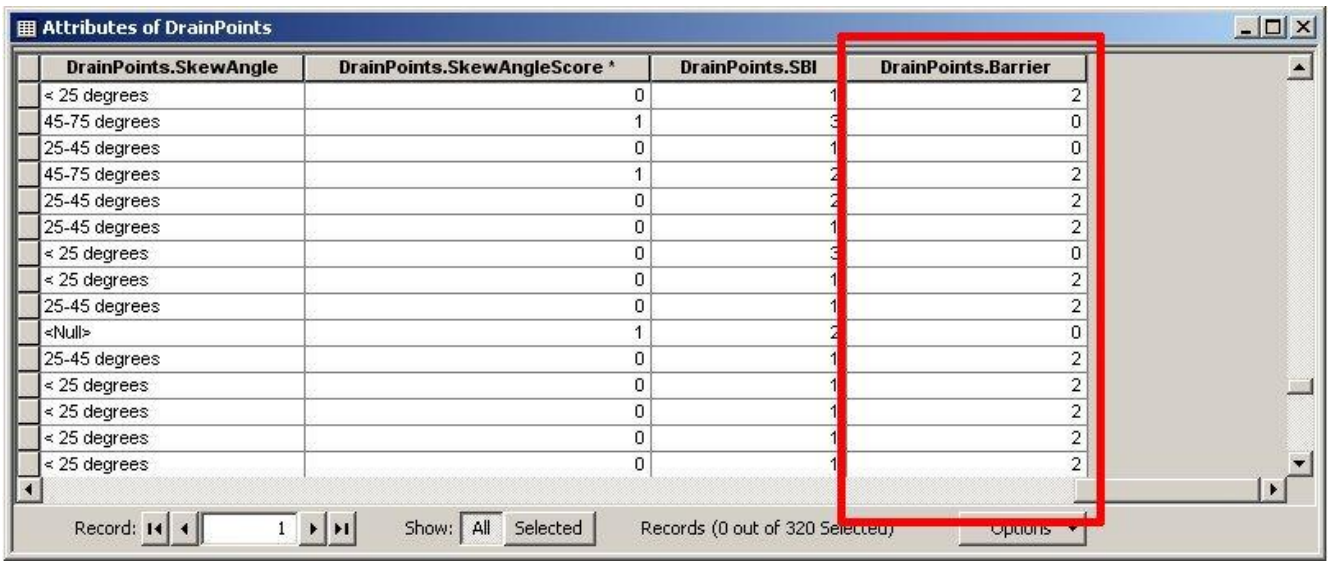
b. You can change the parameters that define a blocked passage.

i. The following are default parameters:

- *Crossing Slope Sp (%)* is 2.
- *Pipe/Channel Width ratio w*p* is 0.75.
- *Outlet Drop ODp (ft)* is 0.8
- *Outlet Drop to Pool Depth ratio* is 1.125.

c. Click *Compute*.

d. Check to make sure that the *Barrier* column is populated with 0-2 at the stream crossings in the DrainPoints Attribute Table.



Attributes of DrainPoints

DrainPoints.SkewAngle	DrainPoints.SkewAngleScore *	DrainPoints.SBI	DrainPoints.Barrier
< 25 degrees	0	1	2
45-75 degrees	1	3	0
25-45 degrees	0	1	0
45-75 degrees	1	2	2
25-45 degrees	0	2	2
25-45 degrees	0	1	2
< 25 degrees	0	3	0
< 25 degrees	0	1	2
25-45 degrees	0	1	2
<Null>	1	2	0
25-45 degrees	0	1	2
< 25 degrees	0	1	2
< 25 degrees	0	1	2
< 25 degrees	0	1	2
< 25 degrees	0	1	2

Record: 1 Show: All Selected Records (0 out of 320 Selected) Options

Appendix A: An Example File Management System

As described in the Introduction, it is important to have a good file management system in place in order to keep track of your data. Keep in mind that there are basically four potential locations for your files: the original DEM folder, the shapefiles folder, the folder with TauDEM and SINMAP files, and a folder with shapefiles that are modified for use in the Combined Stability Index. You may want more or less or different folders, such as if you desired to save all of the files that are generated by the GRAIP Preprocessor in a separate place from the shapefiles. Other files systems may work just as well or better than this one.

All workspaces under C:\WorkSpace\GRAIPWorkspace…

…\SiteWorkspace				Holds all data for a site or area, usually within a watershed.
	\DEM			30 m DEMs, original download through version used in GRAIP.
	\ComparisonsAndData			Excel files, exported tables, saved layer files, etc. for use in the data analysis.
	\SpecificSiteSpace			E.g. pre-treatment or post-treatment. Contains all data for that specific site. You would not need this subfolder if you were not comparing different data sets from the same.
		\Shapefiles		All .shapefiles and the GRAIP file.
		\SICShapefiles		Shapefiles with the diffuse and stream crossing CTimes replaced by a dummy CTime for use in determining the Combined Stability Index.
		\GridsWorkspace		All grids created by TauDEM, SINMAP, and GRAIP.
			\SINMAPData	Created by SINMAP for its grids.
			\dem	*Copy* of the DEM for data processing on that specific site.

Appendix B: More Details About The GRAIP Preprocessor and Toolbar Functions

The nuts and bolts of each function used in GRAIP have been partially omitted from the Section III instructions for brevity. This Appendix has more details about what each of the GRAIP toolbar functions do, and the equations they use. It is organized by GRAIP toolbar menu and function.

GRAIP Preprocessor

The GRAIP Preprocessor is an application that validates and imports GRAIP road inventory shapefile attributes into a relational database structure created in the MS Access file format. The purpose of the GRAIP Database is to enforce referential integrity and ensure consistency between related attributes. The Preprocessor helps to correct and/or screen out invalid, corrupt, or missing data so the user has a better dataset with which to perform the forest road impact analysis. It also consolidates multiple drain point and road line shapefiles, creating a single shapefile for each.

