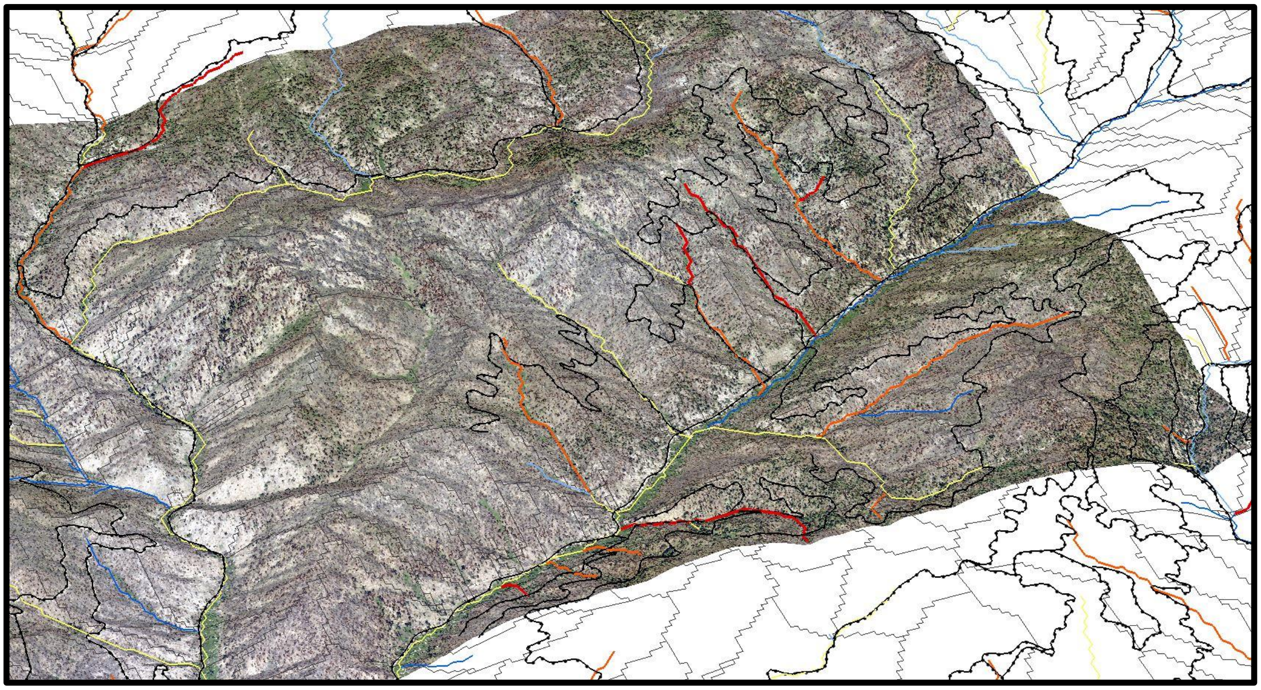
GRAIP_Lite: A System for Road Impact Assessment



Nathan Nelson, Charlie Luce, and Tom Black

January 2019

Boise Aquatic Sciences Lab
RMRS Rocky Mountain Research Station

Abstract

GRAIP_Lite is a system of tools developed for ArcGIS that is used to model road-related sediment impacts to stream habitats. GRAIP_Lite uses a topographic model, along with other inputs, to create road segments, applies average vegetation parameters and calculates sediment production from individual road segments, uses a local polynomial fit to describe stream connection probabilities and fractional sediment delivery based on flow distance to streams, and accumulates routed sediment throughout the modelled stream network. Road-related sediment impact is described using specific sediment (Mg/yr/km2) in the modelled stream network. This metric can easily be used to determine areas where roads present a higher risk to stream habitats when prioritizing areas for restoration or remediation efforts. When used for alternatives analysis, GRAIP_Lite allows the user to specify various treatment options for individual roads and then models the road-related sediment conditions at the initial condition (before work begins), disturbed condition (immediately post-work or during haul), and the recovered condition (once vegetation has recovered to normal values). GRAIP_Lite also has reporting tools that generate basic maps for use in reports based on the model results.

Acknowledgements

We would like to thank Brian Anderson, Terry Hardy, John Thornton, Melanie Vining, Brian Staab, Richard Cissel, and others who gave us encouragement and advice in our efforts to adapt the GRAIP_Lite model into a tool that would fit the needs and abilities of management and regulatory agencies.

Leigh Woodruff, Lynn Hood, Dwight Atkinson, and Teresa Kubo at the U.S. Environmental Protection Agency secured the funding for the development and programming of the GRAIP_Lite model and tools.

We would also like to thank Christine Dartiguanave at ESRI, who has done all the programming for the GRAIP_Lite tools.

Table of Contents

Introduction

Fine sediment accumulations in streams reduce the quality of critical stream habitats by impairing spawning gravels and reducing productivity. Forest roads are common sources of chronic fine sediment delivery in otherwise clear mountain streams. While the amounts delivered may be small compared to long-term sedimentation rates and sediment transport capacity (Goode et al., 2012), short-term road-related sediment can be significant and represent a large portion of the stream's short-term sediment load. Furthermore, the chronic nature of road erosion inputs may have important consequences for fish habitat (Maturana et al., 2014).

Road density is one tool that has been used to estimate road-related sediment risks to streams. It is generally assumed that where there are higher densities of roads there should also be greater road-related sedimentation, and to some extent this is true. The issue is that this approach treats all roads and environments as equals, even though anyone who has spent time exploring or working on forest roads knows that not all roads are created equal; there is substantial variability in road design, location, and maintenance practices (e.g. Luce et al., 2001). The one benefit of the road density approach is that it is quick, easy, and inexpensive to apply.

Road inventories are a fairly direct approach to identifying the unique qualities of each road. For instance, the Geomorphic Roads Analysis and Inventory Package (GRAIP, Black et al., 2012, Cissel et al., 2012) uses a GPS inventory to map the road network hydrology at the scale of individual road segments and drainpoints. An empirical model is used to estimate road sediment production on individual road segments, and the estimated sediment production is routed to the observed drainpoints and to the stream network, if the drainpoint was observed to be hydrologically connected to the stream network. This allows GRAIP to provide a detailed map of road sediment production, delivery, and accumulation in streams within a watershed. GRAIP also addresses a number of other potential road related risks, including landslide and gully initiation risks and stream crossing problems. The detailed information comes at greater cost than road density information; however such costs are a tiny fraction of actual road treatment costs, and targeting treatments to where they will have the greatest outcomes can more than offset inventory expenses. The amount of information provided by field surveys is suitable for project planning and some design level decisions. Such detail may be much greater than is necessary for many broad planning-level exercises.

Practical, intermediate information-content tools would be useful to managers. GRAIP_Lite leverages empirical patterns and information from several watershed studies done using GRAIP inventories and analyses to substantially refine the information that can be extracted from GIS map-level information. In keeping with a modeling philosophy that seeks to match decision maker information needs to modeling effort (Figure 1), GRAIP_Lite can be implemented using only existing GIS data, or it can be supported using a field-collected calibration data set to inform a statistical estimation of vegetation cover and delivery curves. Existing GRAIP data can be used to supply this calibration data set or new calibration data can be collected in areas where existing GRAIP data is not available or applicable. We also offer a calibration survey design that takes less time and expense than complete inventories. Again, the intent is to provide a spectrum of tools to allow managers to match their needs for precision and accuracy to the level of effort expended (Figure 1).

Figure 1: The information-effort scale for road erosion estimation.

Calculations

Supporting Data

GRAIP_Lite was developed from data associated with several large GRAIP watershed inventories, which provided the means of determining the underlying relationships between sediment delivery and flow distance to streams. Over 77,000 drainpoint observations were used to test various predictive variables and model relationships. Road segment data was used to derive average vegetation states for different surface type and maintenance level classes. The more detailed GRAIP model provided the basic structure, with the GRAIP_Lite model being similarly composed of separate components for sediment production, sediment delivery, and sediment accumulation.

GRAIP_Lite uses a single flow path road model where each road segment drains completely at a single drainpoint located at the downhill end of the road segment. This is a simplification from the GRAIP model, which allows two flow paths and more complex flow routing through multiple road segments, but without the complete road inventory there is no way to predict such routing. What can be done, and what GRAIP_Lite does, is to use topography and maintenance level as the bases to break up the road network into individual road segments, each of which can be assigned a drainpoint, model sediment production from that road segment based on several factors, model sediment delivery based on connection probabilities, and then accumulate the delivered sediment through the stream network to assess sediment loads and risks.

Components

GRAIP_Lite estimates sediment production and delivery separately. The first component calculates an estimate of the amount of sediment produced from each segment of, and the second component then models how much of that sediment is actually delivered to the stream network, where it can impact aquatic habitat.

Sediment Production

Sediment production is the amount of sediment eroded from the road surface, and is estimated for each road segment as

$$E = BRSV$$

where E is the total sediment production for the road segment, B is the baserate, R is the elevation difference between road segment ends, S is the surface type factor, and V is the vegetation factor. These components are shown in Figure 2.

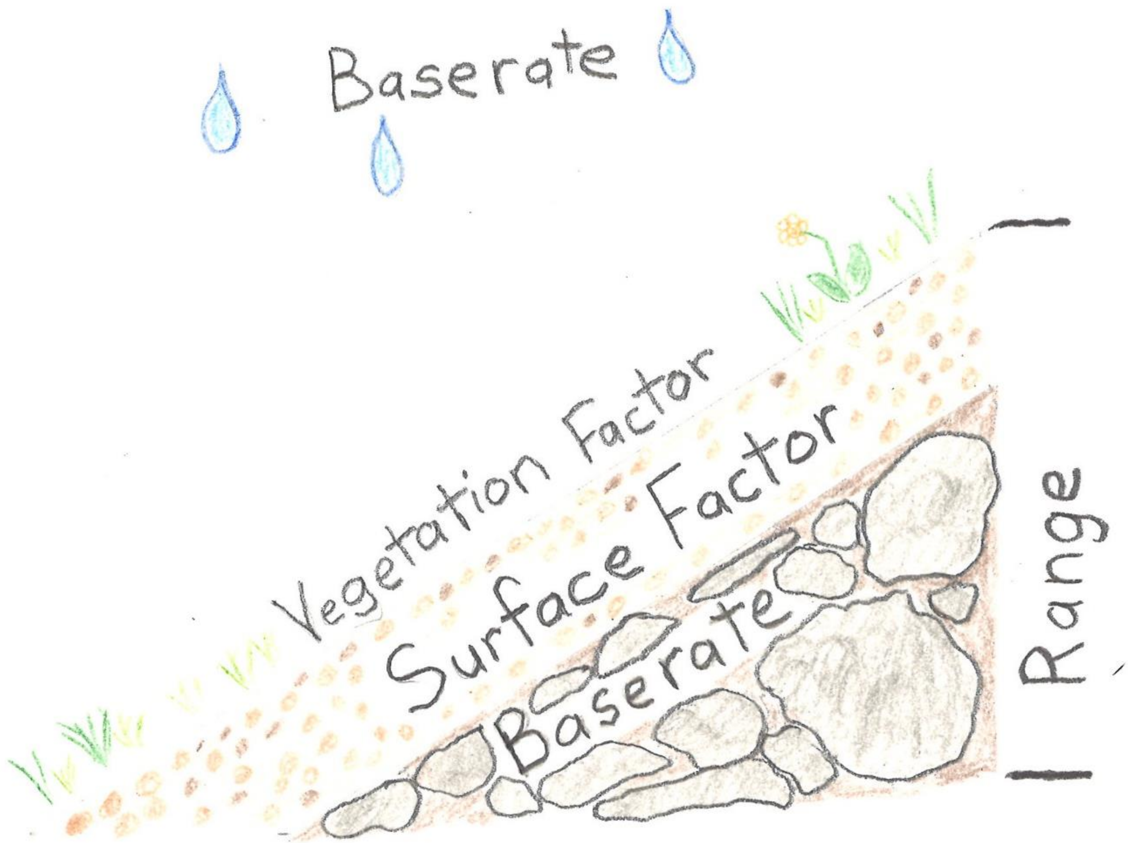


Figure 2: Components of the Sediment Production equation.

Baserates

The baserate is used to describe the erodibility of the road surface and the power of rainfall to detach and transport sediment, and is used to take into account different variables including local geologic and climatic factors. In most cases, baserates are measured using plot studies, as described in Black and Luce (2013). In some cases, baserates have been inferred from other methods, including WEPP model runs (e.g. Tysdal et al., 1999). The "base" condition is a graveled road segment 80 meters long with no vegetation low traffic and a 6% slope (so R is about 5m). The default baserate is 79 kg/yr/m vertical drop along the road based on a field site in western Oregon (Luce and Black, 1999). Baserates for other calibrations can be found in Appendix A.

Surface Factors

The surface factors used in GRAIP_Lite are dependent on the surface type and the traffic level of the road being modelled. This allows GRAIP_Lite to account for differences observed between roads with varying amounts of traffic and with different surface types. The surface type “Not a road” is used to model planned roads that do not yet exist as part of how GRAIP_Lite models different treatment alternatives. These factors are shown in Table 1. The entries for the “Low” traffic level and varying surfacing are based on field data in western Oregon (Luce and Black, 1999). There have been a limited number of studies examining the effect of vehicle traffic on road surface erosion. These studies have typically measured erosion at the bottom of a road segment under different traffic levels with different levels of road maintenance that generally accompany increased road use. Kochenderfer and Helvey 1987, Bilby et al. 1989, Fahey and Coker 1989, Foltz 1999, and Sheridan et al 2006 found that a change from light vehicle use to more than 5 heavy truck passes a day resulted in an increase by a factor of 2-5 in the observed erosion. This traffic change is typical of a US Forest Service maintenance level 2 or 3 road that is being used as a haul route for a timber sale. Observations on erosion from closed, gated and unused roads are rare. In a study on the Lolo National Forest (Black et al. unpublished) we found that erosion on unused road with vegetation on the surface was less than 10% of that on similar roads with occasional light vehicle use.

Table 1: Surface Factors by Surface Type and Traffic Level.

Surface Type	Traffic Level			
	None	Low	Medium	High
Crushed Rock	0.1	1.0	2.0	4.0
Native	0.5	5.0	10.0	20.0
Paved	0.1	0.2	0.2	2.0
Not a road	0.0	0.0	0.0	0.0

Vegetation Factors

Vegetation growing in the flowpath on the road’s surface acts to reduce sediment production by increasing surface roughness and by anchoring material. The vegetation factor is calculated as

$$V = 1 - 0.86\,x$$

where x is the fraction of the road segments where the flowpath vegetation cover is greater than 25%, as observed in a calibration data set. This is calculated for each combination of surface type and maintenance level and represents the average vegetation on those resulting classes of roads.

Sediment Delivery

Data from GRAIP inventories shows that not all sediment eroded from the road surface is delivered to streams, and that the majority of the sediment that is delivered to the stream network is delivered by a small portion of the total road network. With the GRAIP model, sediment delivery is based on a direct field observation indicating if each individual drain point is hydrologically connected to the stream network. Since GRAIP_Lite does not use those direct observations, a different method of modelling sediment delivery is required.

Stream Connection Probability as Fractional Delivery

GRAIP_Lite uses a fractional delivery model instead of the yes/no model that GRAIP uses. Calibration data is used to define a set of curves describing the probability that a drainpoint would be observed to be stream connected based on the modeled flow distance to the modeled stream network and the length of the road segment it drains (Figure 3). We define the fractional sediment delivery to be equal to the probability of observed stream connection, and use a local polynomial regression (Loader, 2013) to estimate those probabilities conditioned on distance to stream and road segment length class. Given that a probability is mapped to fractional delivery, this approximation is only applicable when averaging across a number of potential delivery sites. It is an application of risk assessment, where the cost is the amount of sediment and the probability of delivery is the hazard.

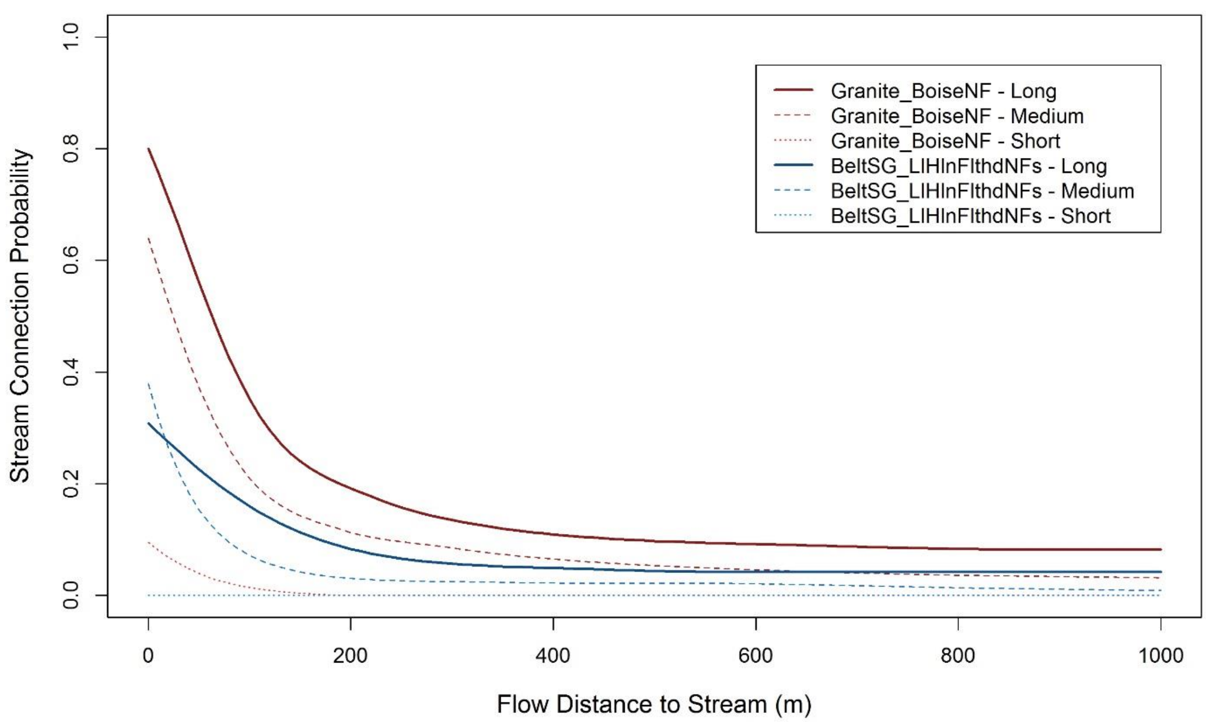


Figure 3: A comparison of the different calibration curves used by two local calibrations.

Sediment Accumulation

The very fine sediments originating in road surface erosion move fairly readily through steeper headwater streams and it is reasonable to ignore Sediment accumulation within the stream network is calculated by the ArcHydro tools in the same way that GRAIP uses the TauDEM tools to route sediment through the stream network and calculate contributing areas and specific sediment loads.

Calibration

Calibration data is collected in the field using GPS and data entry at each site. At each sample drainpoint, the crew collects data on drain type, stream connection, road surface type, recent road maintenance, and flowpath vegetation and records the data in the database. Excepting road maintenance, GRAIP data can be used to derive a calibration data set if there is pre-existing GRAIP data available. The observations of stream connection provide the basis for local polynomial regression curves used to predict the probability of stream connection as a function of stream distance. Stream distance is the modelled flow distance from the observed drainpoint and the stream network modelled by the ArcHydro tools. The road surface type, maintenance level, and flowpath vegetation records are used to calculate the vegetation factor for road surface type and maintenance level combinations.

If you are using one of the included calibrations, you will see a message in green text advising you that the delivery probability, vegetation factor, and baserate tables are missing (Figure 4). The table values are already in the tables and so this is not an issue when using these calibrations.

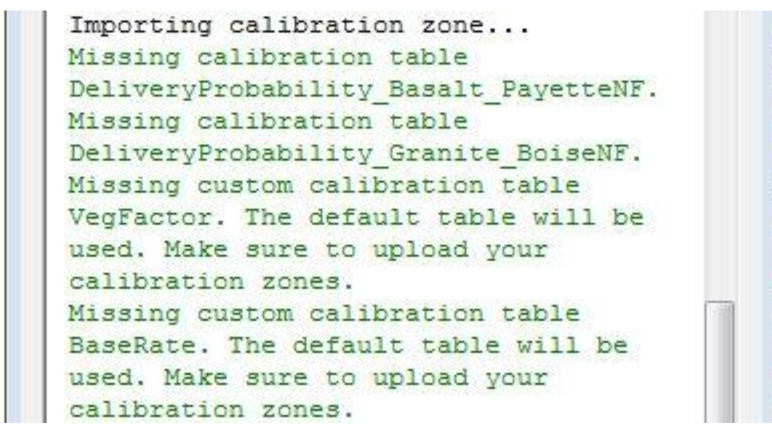


Figure 4: Messages advising that calibration tables are missing.

Prerequisites and Installation

To install GRAIP_Lite, make sure that the computer has ArcGIS 10.3.1 or higher, with the Spatial Analyst and 3D Analyst extensions and the Advanced License, then install the most recent version of Arc Hydro Tools (10.3.172 or later). GRAIP_Lite is part of the Arc Hydro Tools package, available at http://downloads.esri.com/archydro/archydro/setup/.

Further information on GRAIP_Lite can be found at https://www.fs.usda.gov/GRAIP/GRAIP_Lite.html.

ArcMap setup.

There are a couple things in the ArcMap settings that are necessary to let GRAIP_Lite run smoothly. These should be set before starting the GRAIP_Lite tools; once set, they should remain set, but they are good places to start when troubleshooting.

First, using the Geoprocessing menu, open Geoprocessing Options (Figure 5). Make sure that the boxes are checked for “Overwrite the outputs of geoprocessing operations” and “Add results of geoprocessing operations to the display” that Background Processing is not enabled. This should eliminate errors where GRAIP_Lite cannot overwrite certain temporary files (like the out_splitlineatpoint feature classes). Background processing is generally less stable than foreground processing.

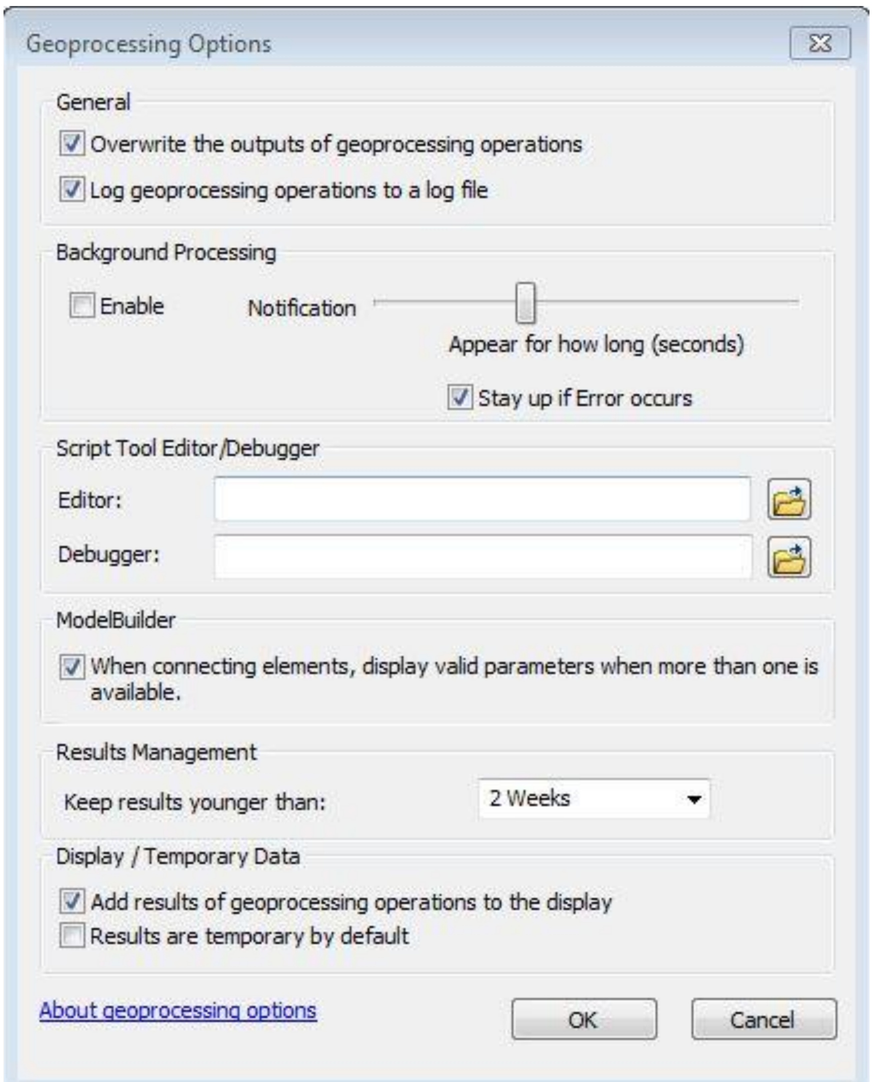


Figure 5: ArcMap Geoprocessing settings. These should also be set in ArcCatalog.

Another useful setting, especially on slower computers, is found in the ArcMap Options window (Figure 6) under the Customize menu. If you uncheck the box by “Make newly added layers visible by default”, ArcMap will not try to draw each layer over and over as different layers are added to the map document. This can significantly speed up slower machines.

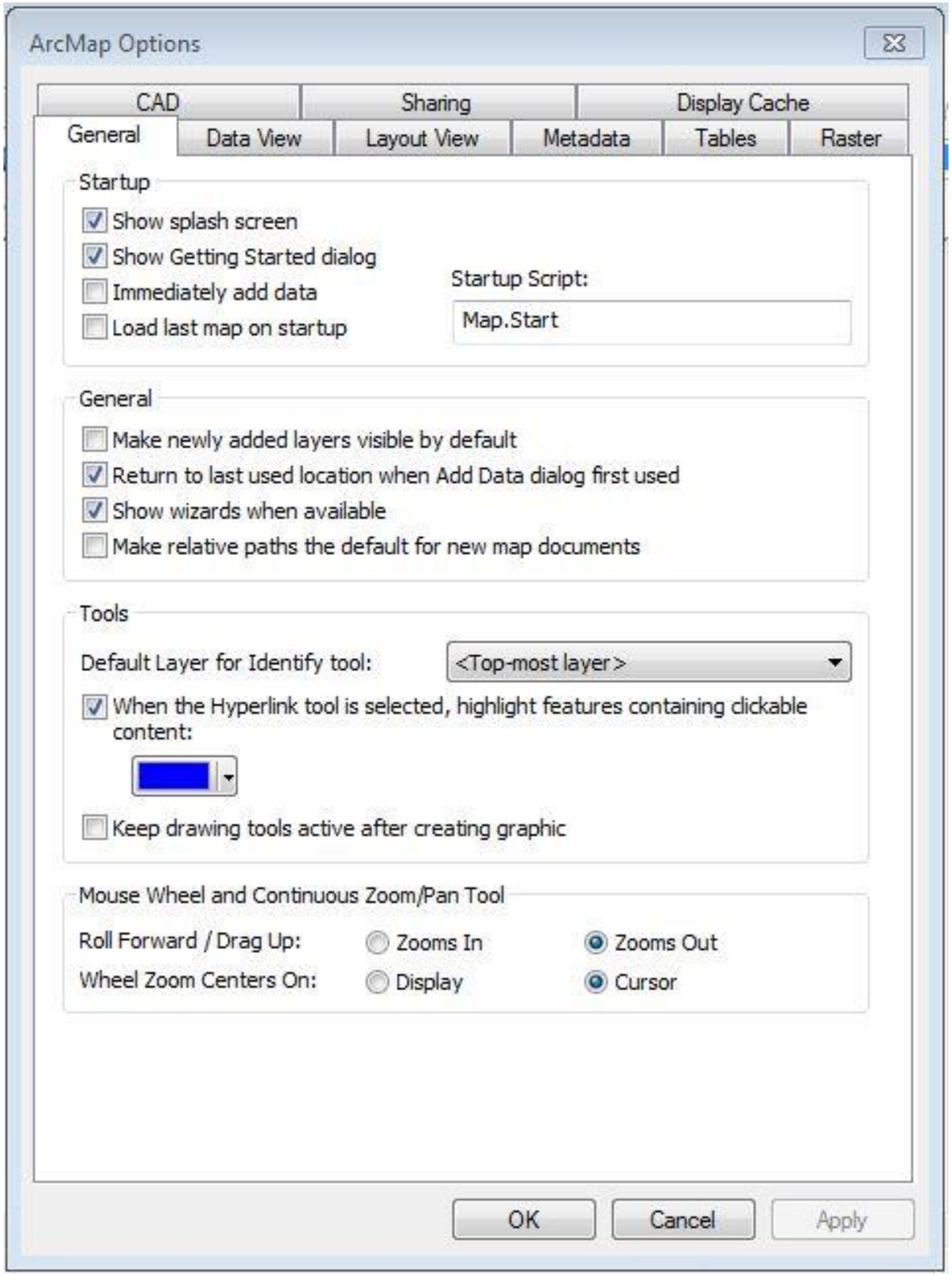


Figure 6: ArcMap Options settings.

ArcHydro and GRAIP_Lite make use of two extensions in ArcGIS: 3D Analyst and Spatial Analyst. Spatial Analyst is also very useful for setting up your GRAIP_Lite projects. You can verify that these are set up and available by going to Customize -> Extensions and making sure the appropriate boxes are checked (Figure 7).