Preprocessor Menu and Associated Functions

Hawth's Tools' *Intersect Lines(Make Points)* function

- This function creates a shapefile called Outlets containing points that are the intersection of the roads from the RoadLines shapefile with the stream network shapefile generated by TauDEM.
- It is used by the *Create TauDEM Stream Network* function to divide the stream network at the road intersections so that road-derived sediment is not routed upstream.

Create TauDEM Stream Network function

- This function runs the TauDEM Stream Network utility to create a new stream network shapefile using the Outlets shapefile which contains the road-stream intersection points created above. This revised stream network shapefile is similar to the previous version except that the stream segments are split at stream crossings so that road-derived sediment is not routed upstream later in the process.

Resample DEM function

- This function re-samples the DEM to a finer scale using the cubic convolution method from the ArcGIS Toolbox. It is best to resample the DEM to 5 m.

– It is used to determine the slope of each road segment in the *Road Segment Sediment Production* function.

Extract Stream Crossings function

– This function was part of the process for the defunct *Fish Habitat Segmentation* function.

Filter Stream Crossings function

– This function was part of the process for the defunct *Fish Habitat Segmentation* function.

Road Surface Erosion Analysis **Menu Functions**

Road Segment Sediment Production function

– The Road Segment Sediment Production function calculates sediment production values for each road segment according to,

$$E_i = \frac{aLSrv}{2}$$

where E is the erosion from each forest road segment in kg/yr, i indicates the side of the road, *a* is the annual base erosion rate (with 79 kg/yr being the default, although a different value could be defined for each road segment shapefile when it is imported with the GRAIP Preprocessor), *L* is the road segment length, *S* is the slope, *r* is the road surface multiplier which varies depending on the type of road surface, and *v* is the flow path vegetation multiplier which varies depending on the density of the flow path vegetation. *LS* is also equal to the difference in maximum and minimum elevations in the road segment. Values of these coefficients can be found in the GRAIP tutorial.

– When the goal of a GRAIP analysis is to predict the sediment production and delivery in absolute terms, it is important to select an appropriate value for *a*. This can be accomplished by installing sediment plots on the roads in question, or by modeling the road segments using their soil texture, constuction, and climate data in a program such as WEPP:Road.

– The three parameters, *a*, *r* and *v* are stored in the following field/tables in the project database which is the .mdb created by the GRAIP Preprocessor. These parameters can be edited prior to executing this step by double clicking on the .mdb file in the file explorer. Then double click on the table for the desired parameter and edit the field listed for that parameter. Changes are automatically saved when you exit each record.

1) *a* (annual based erosion rate) is stored in the *BaseRate* field in the RoadNetworkDefinitions table
2) *r* (road surface multiplier) is stored in the *Multiplier* field in the SurfaceTypeDefinitions table

3) *v* (flow path vegetation multiplier) is stored in the *Multiplier* field in the FlowPathVegDefinitions table

- The Road Sediment Production function populates the following fields in the RoadLines table in the GRAIP database (the.mdb).
  1) *Slope*: Road slope (no unit).
  2) *Length*: Road length (meters)
  3) *SedProd1*: Sediment production for one side of the road (kg/yr)
  4) *SedProd2:* Sediment production for the other side of the road (kg/yr)
  5) *UnitSed*: Unit sediment production from the road segment (kg/m/yr)
  6) *TotSedProd*: *SedProd1+SedProd2* (kg/yr)
  7) *TotSedDel*: Sediment delivered to streams (calculated using stream connection information for each road) (kg/yr)
  8) *UnitTotSedDel*: *TotSedDel*/Length (kg/m/yr)

Drain Point Sediment Accumulation function

- This function calculates sediment accumulation values for each drain point. As part of this, the following drain point fields are populated:
  1) *SedProd*: Total accumulated sediment load at each drain point due to road surface erosion (kg/yr)
  2) *ELength*: Effective cumulative length of road draining to each drain point (meters).
  3) *UnitSed*: SedProd/Elength (kg/m/yr)
  4) *SedDel*: Sediment delivery depending on stream connection (kg/yr)
- This function adds up the total road sediment production from all contributing road segments at each drain point, and then determines where the sediment goes.
  1) If the value in the *StreamConnectID* column of the DrainPoints Attribute Table is 1, the drain point is not stream connected, so the sediment is not delivered to the stream.
  2) If the value in the *StreamConnectID* column is 2, the drain point is stream connected, so the sediment goes into the stream.
- ELength is also used in the *Combined Stability Index* function to determine the amount of water present at each drain point.

Accumulated Upstream Sediment Load function

- This function creates the following output grids:
  1) Weight grid with drain point accumulated sediment load (with a demsac name format). This grid shows the location and quantity of total sediment in the stream network, such that the value of each cell is the total of all road sediment that has been input above that cell.
  2) Weighted Sediment Production grid (with a demswt name format).
- The user can select between D8 and Dinf Contributing area functions.
- These grids are used to determine the quantity of sediment in each stream segment in the *Upstream* and *Downstream Sediment Input Functions*.

Accumulated Upstream Specific Sediment function

- This function creates the upstream specific sediment accumulation grid (with a demspe name format).
- This grid is used to determine the quantity of sediment in each stream segment in the *Upstream* and *Downstream Sediment Input Functions*.

Upstream Sediment Input function

- This function calculates sediment accumulation for the downstream end of each stream segment. The following fields are appended to the stream network shapefile (that has a demnet.shp name format):
  1) *SedAccum*: Accumulated Sediment Inputs for each stream segment (kg/yr). As of GRAIP version 1.0.8 and previous versions, there is an error in this step that results in the numbers reported in this column being about ten times higher than they should be.
  2) *SpecSed*: Accumulated Specific Sediment Load per unit area for each stream segment (Mg/km2/yr).

Direct Stream Sediment Input function

- This function calculates the sediment load for the area draining directly to a stream segment. These fields are appended to the stream network shapefile (that has a demnet.shp name format).
  1) *SedDir*: Direct Sediment Inputs for each stream segment (kg/yr). As of GRAIP version 1.0.8 and previous versions, there is an error in this step that results in the numbers reported in this column being about ten times higher than they should be.
  2) *SpecSedDir*: Direct Specific Sediment Load per unit area for each stream segment (Mg/km2/yr).

Mass Wasting Potential Analysis **Menu and Associated Functions**

SINMAP functions

- SINMAP 2.0 is used to create a Stability Index (SI) grid and a calibration region grid from the DEM. Calibration regions are areas within which single lower bound and upper bound calibration parameters values can represent T/R (Transmissivity and Recharge Rate), dimensionless cohesion, friction angle (ø) and soil density (ρ). In a large watershed GRAIP study, substantial geologic and climatic variations may require multiple calibration regions. More information is available on the SINMAP website.

Stability Index function

- This function looks up the Stability Index grid values at each drain point and stores them in the *SI* field in the DrainPoints table.

Select Calibration Region Grid function

- This function opens the calibration grid created in SINMAP and is used for the *Combined Stability Index* function.
- Note that you will still have to change the calibration parameters separately in the *Combined Stability Index* function.

Combined Stability Index function

- This function creates a Combined Stability Index Grid (with a demsic file format) and stores the value from that grid at each drain point in the *SIR* field of the drain pint table in the GRAIP database.
- The output and intermediate files created are below. The intermediate outputs (1) and (2) are not added to ArcMap. The output file (3) is added if the "*Add SI combined grid to the Map*" checkbox is checked, which is the default. There is an additional file created that stores the calibration parameters (demcalp.csv)
  1) Minimum and maximum depth of terrain runoff generated (with demrmin and demrmax file formats).
  2) Specific discharge due to road drainage for minimum runoff and maximum runoff (with demrdmin and demrdmax file formats).
  3) Combined Stability Index grid (with a demsic file format).
- In this function, stability index (SI) due to terrain contributing area can be calculated by setting the road surface runoff to be 0, and SI due to road runoff only can be computed setting terrain recharge to be 0. The SI values from the grid are used to identify SI values to store in the *SIR* field in for each drain point in the GRAIP database.

D8 Slope Grid with Downslope Averaging function

- This function uses the D8 flow directions approach to trace downslope and find the average slope for each grid cell over the specified averaging distance. The output from this function is the slope grid with downslope averaging (called demslpd).
- You need to use at minimum two cells to get a slope, so the minimum distance you can use is 45 m, because the diagonal distance across a 30 m square is about 42 m. Longer distances (at least 90 m, or three cells at a diagonal) are recommended, as the road itself will often appear to influence the hillslope slope at the drain point.
- This grid is used to determine the slope at each drain point, which is used to determine each drain point's ESI.

Slope at Drain Point function

- This function extracts the average slope below each drain point from the D8 slope grid (created above) and stores it in the *Slope* field in the DrainPoints table of the GRAIP database.
- This data is used to determine the ESI of each drain point.

Erosion Sensitivity Index function

- This function populates the *ESI* field in the DrainPoint table. ESI is equal to LS^{α}, where *S* is the hillslope and *L* is the effective length (ELength) of the road draining to each drain point, and α operates on slope and has been shown to have a value of about 2 (Istanbulluoglu et al. 2003).

Length Slope Plot function

- This function shows the ELength-Slope plot with ELength on the logarithmic Y-axis and Slope on the X-axis.
- This plot can be used to calibrate the critical ESI (ESI_{crit}), which is the ESI, above which, the risk of gullies significantly increases.

Stream Blocking Index function

- This function was developed by Flanagan et al. (1998).
- This function populates these fields in the DrainPoints Attribute Table in the GRAIP database for stream crossing points with a culvert only:
  1) *PipeDiaToChanWidthRatio*: Ratio of the width of the culvert to the width of the channel. For example, a culvert that is 48 inches with a channel that is 5 feet (60 inches) will have a ratio of 0.8.
  2) *PipeDiaToChannelWidthScore*: The pipe to channel ratio is given a score, based on the range in which the ratio falls:

Condition	**Pipe to Channel Ratio Range**	**Score**
Big pipe, small stream	*≥ 1*	*1*
	0.5 - 1	*2*
Small pipe, big stream	*< 0.5*	*3*

  3) *Skew Angle*: The angle of the channel to the pipe, as determined in the field.
  4) *SkewAngleScore*: The skew angle is given a score, based on the range in which the angle falls:

Channel angle	**Skew angle score**
$> 45^{o}$	*1*
$< 45^{o}$	*0*

  5) *SBI*: Stream Blocking Index indicating plugging susceptibility based on the ratio of pipe diameters to channel width ratio class and skew angle score according to,

$$SBI = PipeDiaToChanWidthScore + SkewAngleScore$$

Note that the range of the SBI is from 1 to 4, where 1 indicates low risk of blockage, and 4 indicates a high risk of blockage.

Habitat Segmentation Analysis **Menu Functions**

Fish Passage Barrier function

- This function was developed from the work of Clarkin et al. (2003).
- This function identifies the fish passage barriers and assigns an identifier representing the status of the stream crossing: 0-Blocked Passage, 1- Possible or Unknown Passage and 2- Clear Passage. This identifier is used to populate the *Barrier* field in the DrainPoints table in the GRAIP database. Possible/Unknown Passage identifies the stream crossings that may be passable to some species, but not to others.

Fish Habitat Segmentation function

- This function is now defunct, because there are less time consuming and more reliable manual methods to glean its information.
- This function assigned an identifier to each stream segment indicating the habitat cluster to which it belongs. The habitat cluster identifier was appended to the TauDEM stream network shapefile Attribute Table.

Appendix C: Terminology

Two kinds of terminology are presented here. First, a section of general GIS terms are defined. Next, a section of specific GRAIP terms, such as drain point types, are defined.

GIS Terms

More terms and definitions can be found in the ArcGIS Desktop Help. The terms here are used in this document.