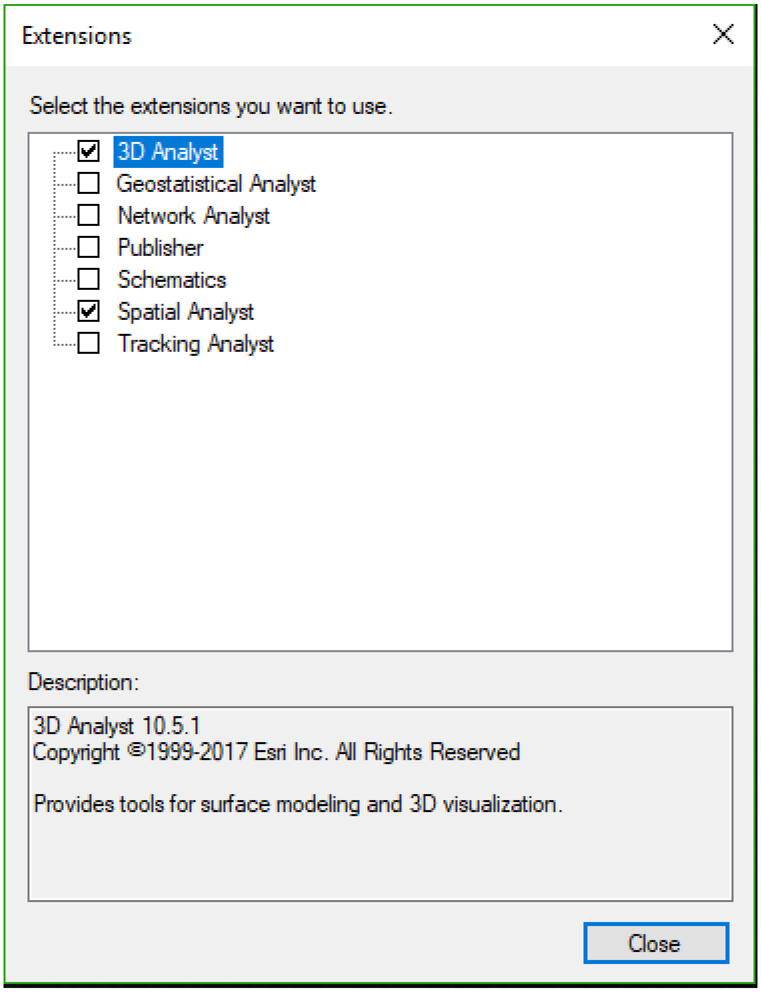


Figure 7: The Extensions window accessed in the Customize menu.

Input Data Requirements

GRAIP_Lite requires that the input data meet certain requirements. While in some cases GRAIP_Lite may still run if these requirements are not met, the model results may not be accurate. GRAIP_Lite requires a rectangular projection with meters as the linear unit. Since input data is often in different projections, or in unprojected geographic coordinate systems, all input data should be checked and projected into a suitable coordinate system. Universal Transverse Mercator (UTM) systems are ideal.

Roads Layer

The roads layer input into GRAIP_Lite also needs to meet specific requirements as to the attributes present in the data set. GRAIP_Lite was designed around the U.S. Forest Service's INFRA road layers, which contain information about road surfacing and maintenance that is used by the model to estimate parameters related to sediment production.

Both the attribute field names and the values contained in those fields needs to fit the specific form that GRAIP_Lite expects. The three required fields for any dataset are the route status (ROUTE_STAT or ROUTE_STATUS), surface type (SUFACE_TY or SURFACE_TYPE), and operational maintenance level (OPER_MAINT or OPER_MAINT_LEVEL) fields; short names are for shapefiles and long names are for geodatabase feature classes.

Where data are missing from these fields, GRAIP_Lite attempts to fill it in by making certain assumptions. If data are missing from the surface type field, the model will assume a native road surface; if data are missing from the maintenance level field, then the model assumes the road is a maintenance level 2 road, meaning that it has minimal design and is intended for slow, high clearance vehicles. Often, INFRA road layers are missing this information from non-Forest Service System roads, which may include private or county roads and state or federal highways. In most such cases, especially with county, state, or federal roads, the surface type may be known and it is just the maintenance level that is missing. Ideally, all missing data will be accurately filled in. Again, the design allows for the manger's discretion with respect to effort versus accuracy. In most cases, the default sets the condition to the highest risk so that analysts may reasonably claim that uncertainty was set to a worst case analysis.

We have seen GRAIP_Lite give an error when the data in Oper_Maint is not in the correct format; for example, if it is set to "D – Decommissioned" it will cause an error because D is not a numeric value and GRAIP_Lite does not know what to do with the value. Such values need to be corrected before the database will initialize by changing the value to one of the expected values; "D – Decommissioned" gets changed to "1 – BASIC CUSTODIAL CARE (CLOSED)" and "NA – NOT APPLICABLE" should be changed to match the road characteristics, if known, or deleted so there is no value for those records.

Digital Elevation Model

Calibration sets included with GRAIP_Lite were developed using DEMs from the 1/3rd arc-second National Elevation Dataset (NED) with a nominal 30m resolution, accessible at https://viewer.nationalmap.gov/basic/. In practice, these DEMs run between about 20m and 28m resolutions when projected into a UTM coordinate space; we usually round the cell size off to the nearest meter for simplicity. When using one of the installed calibrations, including the default calibration, a nominal 30m DEM has been assumed and should be used.

Because Arc Hydro uses a threshold approach to determining stream head locations and that contributing area threshold is determined by the number of contributing cells rather than the contributing area, using a higher resolution DEM without also changing the threshold cell count results in a denser modelled stream network (Figure 8), which in turn results in shorter modelled flow distances to streams and differences in road connectivity and sediment delivery. DEM resolution must match that of the calibration being used, or care must be used to set the *Number of Cells* threshold when running the *DEM Processing* tool to match the contributing area threshold, and therefore modelled drainage density, of the calibration. The contributing area threshold is described by

$$C\,L^2 = A$$

where C is the *Number of Cells* threshold, L is the resolution of the DEM, and A is the contributing area threshold.

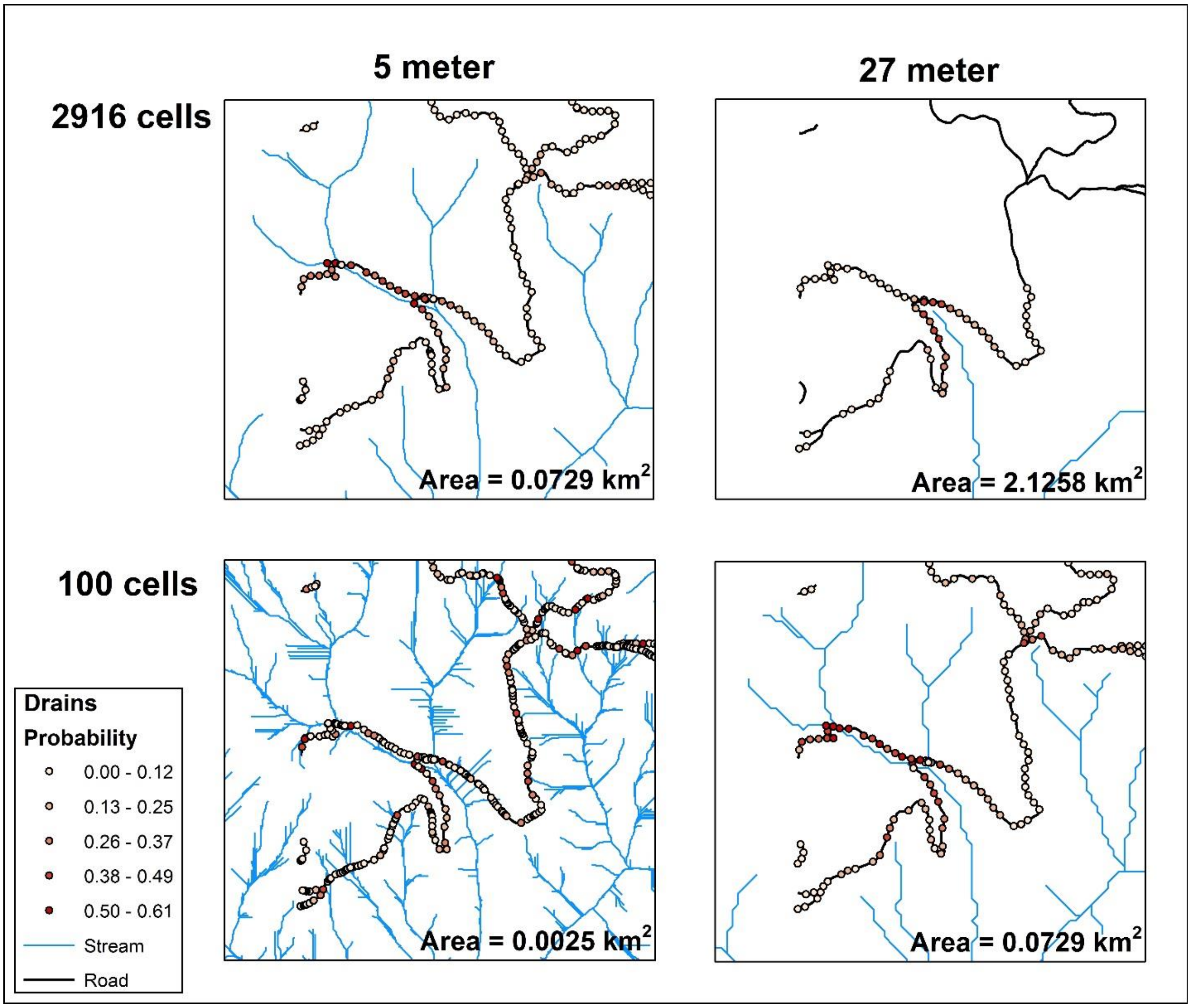


Figure 8: Relationships between DEM resolution, contributing cell threshold, and resulting contributing area thresholds in terms of resulting modelled drainage density and stream connection probabilities.

It is also important to keep in mind that the streams in GRAIP_Lite are modeled streams at all steps beyond the collection of the field calibration data. This means that there will be discrepancies between these modeled streams and the actual streams on the ground when it comes to the location and extent of the stream networks. Local controls on steam head locations may not be apparent when modeling stream networks from a DEM when using a simple threshold cell-count approach.

Using Calibration Zones

Calibration zones are defined by a polygon shapefile or feature class with an extent equal to that of the DEM. These define areas where characteristics are relatively similar (e.g. climate and geology) and the necessary model parameters are known. A given run of GRAIP-Lite can use one or more zones. Each defined zone requires a field called "Name" that contains the name of the calibration for that area. Included calibrations can be used by assigning the names of the desired calibrations (Table 2). Managers seeking to increase the accuracy and precision for their project area can complete surveys to create a custom calibration (effort-accuracy balance). Custom calibrations require that the appropriate parameter tables are included in the same directory as the calibration zone shapefile or feature class.

Table 2: Included GRAIP_Lite calibrations.

Name		**Baserate**	**Mean Annual Precipitation**	**Mean Elevation**	**Connection Rate**	**Number of Years of Data**	**Number of Plots**
Formal	*Used in GRAIP_Lite Tables*	*(kg/yr/m)*	*(mm)*	*(m)*			
Default	Default	79.0			15%		
Andesite - Eldorado NF	Andesite_EldoradoNF	53.0	1287	1718	13%	3	3
Andesite - Plumas NF	Andesite_PlumasNF	77.6	803	1906	15%	4	4
Basalt - Payette NF	Basalt_PayetteNF	27.2	1009	1722	17%	5	5
Basalt - Umatilla NF	Basalt_UmatillaNF	1.5	464	1178	26%		
Basalt/Sandstone - Siuslaw NF	BasaltSandstone_SiuslawNF	79.0	2096	200	4%		
Belt Super Group - Colville NF	BeltSG_ColvilleNF	14.0	625	1151	8%		
Belt Super Group - Lolo Helena Flathead NFs	BeltSG_LlHlnFlthdNFs	14.0	680	1523	6%	7	15
Granite - Boise NF	Granite_BoiseNF	21.3	850	1707	17%	9	6
Granite - Eldorado NF	Granite_EldoradoNF	49.5	1302	1766	17%	3	3
Granite - Plumas NF	Granite_PlumasNF	30.2	751	1701	11%	4	4
North Cascades - Mount Baker Snoqualmie NF	NCascades_MtBkrSnqlmNF	79.0	3147	631	35%		

Known Drainpoints-*optional*

The known drainpoints layer is a point shapefile or feature class containing the locations of known, surveyed drainpoints along the modeled roads. GRAIP_Lite makes use of points within 10m of the roads layer by snapping those points to the road layer and using them as split points when breaking up the road layer into road segments. This allows the user to force GRAIP_Lite to create split points at engineered drainage features in addition to relying on topographic and maintenance level based split point predictions.

Input Data from Other Sources

Road layers from other sources may be used, but some pre-processing will likely be necessary to make such layers compatible. It will likely be necessary to add and populate the required fields, which are the route status (ROUTE_STAT or ROUTE_STATUS), surface type (SUFACE_TY or SURFACE_TYPE), and operational maintenance level (OPER_MAINT or OPER_MAINT_LEVEL) fields; you can use either long or short names depending on the data type. All of these fields are text fields.

To populate the fields with appropriate data, you will need to know something about your roads and know what values to input (Table 3) so GRAIP_Lite understands what your roads are like. The easiest field is the route status field; this field is used primarily to guess the maintenance level if the maintenance level field is blank but should still be filled in. The surface type field should also be fairly easy to assign. Maintenance levels are probably the trickier values to assign. For more information on Forest Service road maintenance levels see Apadoca et. al. 2012.

Table 3: Input values for GRAIP_Lite.

Field	Input Values	GRAIP_Lite Values
Route Status	EX - EXISTING	2
	DE - DECOMMISSIONED	1
	CV - CONVERTED	2
	DEP - DECOMMISSIONING PLANNED	2
	PL - PLANNED	2
	PLN - PLANNED NON-NEPA	1
Surface Type	AGG - CRUSHED AGGREGATE OR GRAVEL	Crushed Rock
	IMP - IMPROVED NATIVE MATERIAL	Native
	NAT - NATIVE MATERIAL	Native
	AC - ASPHALT	Paved
	BST - BITUMINOUS SURFACE TREATMENT	Paved
	P - PAVED	Paved
Maintenance Level	1 - BASIC CUSTODIAL CARE (CLOSED)	1
	2 - HIGH CLEARANCE VEHICLES	2
	3 - SUITABLE FOR PASSENGER CARS	3
	4 - MODERATE DEGREE OF USER COMFORT	4
	5 - HIGH DEGREE OF USER COMFORT	5

Applications and Uses

GRAIP_Lite has several applications and uses for management purposes. These applications extend from forest-wide watershed condition assessments to project scale NEPA work. Different types of analysis have some different assumptions and limitations.