Attribute table… A database or table file that relates geographic features to information about them, usually arranged so that the individual features make up the rows, and information about them makes up the columns. In this document, when Attribute Table is capitalized, it refers to the attribute table for a specific layer you can view in ArcMap by right-clicking the layer name and selecting *Open Attribute Table*.

Database……. A structured data set or sets, stored and managed together, and usually related to software that can query and modify the data.

DEM…….... Digital Elevation Model. A DEM is a grid with cells that each represent continuous elevation, and are reference to a datum. The size of the grid cell determines the resolution of the DEM. 5x5 m, 10x10 m, and 30x30 m are common grid cell sizes. A "five meter DEM" refers to a DEM with 5x5 m grid cells.

Extent…….. The extent of a piece of data is the smallest rectangle that the data can fit in, defined by its minimum and maximum x- and y-values. The extent of a window in ArcMap is the maximum and minimum x- and y-values of the view contained by the window.

Grid……. ESRI Grid; an ESRI data format that stores raster data.

HUC…… Hydrologic Unit Code. The system used in the United States to divide the land area based on drainage into up to six levels, from large area (e.g. Missouri River) down to small watersheds. For GRAIP purposes, this refers to a shapefile containing polygons that conform to usually sixth level (6th code) watershed boundaries. Each polygon covers one watershed, and each set of HUCs contains many polygons, generally for an entire state.

Isoline…….. A line that represents a constant value on a map or graph, such as elevation (contour line) or pressure (isobar).

Map file…… AKA map document. The type of file in which you do your work in ArcMap. If you save your work in ArcMap, it is saved as a map file, with the extension .mxd. Layer symbology can be preserved in this way.

Raster…….. Defines space as a series of equally sized square cells arranged in rows and columns. Each cell stores a geographic attribute about its place, such as elevation or slope, and is referenced by its (x,y) coordinate system.

Shapefile……. Stores the location, shape, and attributes of vector data, such as roads, cities, lakes, and, in the case of GRAIP, drain points, etc.

Toolbar……... In ArcMap, a toolbar is a set of related tools grouped together with menus or buttons that allow the user to execute functions and other software commands.

GRAIP Terms

Adapted from Black, et al. (2009), Fly, et al (2010), and Moll (1997).

Broad based dip…… ***Constructed:*** Grade reversal designed into the road for the purpose of draining water from the road surface or ditch (also called dip, sag, rolling grade, rolling dip, roll and go, drainage dip, grade dip). ***Natural:*** A broad based dip point is collected at the low point where two hillslopes meet, generally in a natural swale or valley. This is a natural low point in the road that would cause water on the surface of the road to drain out of the road prism.

Cross drain……. This is not a feature collected specifically in GRAIP, and it can refer to a number of other drainage features. It is characterized by any structure that is designed to capture and remove water from the road surface or ditch. Ditch relief culverts, waterbars, and broad based dips can all be called cross drains.

Diffuse drain…... This is a point that is characterized by a road segment that does not exhibit concentrated flow off the road. Outsloped roads or crowned roads often drain half or all of the surface water diffusely off the fillslope. Although collected as a drain point, this feature is representative of an area or a road segment rather than a concentrated point where water is discharged from the road prism. A

drop of water that lands on a diffuse road segment will not flow down the road or into the ditch, but more or less perpendicular to the centerline off the road surface and out of the road prism. Also called sheet drainage or inter-rill flow.

Ditch relief culvert…….... This drain point is characterized by a conduit under the road surface, generally made of metal, cement, or wood, for the purpose of removing ditch water from the road prism. This feature drains water from the ditch or inboard side of the road, and not from a continuous stream channel.

Flow path…… This is the course flowing water takes, or would take if present, within the road prism. It begins where water is concentrated and flows along the road or it enters the road prism, and ends where water leaves the road prism. This can be either on the road surface, or in the ditch. Flow path types in GRAIP are ditch, diffuse, and concentrated.

Lead off ditch…. This drain point is characterized by a ditch that moves flow from the roadside ditch and leads it onto the hillslope. Occurs most often on sharp curves where the cutslope switches from one side of the road to the other. Also known as a daylight ditch, mitre drain, or a ditch out (though this term can also describe other types of drainage features).

Non-engineered drainage……... This drain point describes any drainage feature where water leaves the road surface in an unplanned manner. This can occur where a ditch is dammed by debris, and the water from the ditch flows across the road, where a gully crosses the road, where a wheel rut flow path is diverted off the road due to a slight change in road grade, or where a berm is broken and water flows through. This is different from a diffuse drain point, which describes a long section of road that sheds water without the water concentrating, whereas this point describes a single point where a concentrated flow path leaves the road.

Orphan drain point……. This is any drain point that does not drain any water from the road at the time of data collection. Examples include a buried ditch relief culvert, or a water bar that has been installed on a road that drains diffusely.

Stream crossing.. This drain point is characterized by a stream channel that intersects the road. This feature may drain water from the ditch or road surface, but its primary purpose is to route stream water under or over the road via a culvert, bridge, or ford. A stream for the purposes of GRAIP has an armored channel at least one foot wide with defined bed and banks that is continuous above and below the

road and shows evidence of flow for some part of most years.

Sump…… ***Intentional:*** A closed depression where water is intentionally sent to infiltrate. ***Unintentional:*** Any place where road water enters and infiltrates, such as a cattle guard with no outlet, or a low point on a flat road.

Waterbar……. This drain point is characterized by any linear feature that is perpendicular to the road that drains water from the road surface and/or ditch out of the road prism or into the ditch. Waterbars may be constructed by dipping the grader blade for a short segment, or adding a partly buried log or rubber belt across the road. Some road closure features may also act as a waterbar, such as a tank trap (also known as a closure berm or Kelly hump). Cattle guards that have an outlet that allows water to flow out are also considered to be water bars. These features may also be known as scratch ditches if they drain water into the ditch.

Appendix D: Attribute Table Field Name Explanations

This appendix presents the field names (column headings) for each of the three main GRAIP-created or modified shapefile attribute tables (DrainPoints, RoadLines, and the stream network shapefile demnet) with an explanation of what is in those columns. Each field name appears in top-down order as it appears in the attribute table left-to-right.

There are a few notable inconsistencies between these tables and those that you may see in the GIS. First, the capitalization may be different; the field names may appear as all caps in the attribute table. The field names may appear to be truncated in the attribute table (e.g. *FlowPathCond2ID* may appear as *FlowPath_2*). The DrainPoints and RoadLines Attribute Tables are joined to other tables from the GRAIP database, which results in *RoadLines* and *DrainPoints* appearing before the field name in each column (e.g. *RoadLines.FlowPathCond1ID*). Finally, many of the fields are numerical representations (called IDs) of data from each shapefile (e.g. *Grass and Herbs* from the ROAD shapefile Attribute Table has the ID *2* in the RoadLines Attribute Table). As such, if the value of a particular ID in one of these columns is zero, then there is no data for that particular field in that feature (e.g. there is no option in the DIFFUSE drain point for the *OrphanID* field, so its value will always be *0*).

RoadLines Attribute Table		
Field Name	***Description***	
FID	Feature ID number	
Shape	Polyline; type of shapefile	
GRAIPRID	GRAIP ID number	
GRAIPRID	GRAIP ID number	
CDate	Collection Date	
CTime1	Collection Time - flowpath 1	
CTime2	Collection Time - flowpath 2	
VehicleID	Crew Identifier number	
RoadNetworkID	Road Network Identifier	
RoadTypeID	Road Type	
	1	*Passenger car road*
	2	*High clearance Road*
	3	*Not trafficable*
	4	*Decommissioned*
OrigDrainD1	Drain point ID - flowpath 1	
OrigDrainD2	Drain point ID - flowpath 2	
GRAIPDID1	Drain point FID - flowpath 1	
GRAIPDID2	Drain point FID - flowpath 2	

SurfaceTypeID	Surface Type ID	
	1	*Crushed Rock*
	2	*Native*
	3	*Paved*
SurfaceConditionID	Surface Condition ID	
	1	*Good*
	2	*Rilled/eroded*
	3	*Washboard*
	4	*Rutted*
	5	*Rocky*
	6	*Ripped*
	7	*Decom potholed*
	8	*Recontoured*
	9	*Tilled*
SurfaceCov	Surface Cover ID	
	1	*None*
	2	*Grass and herbs*
	3	*Live woody veg*
	4	*Straw*
	5	*Organic debris*
RoadEdge1ID	Road Edge 1 ID (ft)	
	1	*Fill*
	2	*0' no ditch*
	3	*0 - 6'*
	4	*>6'*
RoadEdge2ID	Road Edge 2 ID (ft)	
	1	*Fill*
	2	*0' no ditch*
	3	*0 - 6'*
	4	*>6'*
EdgeConditionID	Edge 1 condition	
	1	*No Problem*
	2	*Badly rilled*
	3	*Badly ravelling*
	4	*Badly slumping*
	5	*Bedrock*
	6	*Seep spring*

FlowPath1ID	Flowpath 1 Type ID	
	1	*Ditch*
	2	*Diffuse*
	3	*Concentrated*
FlowPath2ID	Flowpath 2 Type ID	
	1	*Ditch*
	2	*Diffuse*
	3	*Concentrated*
FlowPathVeg1ID	Flowpath 1 Veg cover	
	1	*<25%*
	2	*>25%*
FlowPathVeg2ID	Flowpath 2 Veg cover	
	1	*<25%*
	2	*>25%*
FlowPathCond1ID	Flowpath 1 Condition	
	1	*No problem*
	2	*Gullied*
	3	*Buried ditch*
	4	*Rocked*
	5	*Eroded*
	6	*Stream course*
FlowPathCond2ID	Flowpath 2 Condition	
	1	*No problem*
	2	*Gullied*
	3	*Buried ditch*
	4	*Rocked*
	5	*Eroded*
	6	*Stream course*
FillChannelID	Distance from base of fill to stream channel (ft)	
	1	*0*
	2	*1-20*
	3	*21-50*
	4	*Above 50*
Comments	Comments from the field crew	
StreamConnect1ID	Stream connection - flowpath 1	
	1	*No*
	2	*Yes*

StreamConnect2ID	Stream connection - flowpath 2	
	1	*No*
	2	*Yes*
Orphan1ID	Drain point orphan - flowpath 1	
Does not function	*1*	*No*
	2	*Yes*
Orphan2ID	Drain point orphan - flowpath 2	
Does not function	*1*	*No*
	2	*Yes*
Length	Length (m)	
Slope	Slope (L/L)	
SedProd1	Sediment production - flowpath 1 (kg/yr)	
SedProd2	Sediment production - flowpath 2 (kg/yr)	
UnitSed	Sediment production - both flowpaths (kg/m/yr)	
TotSedProd	Sediment production - both flowpaths (kg/yr)	
TotSedDel	Sediment delivery - both flowpaths (kg/yr)	
UnitTotSedDel	Sediment delivery - both flowpaths (kg/m/yr)	
RoadNumber	Road number entered in field survey	

DrainPoints Attribute Table		
Field Name	***Description***	
FID	Feature ID number	
Shape	Point; type of shapefile	
GRAIPDID	GRAIP ID number	
GRAIPDID	GRAIP ID number	
DrainTypeID	Drain Point Type ID	
	1	*Broad Based Dip*
	2	*Diffuse Drain*
	3	*Ditch Relief*
	4	*Lead Off Ditch*
	5	*Non-Engineered*
	6	*Stream Crossing*
	7	*Sump*
	8	*Water Bar*
	9	*Excavated Stream Crossing*