Model validations between GRAIP_Lite and GRAIP reveal typical patterns of potential errors created by the differences between the two models, largely due to GRAIP_Lite using a probabilistic fractional delivery model and GRAIP using binary (yes or no) observations of delivery. When there is a small amount of road being modeled, there is a greater chance that GRAIP_Lite sediment predictions for individual stream reaches may be significantly different from those predicted by GRAIP (Figure 9A). At the same time, the predictions showing the greatest error are also likely to be relatively smaller masses of sediment (Figure 9B). In both cases, the mean errors, and even the standard deviations, are small even with small amounts of road and smaller amounts of modeled sediment. Some of the errors are also due to GRAIP's ability to describe road segments and drainpoints that do not fit average observed conditions, either by being in better shape than average or by being in worse shape than average.

Another important factor is the accuracy of the input information, especially the data in the road layer. GRAIP has an advantage in this case because of the intensive field inventory; all of GRAIP's input data is effectively field verified and can vary at the scale of individual model road segments. GRAIP_Lite is dependent on the accuracy of the road layer input; if the data in the road layer is inaccurate or out of date, the model results will be as well, and where data are missing, for example where surface type or maintenance level attributes are not complete, GRAIP_Lite must assume parameters which may not reflect reality. Any model is, at best, only as good as the data driving it. A range of options are available in GRAIP_Lite for accepting lower quality input data while still using some understanding of road systems to give a reasonable estimate.

GRAIP_Lite is an ideal tool for use in watershed condition assessments that may be done across one or more forests at a time. In this type of analysis, GRAIP_Lite is used to assess road surface-related sedimentation within areas ranging from 6^{th}-code HUCs to about half a 6^{th}-code HUC across the total landscape. At these scales, GRAIP_Lite yields similar sediment accumulation and delivery values to GRAIP, and absolute values may be used with confidence, insofar as the road data in INFRA are accurate. The goal of this kind of assessment is to prioritize 6^{th}-code or half 6^{th}-code sized HUCs in regards to road-related impact so that future work can be focused in areas that address the greater needs where higher road-related impacts exist. This allows more effective use of project dollars. This application is fast and easy enough to implement that it can replace road density as a sort of basic index. GRAIP_Lite essentially adds that steeper roads, roads closer to streams, and roads with more traffic and less surface preparation pose greater risk from the perspective of road surface erosion. While such concepts are generally well understood, their implementation in GIS has previously been burdensome.

On the other end of the scale spectrum, GRAIP_Lite is used to assess how different proposed road treatments may affect road-related sediment risks in support of a NEPA proposal. This type of analysis usually covers a smaller area, being run on a project scale, and is assessing a smaller set of roads. As a result, this becomes an analysis of relative risk rather than of absolute values. Keeping this in mind, GRAIP_Lite uses the Alternatives module to assess how road-related sediment impacts are likely to change depending on the specified current conditions and treatments applied, modeling the treated road network at an initial condition before any work has been done, at a disturbed condition when the work is recently completed, and at a recovered condition when road surface vegetation and traffic levels have recovered to an equilibrium condition after the work has been completed.

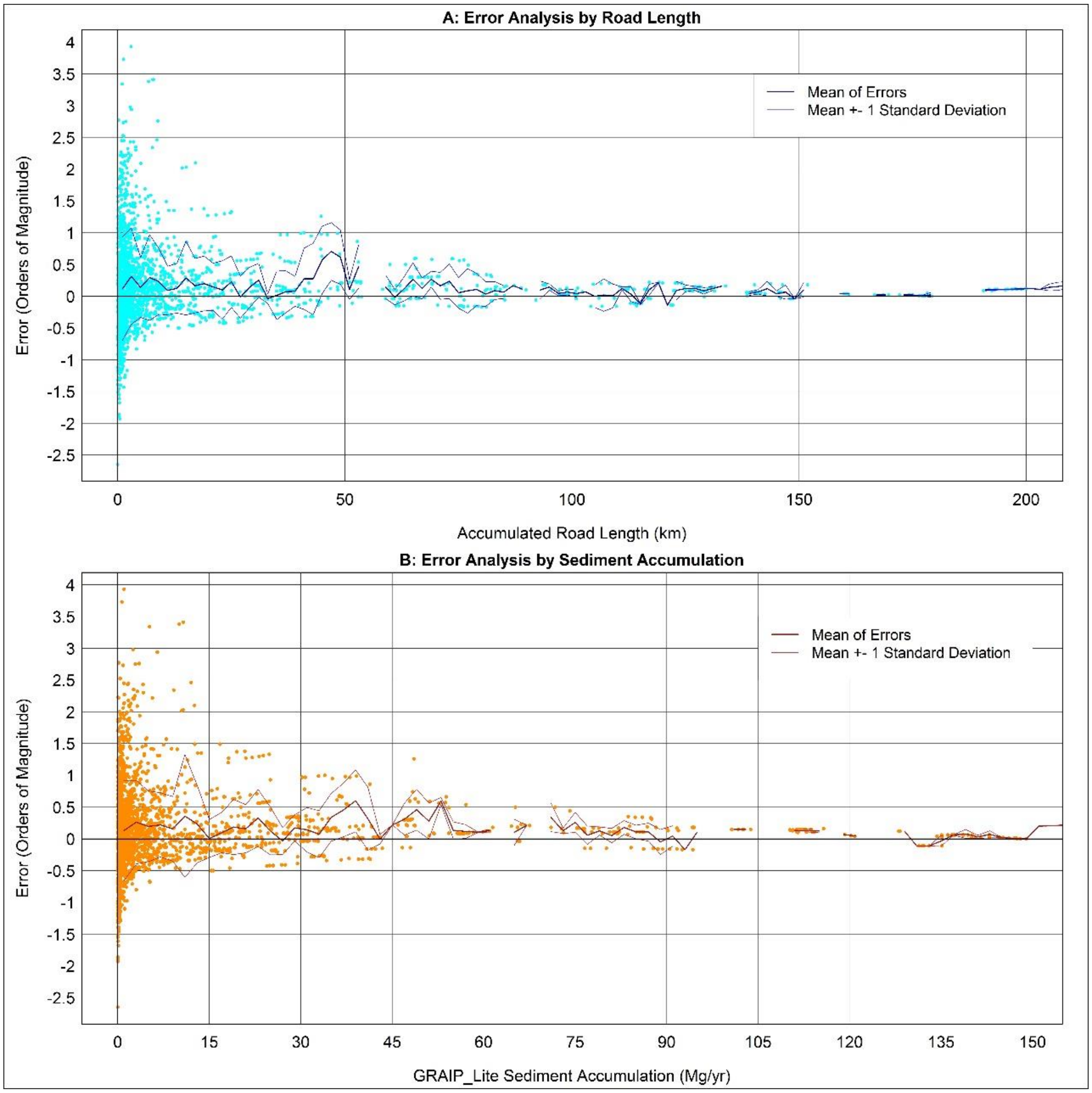


Figure 9: Typical error distributions when validating GRAIP_Lite against the GRAIP model, based on accumulated road length and accumulated sediment.

Model Run Tutorials

Several tutorial data sets have been prepared to illustrate potential applications like those outlined above. A "basic" run may be used to assess the relative risk from road surface erosion across sub-watersheds. It is ideal for prioritization of watershed restoration efforts and is a substantial improvement over road density. A "calibration zone" example is included to show how a more heterogeneous area, say with variation in geology, can be modeled. It has similar purposes to the basic run, but accounts for environmental variation in the calculus of determining which basins have greater risk. Finally, an example of how to apply GRAIP_Lite for alternative comparison, as one would do for project planning under NEPA, is included. Here an input system describing most treatments has been set up to make treatment specification easier, and execution of the multiple runs and preparation of output graphics has been automated to speed analyses. The three tutorial examples have been set up as a progression to let users become familiar with easier applications before taking on more advanced tasks.

Basic

This tutorial shows how to use the tools in GRAIP_Lite's Basic Run toolbox. The data set uses INFRA roads sourced from a geodatabase, in this case for the North Fork Boise River drainage on the Boise National Forest, current as of 8 January 2016. The Basic Run is intended to provide the user with a quick view of higher risk areas within the road network and uses the default model calibration. The tool provides a simple analysis and includes a reporting tool to create basic maps for use in reports or presentations.

The first step in any GRAIP_Lite model run, including a basic run, is to save the map document in the project folder. This sets the default locations for files created and accessed by GRAIP_Lite and names the geodatabase in which GRAIP_Lite stores the various feature classes created. With ArcMap open with a blank document, go to *File -> Save As*, navigate to your project folder, and save the document, in this case as *BasicRun.mxd* (Figure 10).

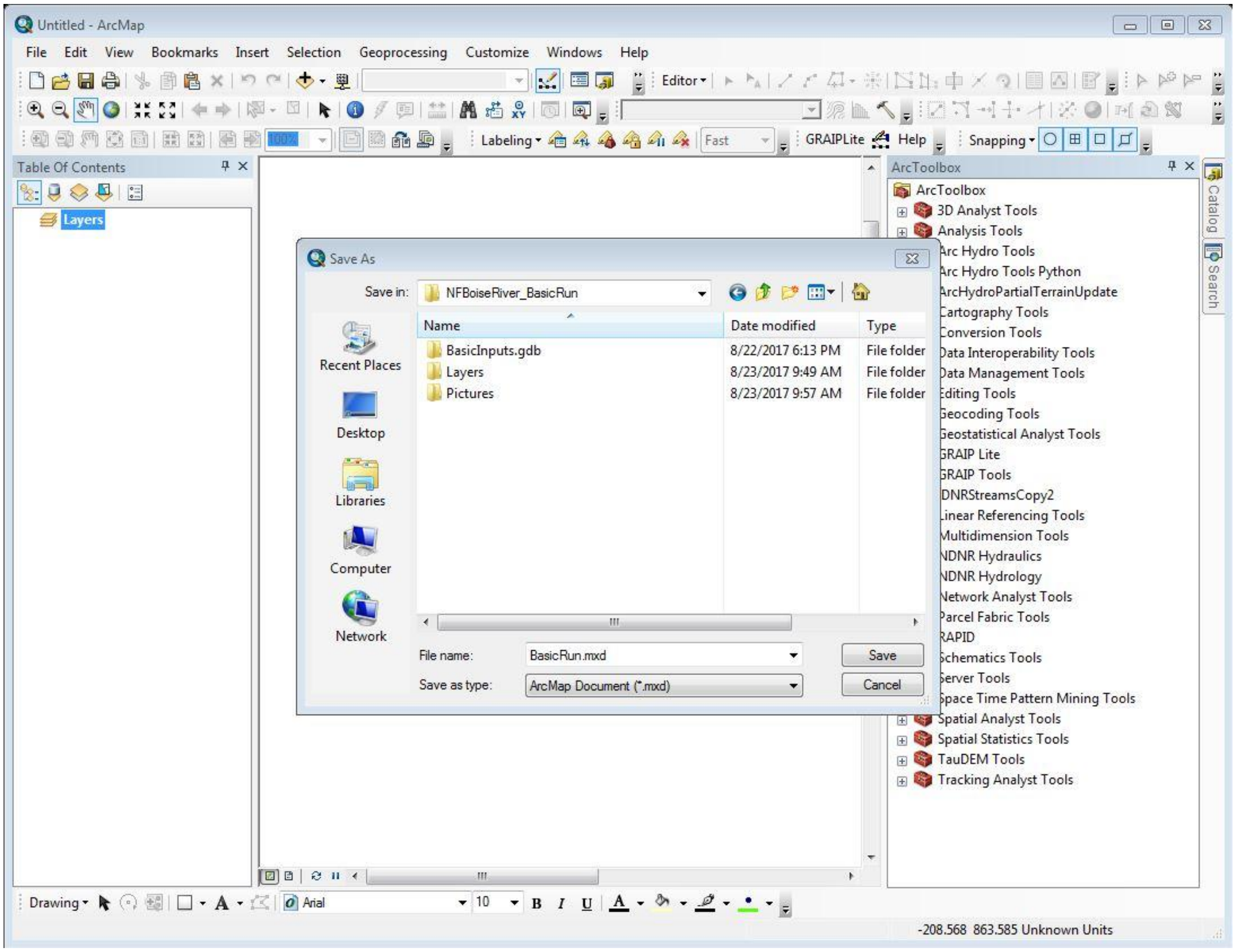


Figure 10: Saving the map document.

Once the map document is saved, it is time to open the Basic Run tool. Open the ArcToolbox window if it is not yet open. The tool is located in *ArcToolbox->GRAIP Lite->Basic Run-> 01. Basic Run – Road and DEM only*. Double-click to open the tool. Notice that the Target Geodatabase Directory and the Target Geodatabase Name fields are automatically filled in based on the location and name used to save the map document (Figure 11).

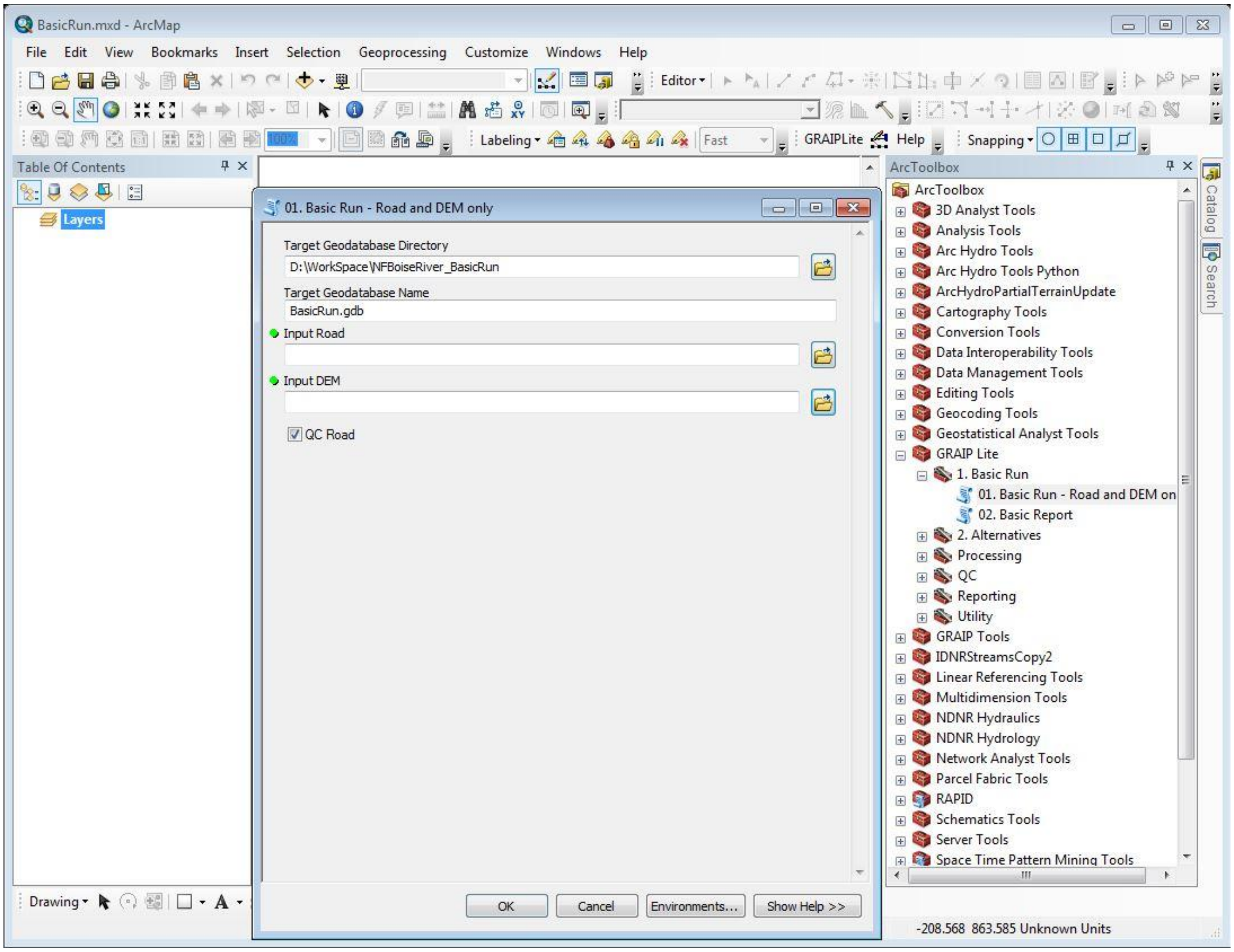


Figure 11: Basic Run tool opened.