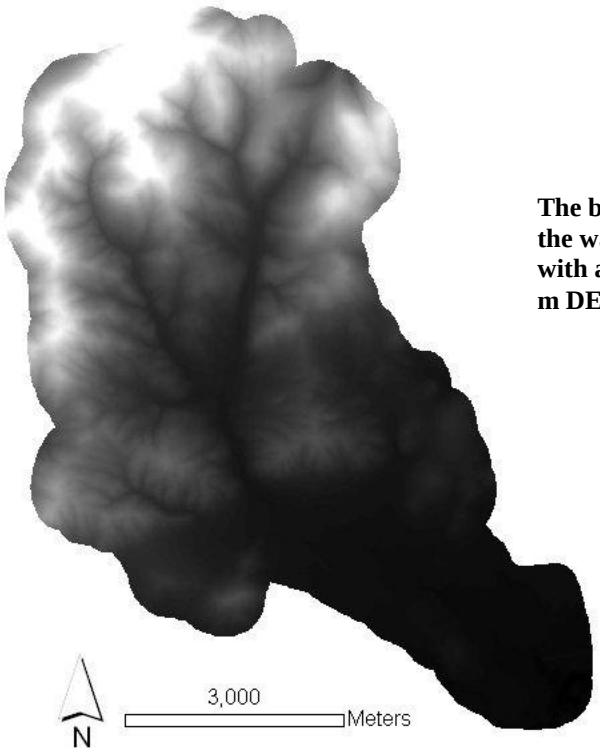
Cdate	Collection Date	
Ctime	Collection Time	
VehicleID	Crew Identifier Number	
DrainID	Drain point ID	
StreamConnectID	Stream Connection	
	1	*No*
	2	*Yes*
OrphanID	Drainpoint orphan	
	0	Not applicable for drain type
	1	*No*
	2	*Yes*
Comments	Comments from field crew	
SedProd	Produced sediment routed to drain point (kg/yr)	
Elength	Effective length of flowpath to drain point (m)	
UnitSed	Produced sediment per meter of road draining to drain point (kg/m/yr)	
SedDel	Sediment delivered to the stream (kg/yr)	
SI	Stability Index	
SIR	Combined Stability Index	
Slope	D8 Slope (L/L)	
ESI	Erosion Sensitivity Index	
PipeDiaToChanWidthRatio	Ratio of pipe diameter to channel width	
PipeDiaToChanWidthScore	Score for PipeDiaToChanWidthRatio	
SkewAngle	Angle between pipe and channel	
SkewAngleScore	Score for SkewAngle	
SBI	Stream Blocking Index	
Barrier	Fish passage barrier score	
	0	*Blocked to all species*
	1	*Blocked to some species*
	2	*Open to all species*

Stream Network Shapefile Attribute Table	
Field Name	***Description***
FID	Feature ID number
Shape	Polyline; type of shapefile
LINKNO	Link number
DSLINKNO	Downstream link number

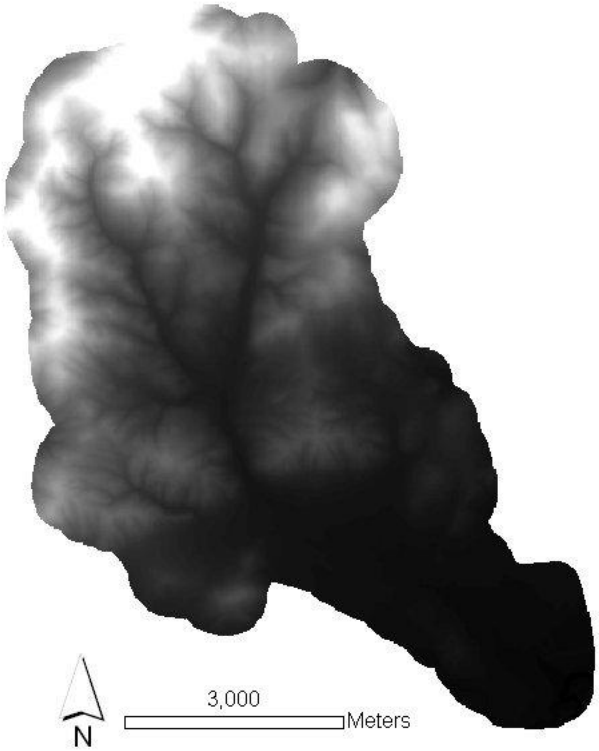
USLINKNO1	Upstream link number 1
USLINKNO2	Upstream link number 2
DSNODEID	Downstream node ID
Order	Strahler stream order
Length	Length of segment (m)
Magnitude	Shreve magnitude
DS_Cont_Ar	Contributing area at downstream end m^2
Drop	Vertical drop (m)
Slope	Slope (L/L)
Straight_L	Straight line distance from start to end of segment (m)
US_Cont_Ar	Contributing area at upstream end m^2
WSNO	Watershed number
DOUT_END	Distance to outlet from downstream end of segment (m)
DOUT_START	Distance to outlet from upstream end of segment (m)
DOUT_MID	Distance to outlet from at midpoint of segment (m)
SedAccum	Sediment accumulation (kg/yr)
SpecSed	Sediment accumulation ($Mg/km^2/yr$)
SedDir	Sediment delivered to section (kg/yr)
SpecSedDir	Sediment delivered to section per catchment area ($Mg/km^2/yr$)

Appendix E: Examples Of The GRAIP-Created Grids

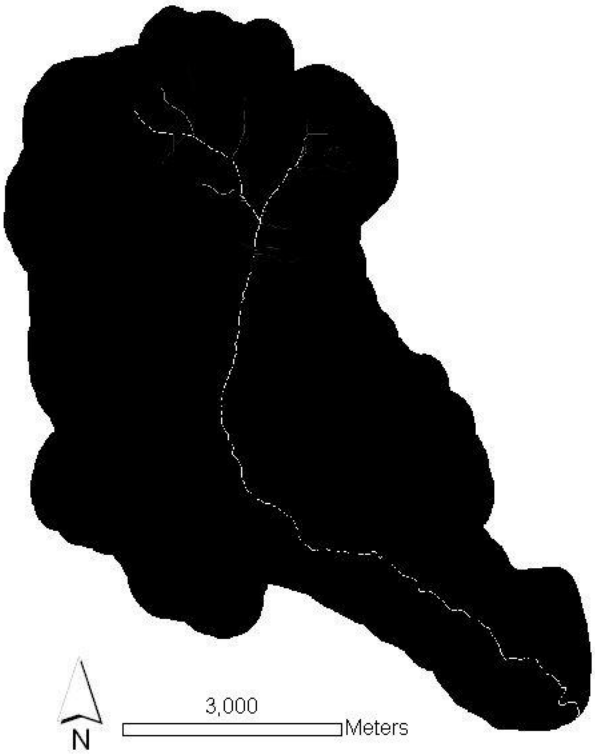
GRAIP creates 10 grids during it's processes. These grids are demr, demswt, demsac, demspe, demrmin, demrmax, demrdmin, demrdmax, demsic, and demslpd. Some are used by GRAIP steps further along, and some are the end product to be used for the analysis. The Appendix contains an example of each GRAIP-created grid in order to show what they all generally look like. Examples are from the Oak Creek watershed in western Oregon.

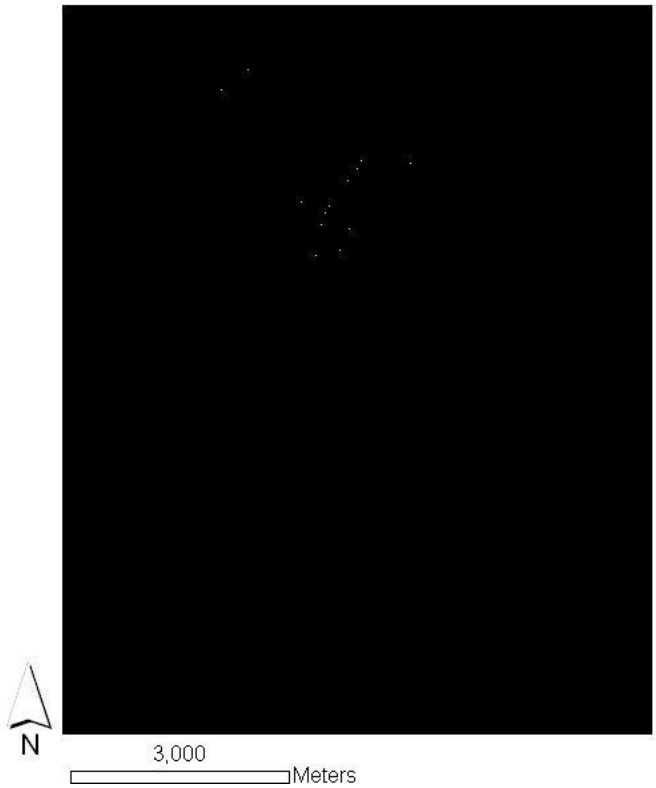


The base DEM, clipped to the watershed boundaries with a buffer. This is a 30 m DEM.



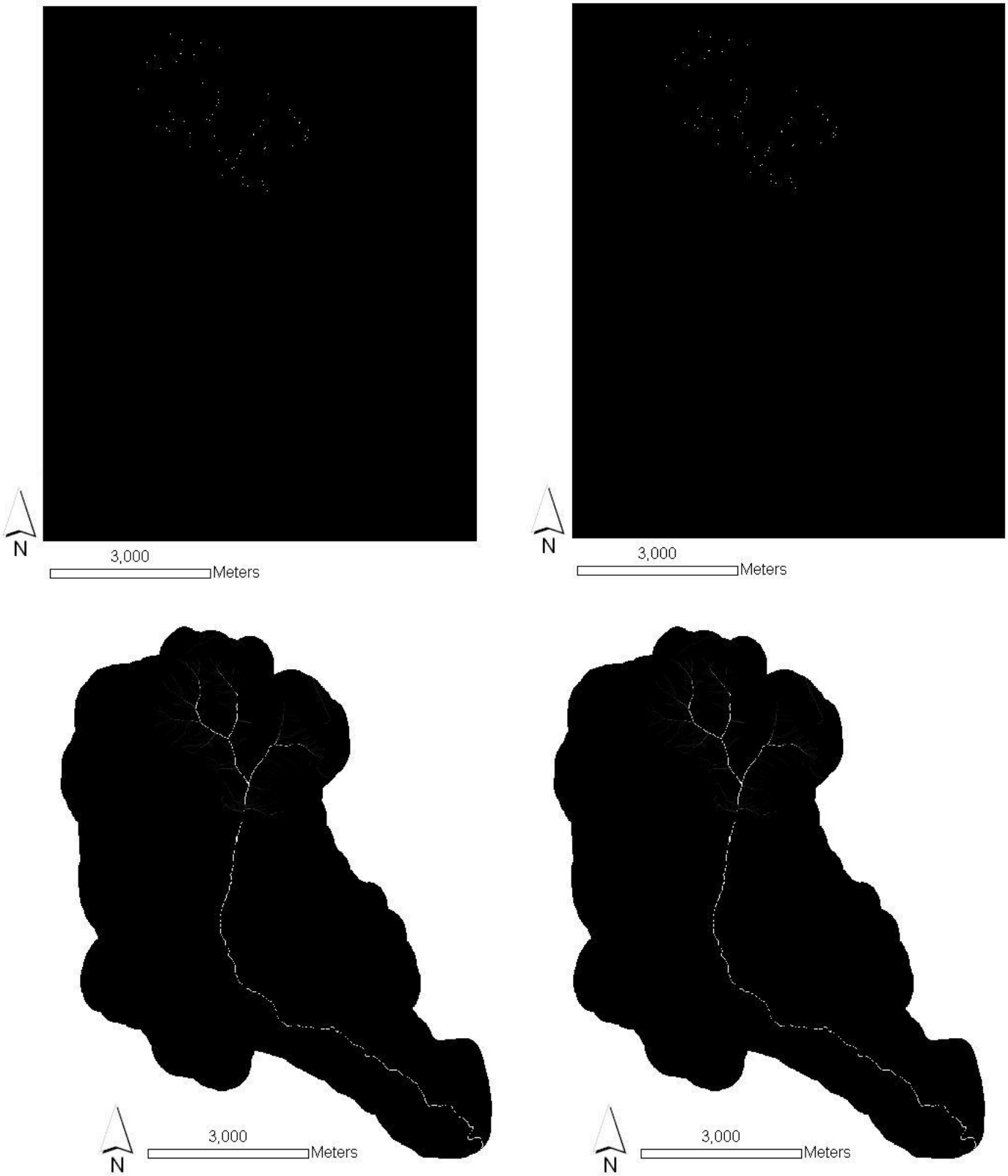
The resampled (to 5 m) DEM (demr) from the *Resample DEM* function in the *Preprocessor* menu.