With the tool open, you will need to populate the Input Road and Input DEM fields. The browse buttons allow you to select the appropriate inputs. For this tutorial, the Input Road is the INFRA_Roads feature class in the BasicInputs.gdb geodatabase (Figure 12) and the Input DEM is nfbc in the Layers folder (Figure 13).

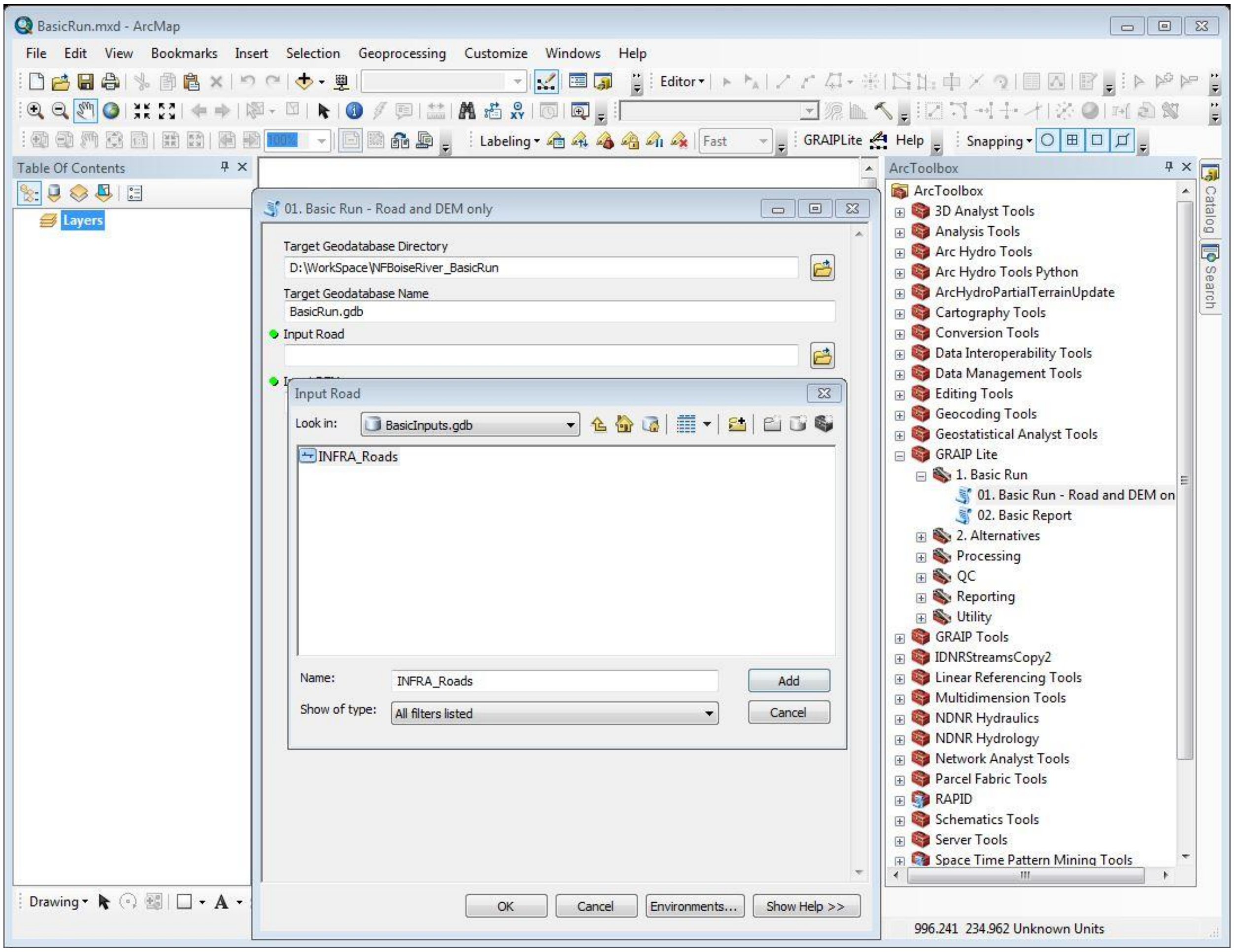


Figure 12: Selecting the Input Road feature class.

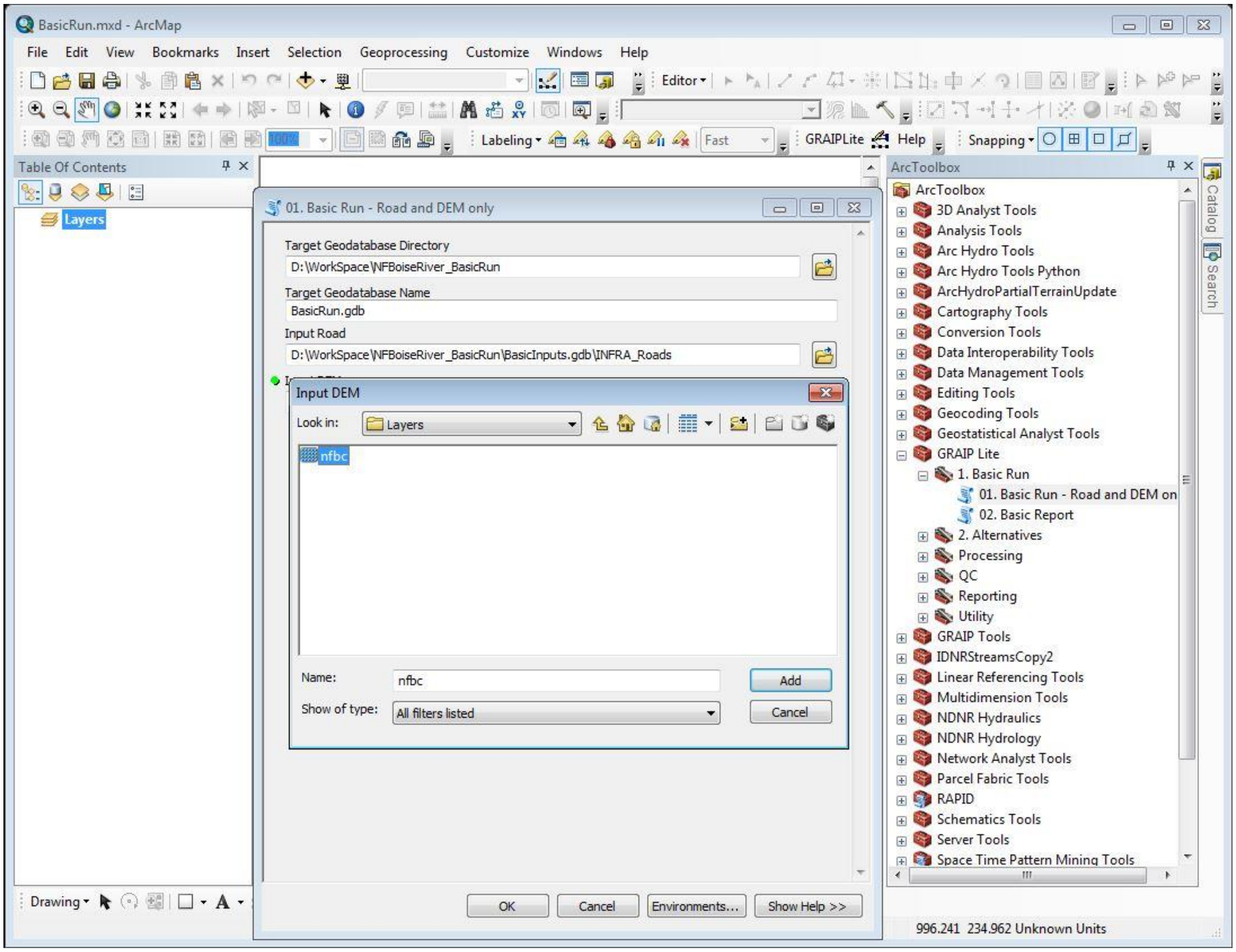


Figure 13: Selecting the Input DEM.

With the road and DEM inputs specified, double check that the box next to QC Road is checked (Figure 14); this ensures that the model will do some basic checks on the input road layer, including looking for loops and geometric duplicates. Click OK and the tool starts running (Figure 15).

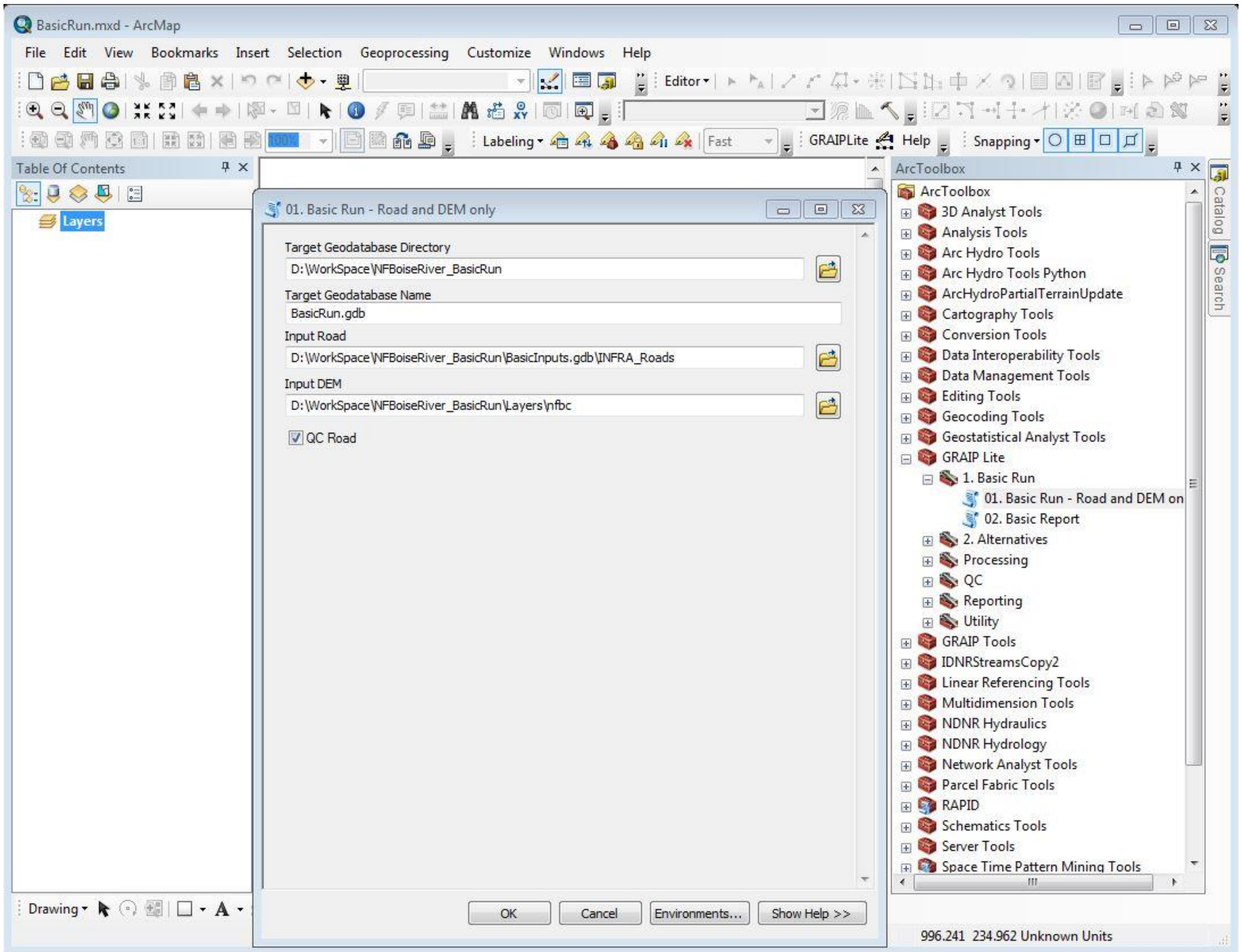


Figure 14: Basic Run tool ready to run.

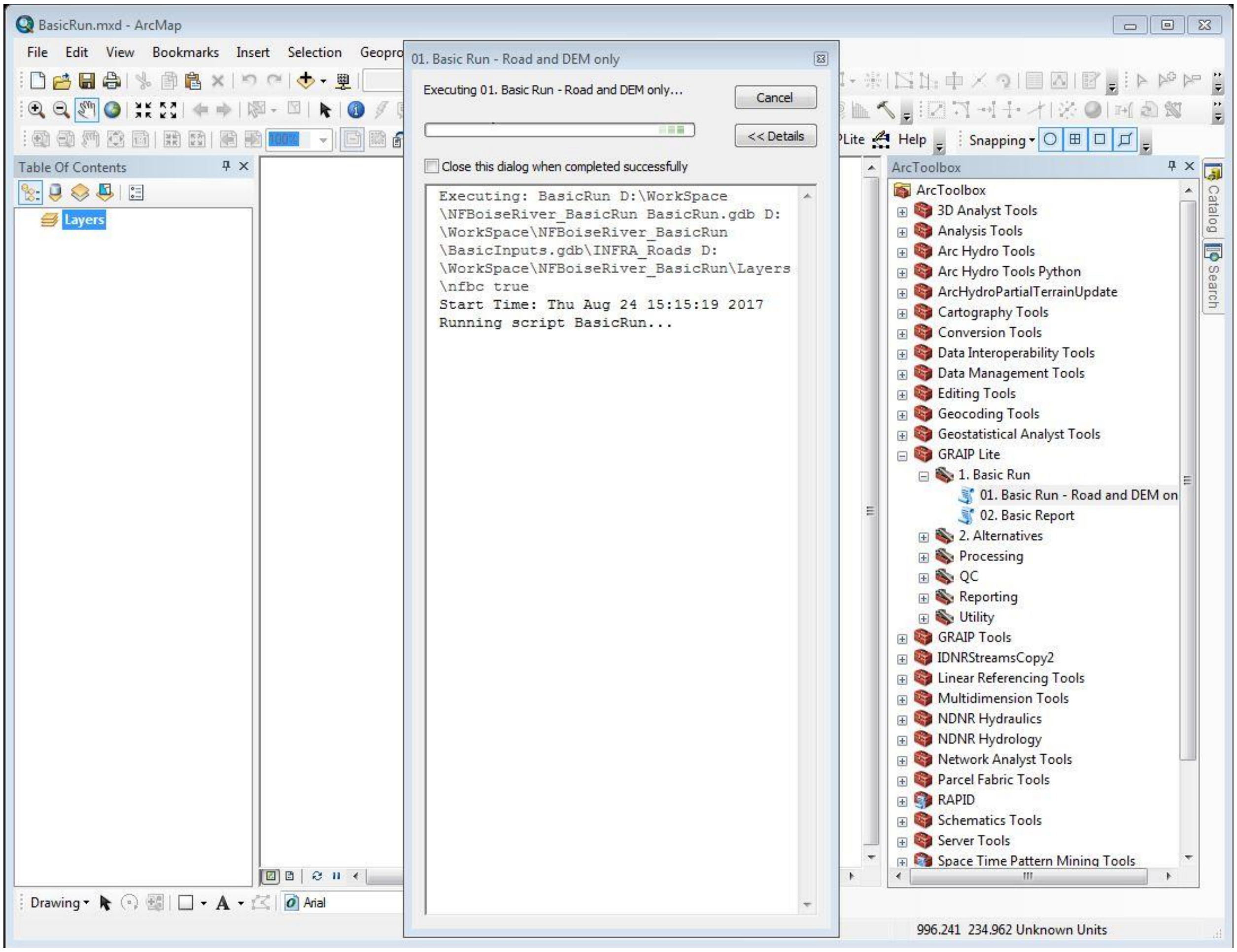


Figure 15: Basic Run tool running.

Once the tool has completed (Figure 16), you can close the tool dialog and view the results in the map window (Figure 17). The model has completed its run at this point and the data is now available for use. One of the primary model outputs is Specific Sediment Delivery, which is shown in the DrainageLine feature class. This is the road surface-related sediment load per unit contributing area, and provides a good measure of road-related sediment impact on aquatic habitats. In Figure 17, we can see streams highlighted in red or orange where the local impact is high; yellows and greens are used for moderate to low impacts, and blue is used where no sediment is delivered to streams.

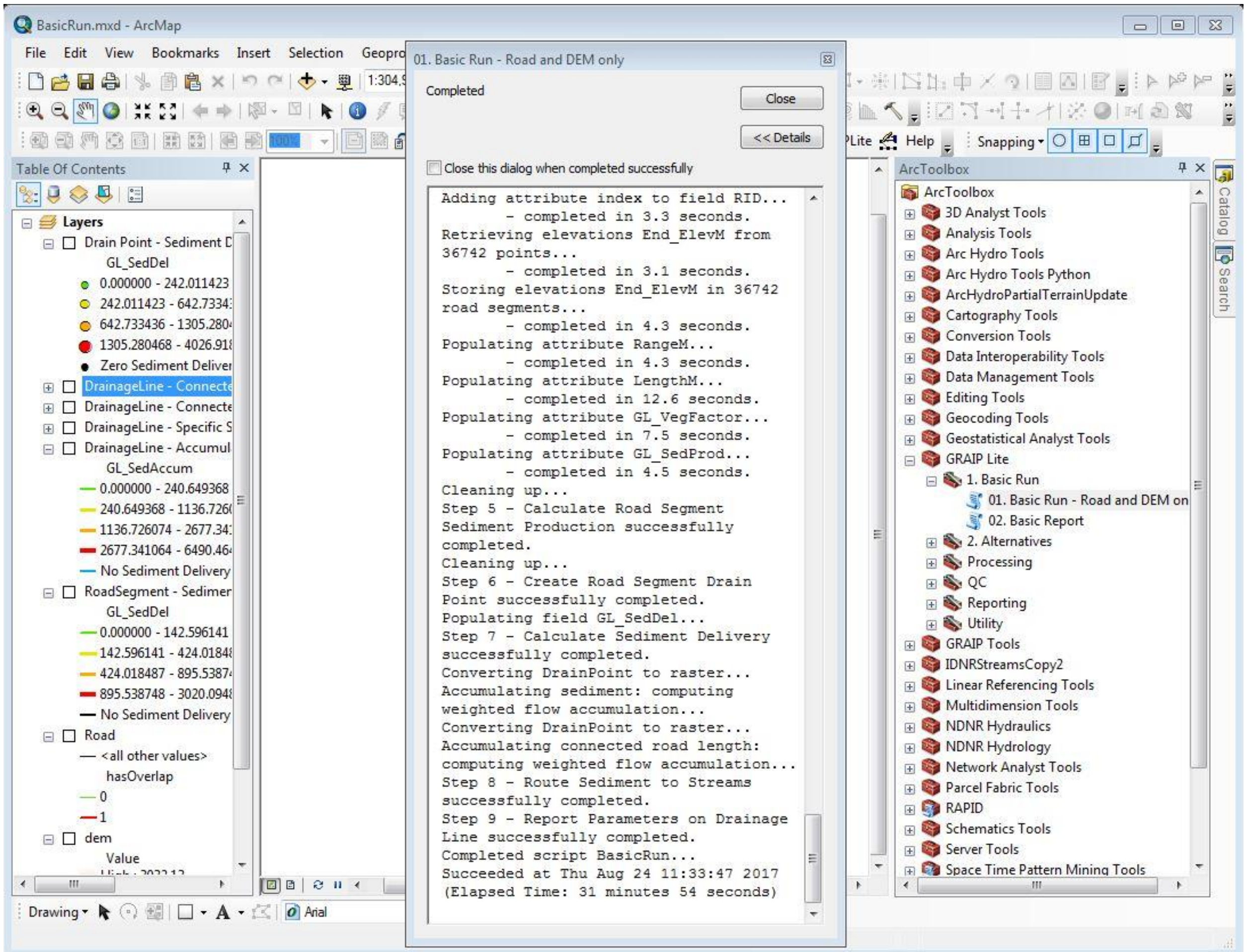


Figure 16: Basic Run tool has completed the model run.

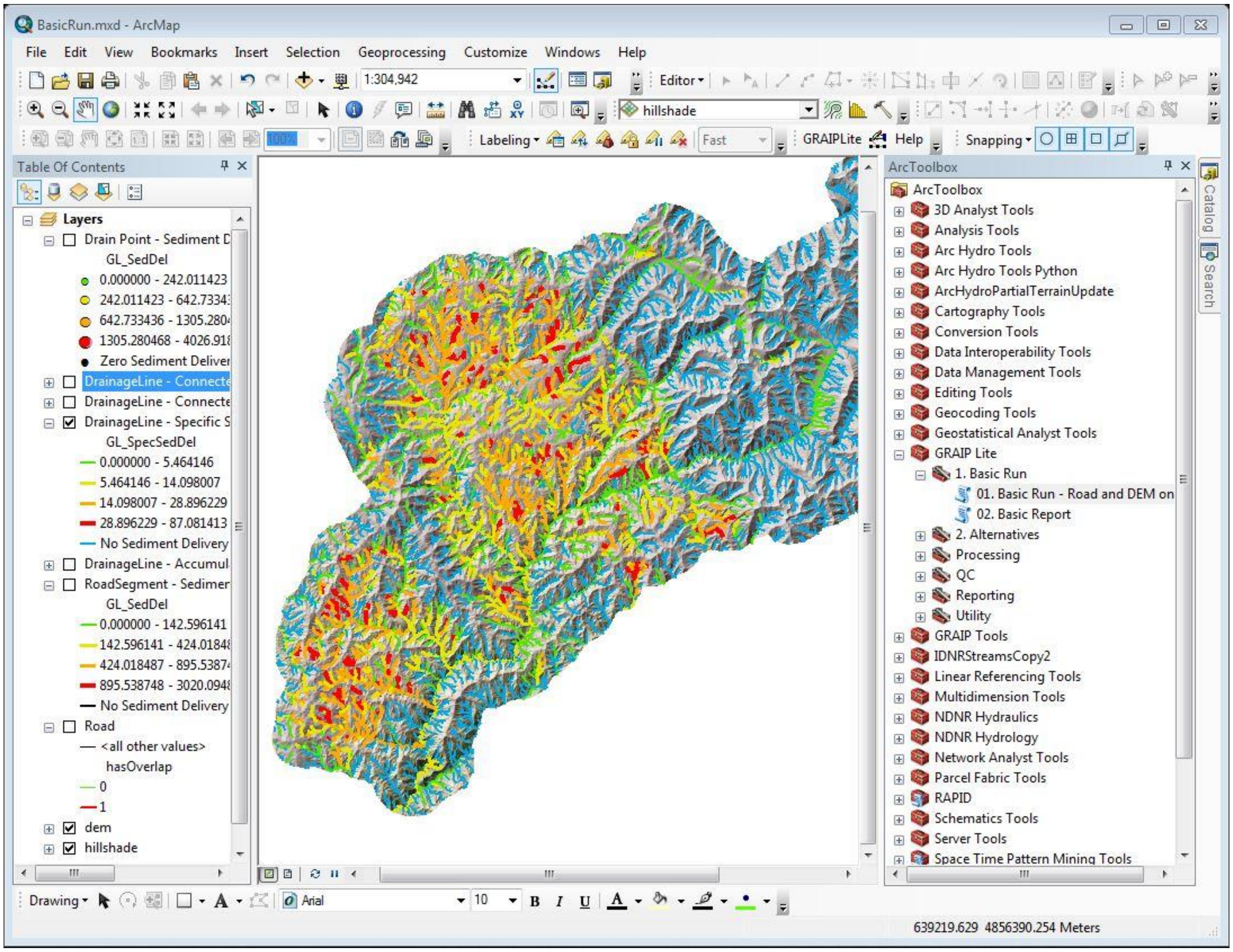


Figure 17: Results from the Basic Run tool Specific Sediment Delivery along Drainage Lines.

The second tool in the Basic Run toolbox is the Basic Report tool. This tool automatically generates a series of maps in both .jpg and .pdf formats; the .jpg files are intended to be used directly in documents and presentations while the .pdf documents provide an easy way of communicating those maps to the public or to various other partners.

Open the tool and note that the Input GRAIP Lite Workspace is already populated (Figure 18). More advanced users may be able to use custom templates, but the defaults are preferred here so there is no need to populate the Input Template Directory field. Hit OK to run the tool.

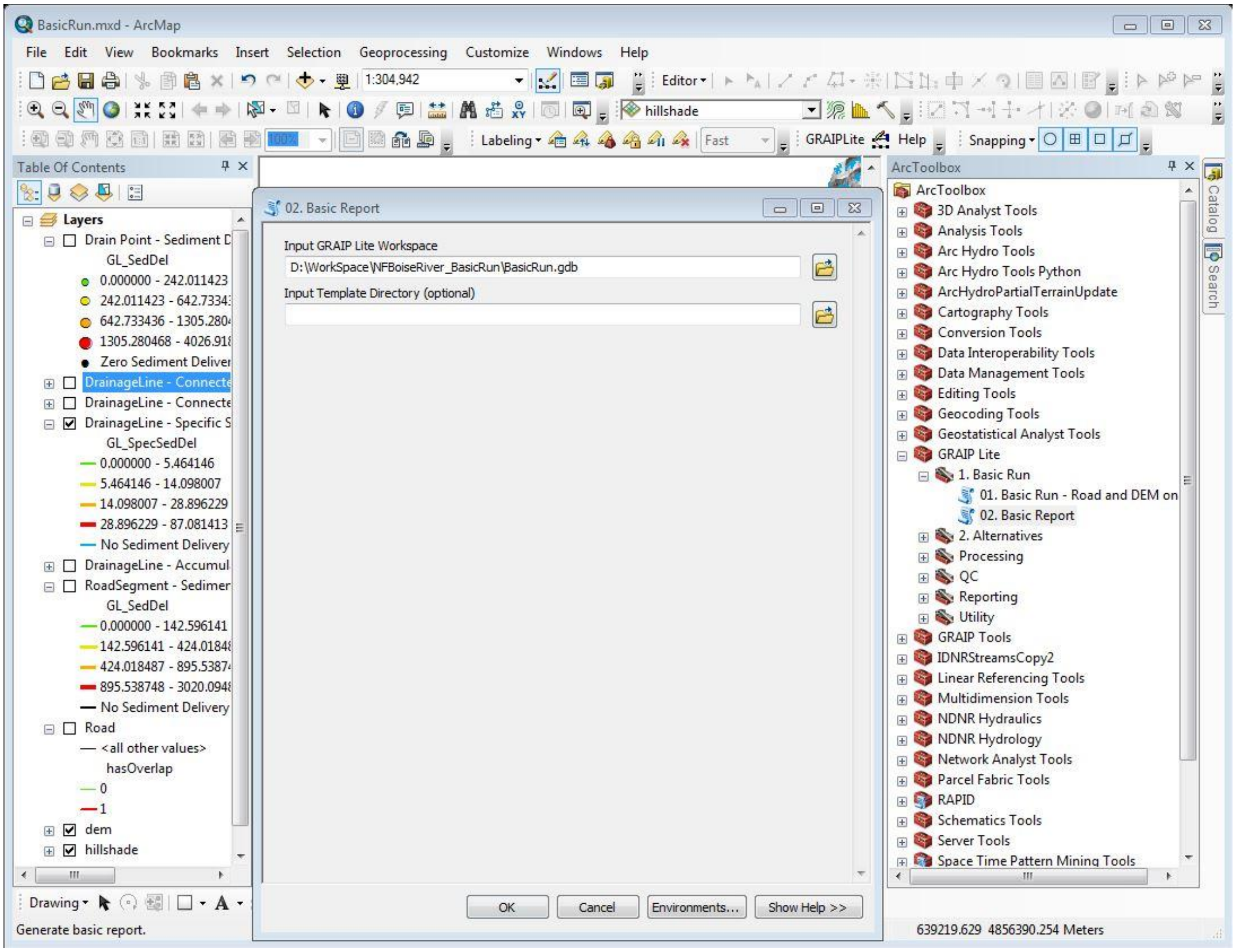


Figure 18: The Basic Report tool ready to run.