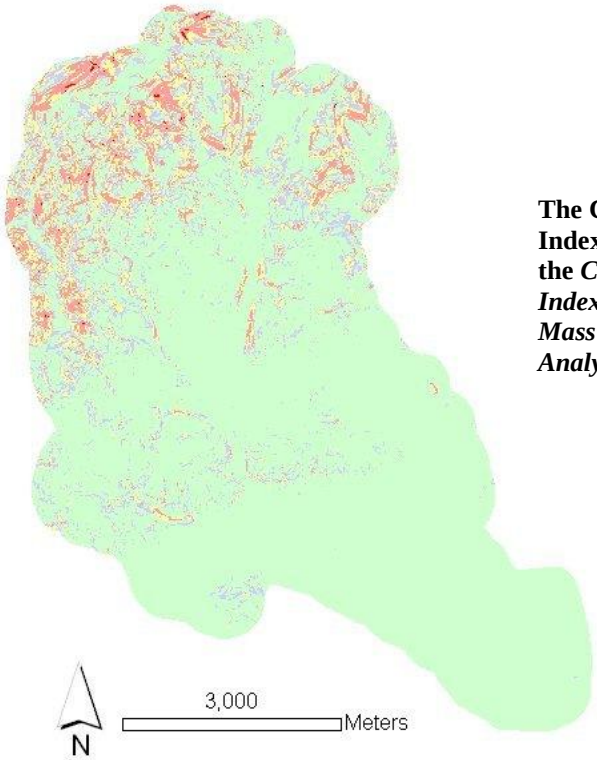


The Accumulated Upstream Sediment Load Grid (demsac, on left) and the Sediment Production Weight Grid (demswt, on right) from the *Accumulated Upstream Sediment Load* function from the *Road Surface Erosion Analysis* menu.

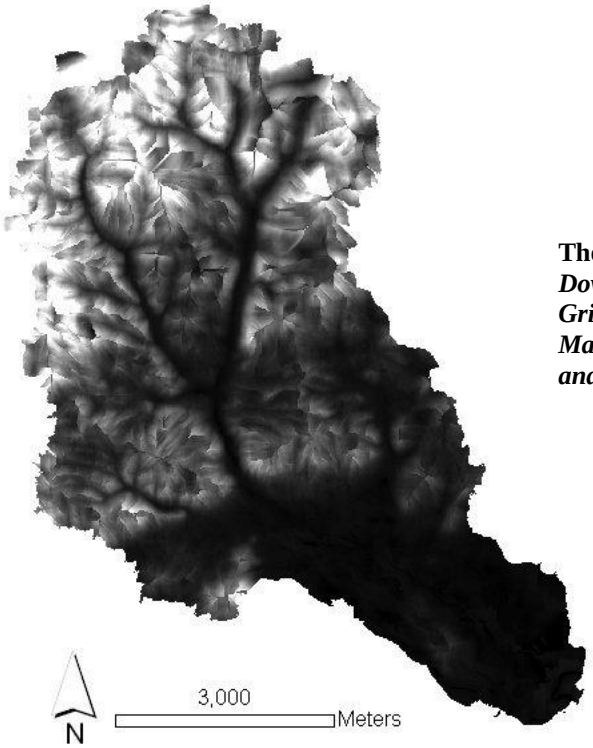
The Specific Sediment Accumulation Grid (demspe) from the *Specific Sediment Accumulation* function under the *Road Surface Erosion Analysis* menu.



Clockwise from top left, the minimum and maximum depth of terrain runoff grids (demrmin and demrmax) and the specific discharge due to road drainage for minimum and maximum runoff (demrdmax and demrdmin). These grids are generated by and used only by the *Combined Stability Index* function under the *Mass Wasting Potential Analysis* menu. They are not automatically added to ArcMap, and you won't need to add them.



The Combined Stability Index Grid (demsic) from the *Combined Stability Index* function under the *Mass Wasting Potential Analysis* menu.



The *D8 Slope with Downslope Averaging Grid* (demslpd) under the *Mass Wasting Potential and Analysis* menu.

Release Notes

Version Number	Release Date	Notes
1.0.0	5/24/07	
1.0.1	6/4/07	
1.0.2	7/6/07	
1.0.3	7/10/07	
1.0.4	8/14/07	– Link between Roadlines and Drainpoints created from CDate, CTime and Vehicle fields
1.0.5	9/14/07	– If near match is found for Add Value, reassign now initially selected – Added alpha and beta parameters to the Filter Stream Crossing function. – Added Slope to the Roadlines table – Added alpha parameter to the LS Plot function. – Clarified the meaning of Possible Passage.
1.0.6	2/29/08	– Added ability to have multiple input shapefiles of the same type – Expanded the length of several text fields in the database. – Fixed the preprocessor so that the file info is saved when an additional file is added to an existing project. – Delete Drainpoints and Roadlines index files when the shapefiles are deleted in the preprocessor so that expired index fields don't cause drain points and road line segments to disappear in ArcGIS.
1.0.7	3/9/09	– Fixed Elength calculation. – Fixed RemoveGrid function to only scan for GRID files rather than all raster dataset files. This prevents errors when there is another file with a raster dataset extension in the workspace.
1.0.8	3/20/10	– Fixed bug in the writing of parameters file for combined stability index function. The program should no longer overwrite parameters with the default parameters after they have been edited.

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