As the tool runs, it lists off each map it is exporting and where it is stored. The tool stores these reports in a Reports subfolder within the project folder, and within this creates a unique folder each time the tool is run. Close the tool when it has completed (Figure 19). Example maps from the Basic Report tool will be included in Appendix D.

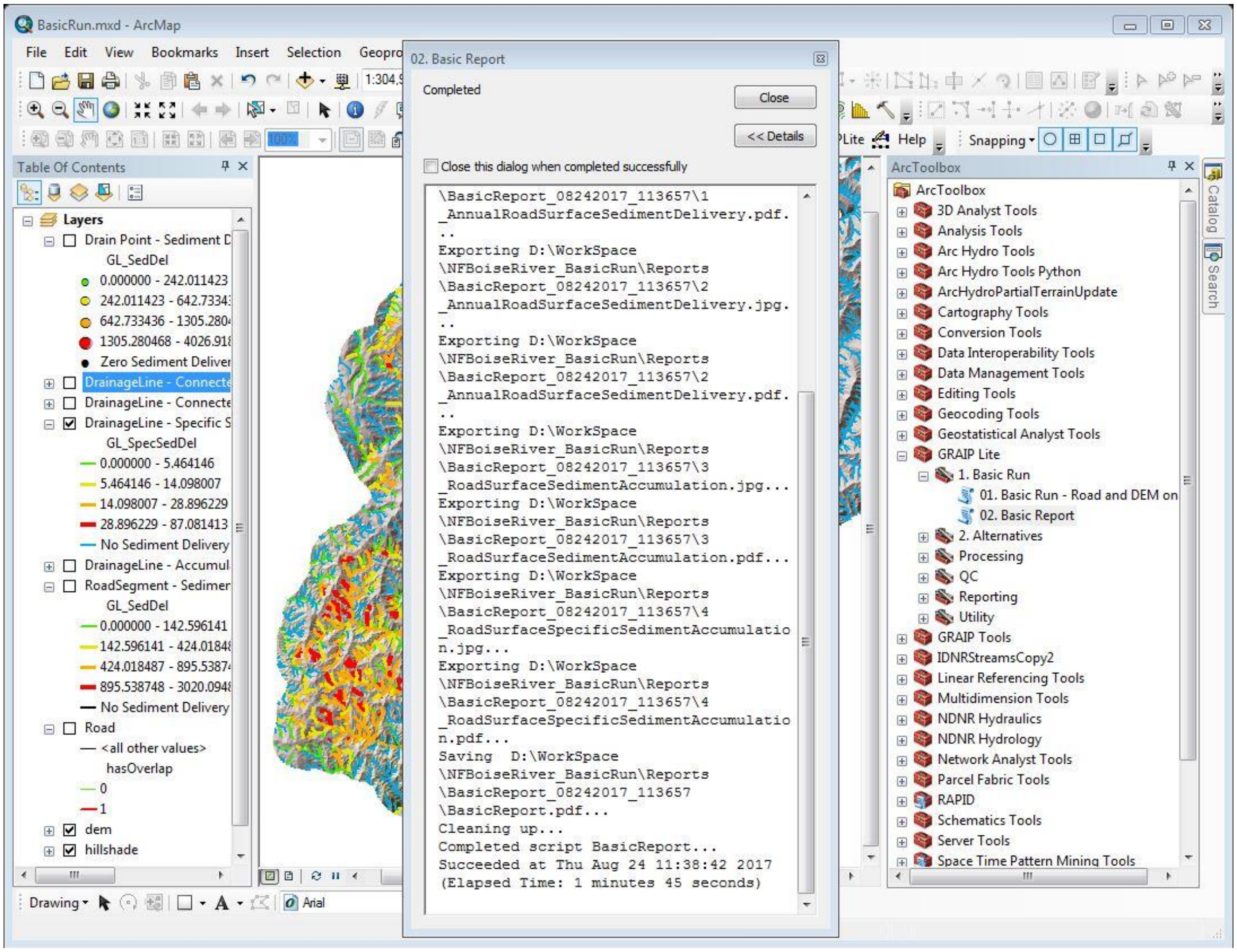


Figure 19: Basic Report tool complete.

Calibrated

The tools in the Processing toolbox can be used to customize the model run and take advantage of additional capabilities. The most important of these is the ability to use different model calibrations to more closely describe the sediment production and delivery characteristics of the project area. As with the Default Run, the first step is saving the map document (Figure 20).

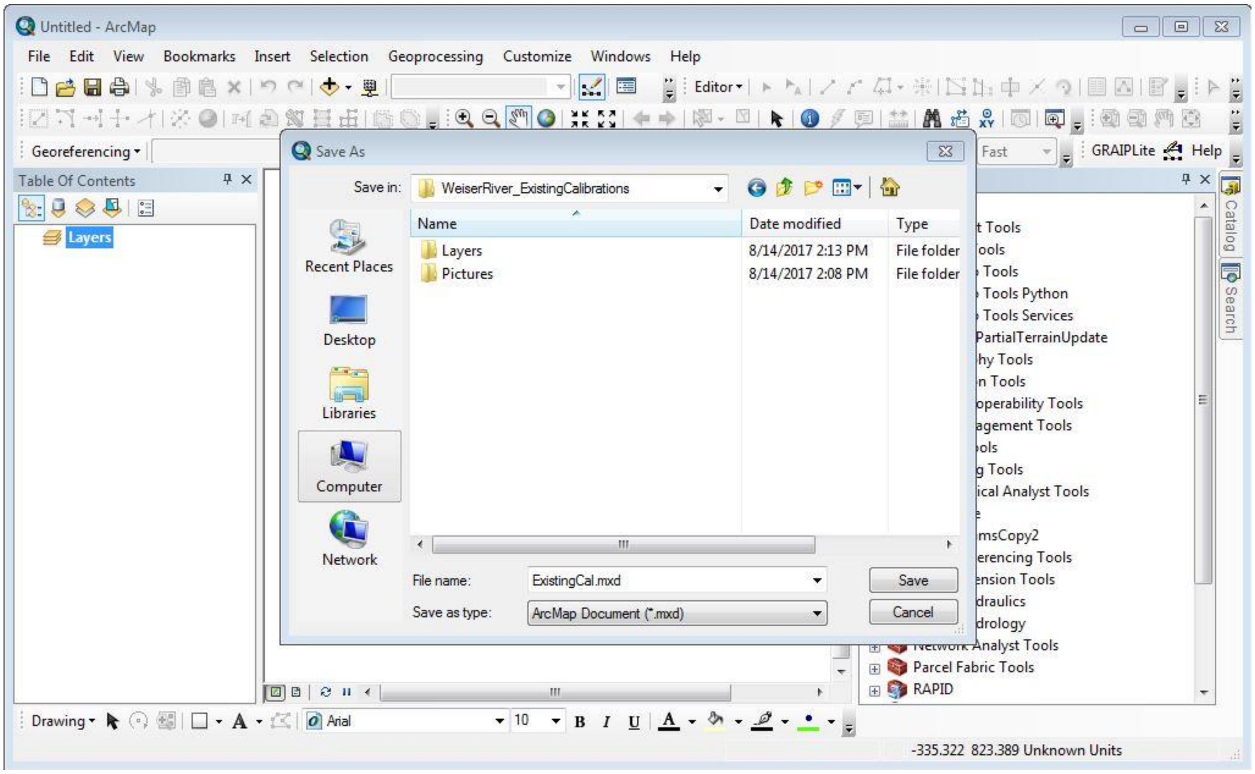


Figure 20: Saving the map document.

The next step is to run the *01. Initialize GRAIP Lite Database* tool (Figure 21). This tool populates the database used to store the inputs for and outputs from the model. The Target Geodatabase Directory and the Target Geodatabase Name fields are automatically filled out based on how you saved the map document; the directory is where you stored it and the name matches the name of the map document.

The Input Road and the Input DEM are required fields and are the same as those for the Basic Run; for this example we want to use PNF_INFRA_Clip.shp for the Input Road and wr as the Input DEM. Using just these two inputs is the same as doing the Basic Run, although it does allow more fine-tuning in some of the steps, namely in the DEM processing steps to come. The two optional fields are the Input Observed DrainPoint field and the Input Calibration Zone field. The Input Observed DrainPoint field, which is not used in this example, is used to provide the model with the locations of known drainage feature from a culvert or other inventory; the model then uses these features as breaks when creating road segments for the model. The Input Calibration Zone field is used to delineate areas that should be modeled using different model calibrations; for this example we are using CalibrationZones.shp as the input. Leave the box for QC Road checked.

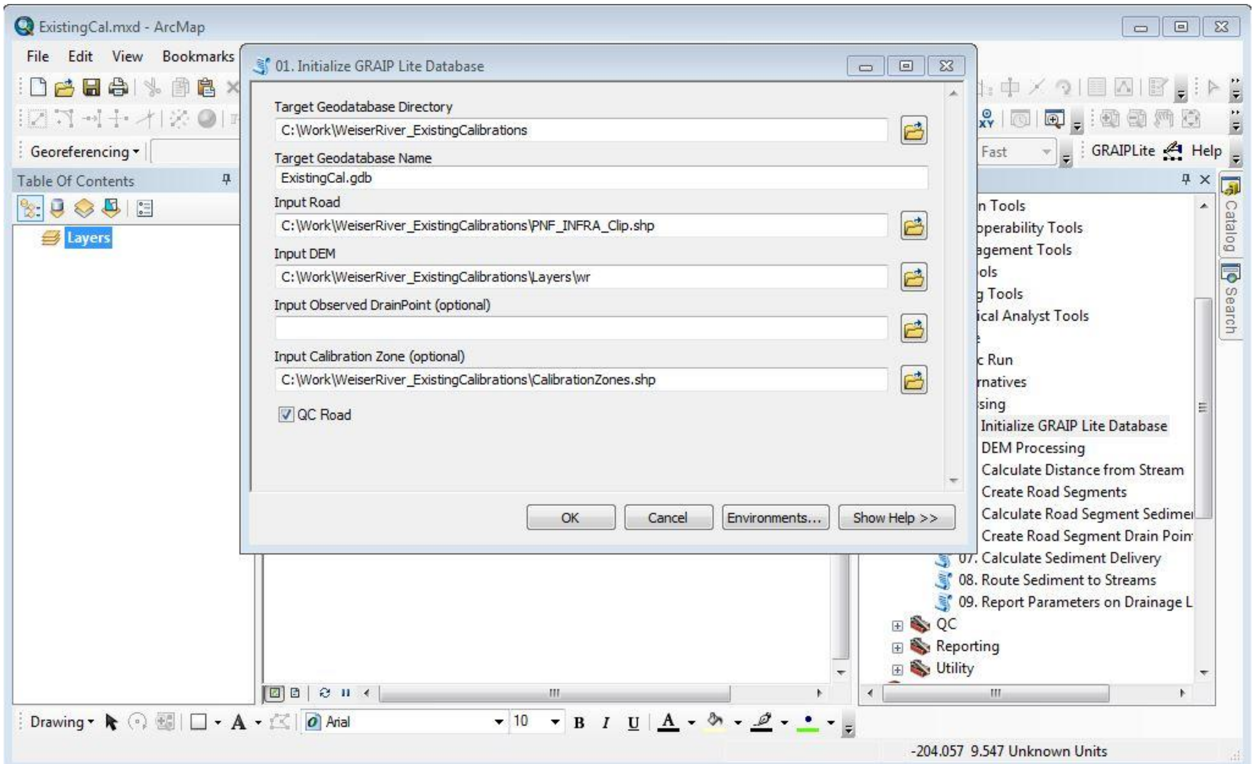


Figure 21: The Initialize GRAIP Lite Database tool.

Next is the *02. DEM Processing* tool (Figure 22). This is the tool that generates the stream network and the grids necessary for routing sediment within the model. The Number of cells field is used to calibrate the number of accumulated gridcells, or contributing area, necessary for generation of a stream head; however, this needs to match what was used for creating the individual calibrations. All of the included calibrations, which we are using in this example, were created using the default threshold of 100. All of the fields should be automatically populated.

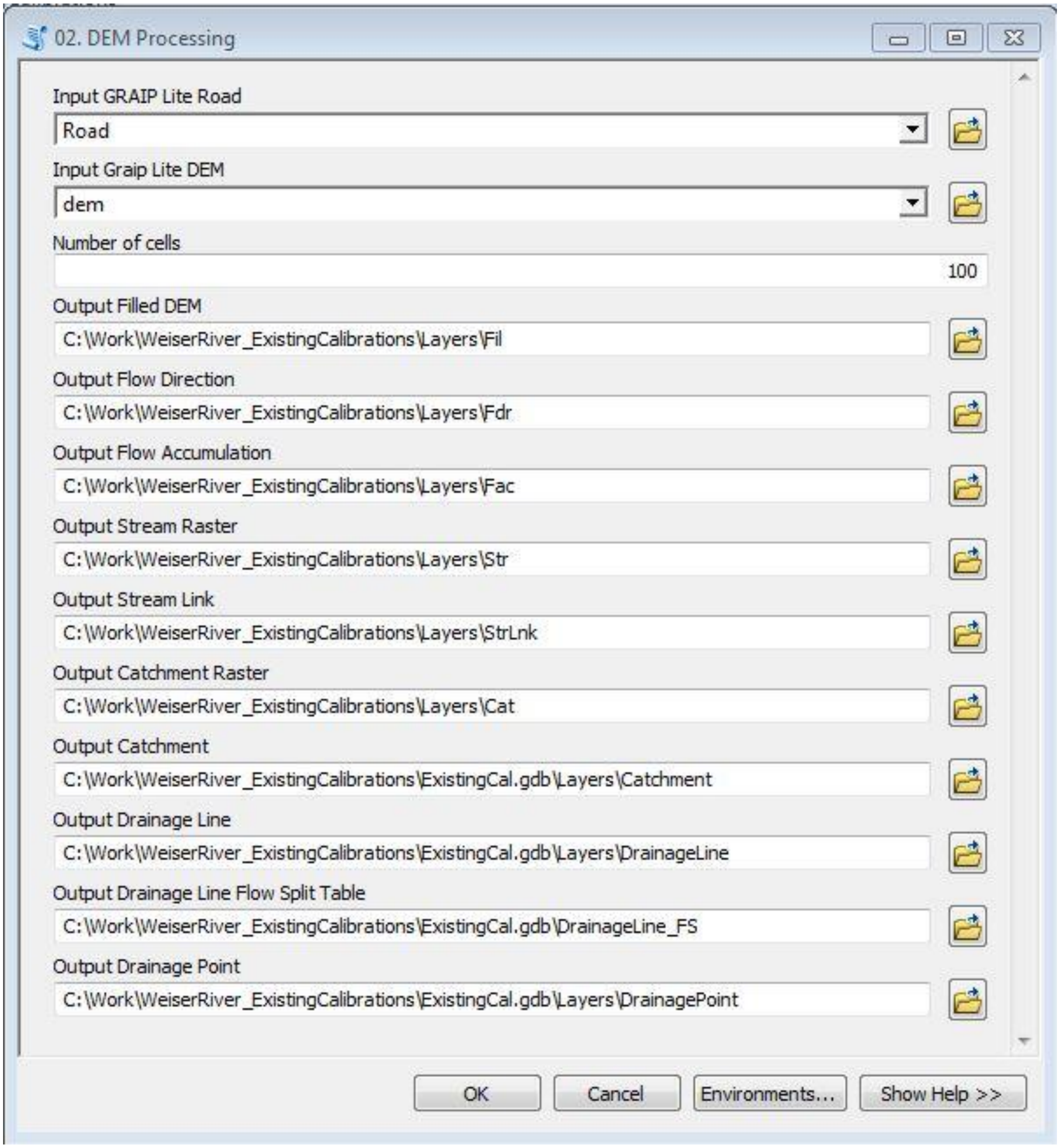


Figure 22: DEM Processing tool.

The next step is the *03. Calculate Stream Distance* tool (Figure 23). This tool calculates the flow distance to the nearest downhill stream and stores it as a raster; the data gets used later to help calculate sediment delivery. All of the fields should be pre-populated and ready to run.

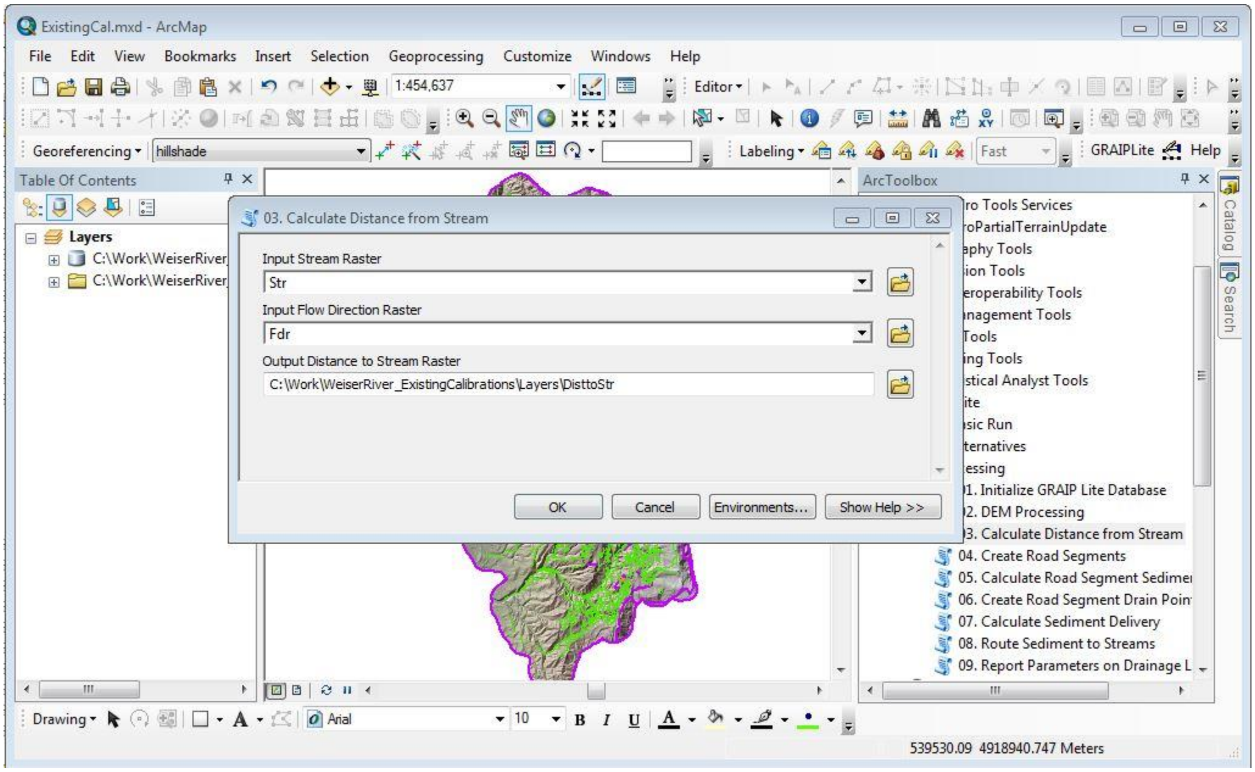


Figure 23: Calculate Distance from Stream tool.

Next is the *04. Create Road Segments* tool (Figure 24). This tool takes the input roads features and splits them into GRAIP_Lite road segments using catchment boundaries, stream crossings, calibration zones, known drainpoints, and pre-determined maximum distances. All of the fields should be pre-populated.

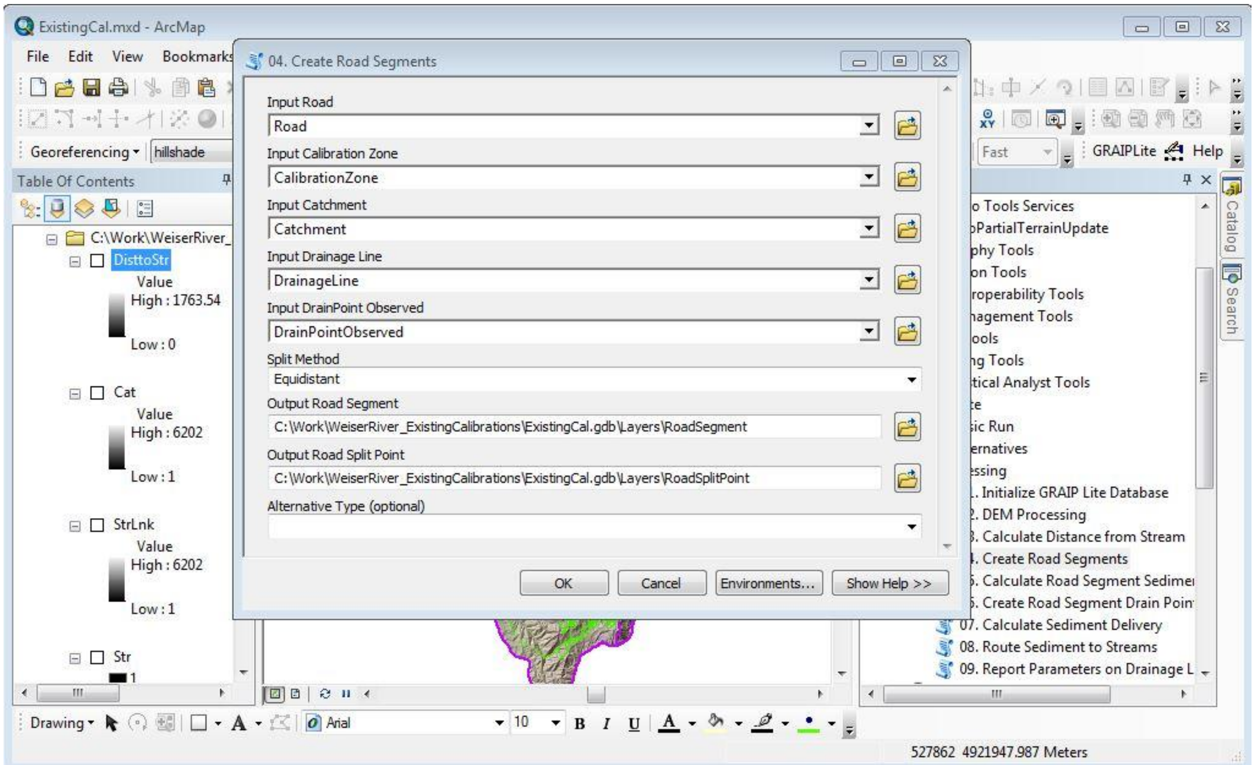


Figure 24: Create Road Segments tool.

The next step is to run the *05. Calculate Road Segment Sediment Production* tool (Figure 25). This tool calculates the sediment production expected from each road segment based on the difference in endpoint elevations, the surface type, the expected vegetation, and the expected traffic. Different calibrations provide different baserates and vegetation factors to customize the calculations. Again, all fields should be pre-populated.

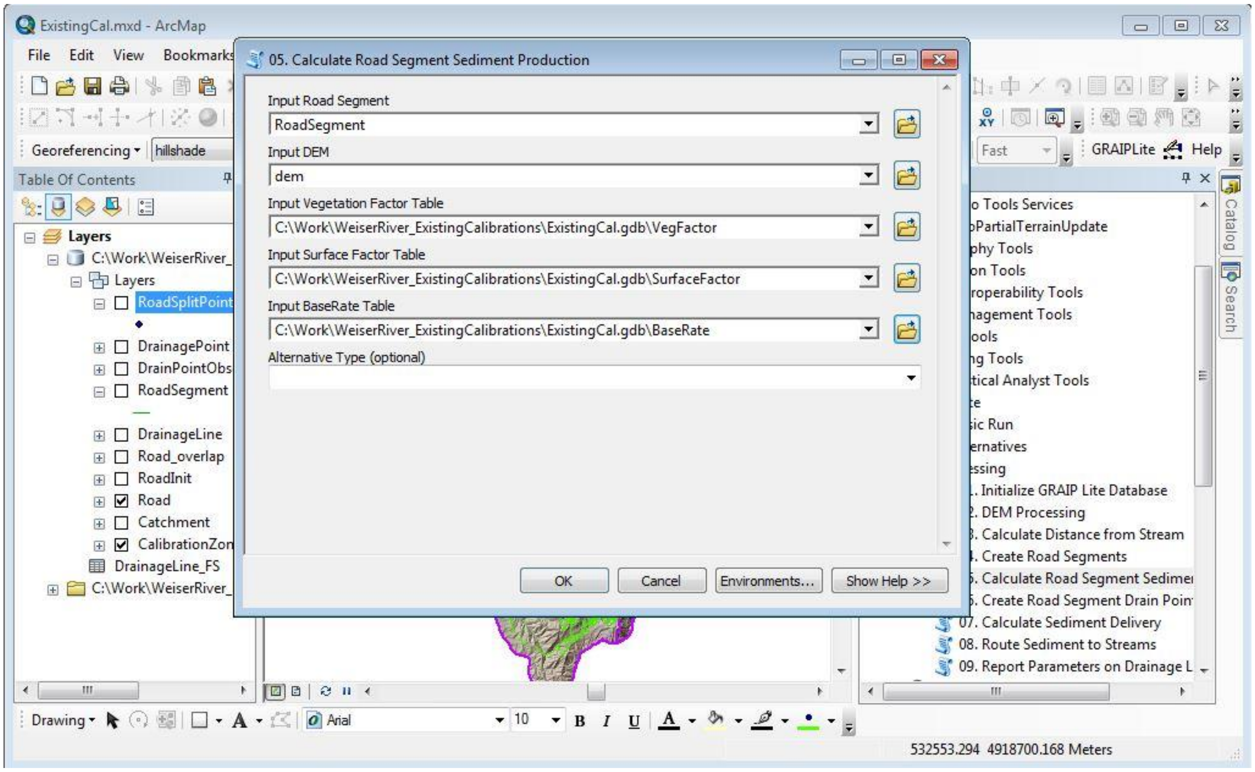


Figure 25: Calculate Road Segment Sediment Production tool.

The *06. Create Road Segment Drain Points* tool (Figure 26) is used to select the end of each road segment which is at the lowest elevation and create drain point features at those location. The tool also appends the flow distance to the nearest stream from the DisttoStr raster.

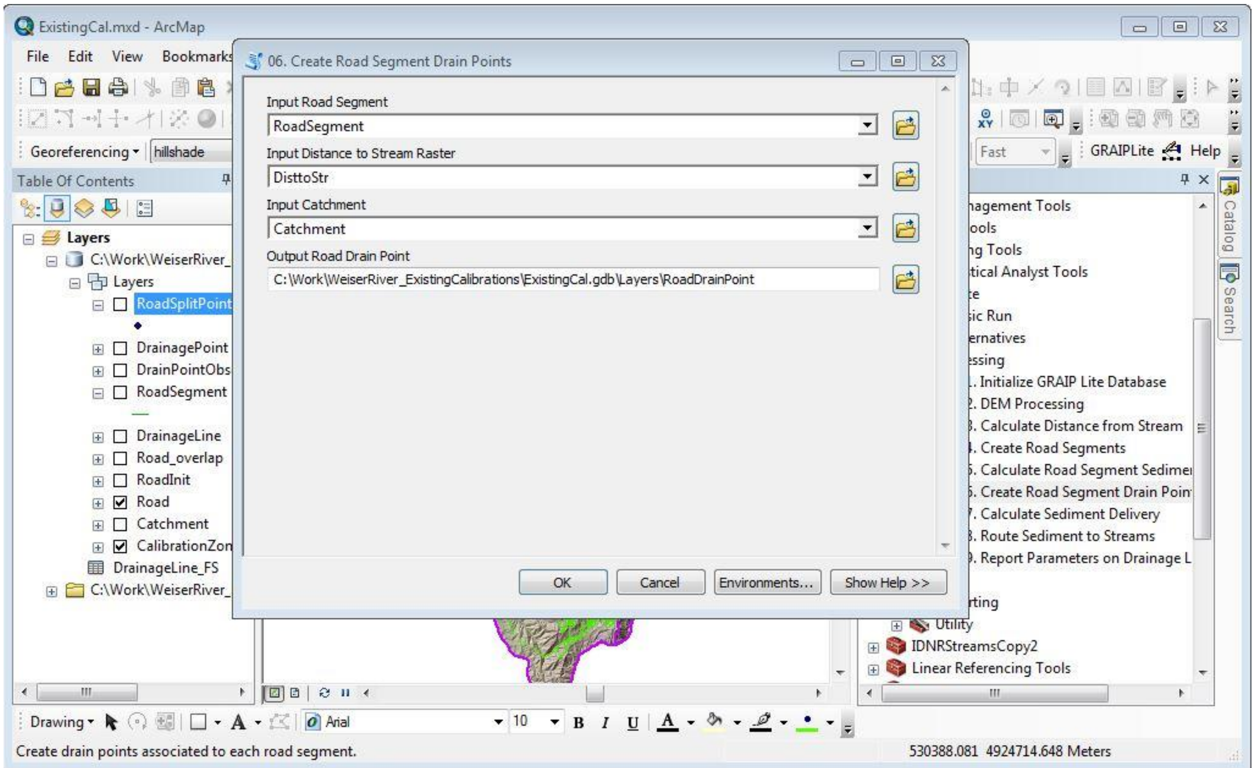


Figure 26: Create Road Segment Drain Points tool.

The *07. Calculate Sediment Delivery* tool (Figure 27) uses the flow distance at each drainpoint and the delivery probability table to calculate the amount of sediment expected to be delivered to the stream network at each drainpoint. This step usually has the longest run time. The Delivery Probability table has values describing different curves for each calibration zone allowing the sediment delivery characteristics of an area to be described as part of the calibration.

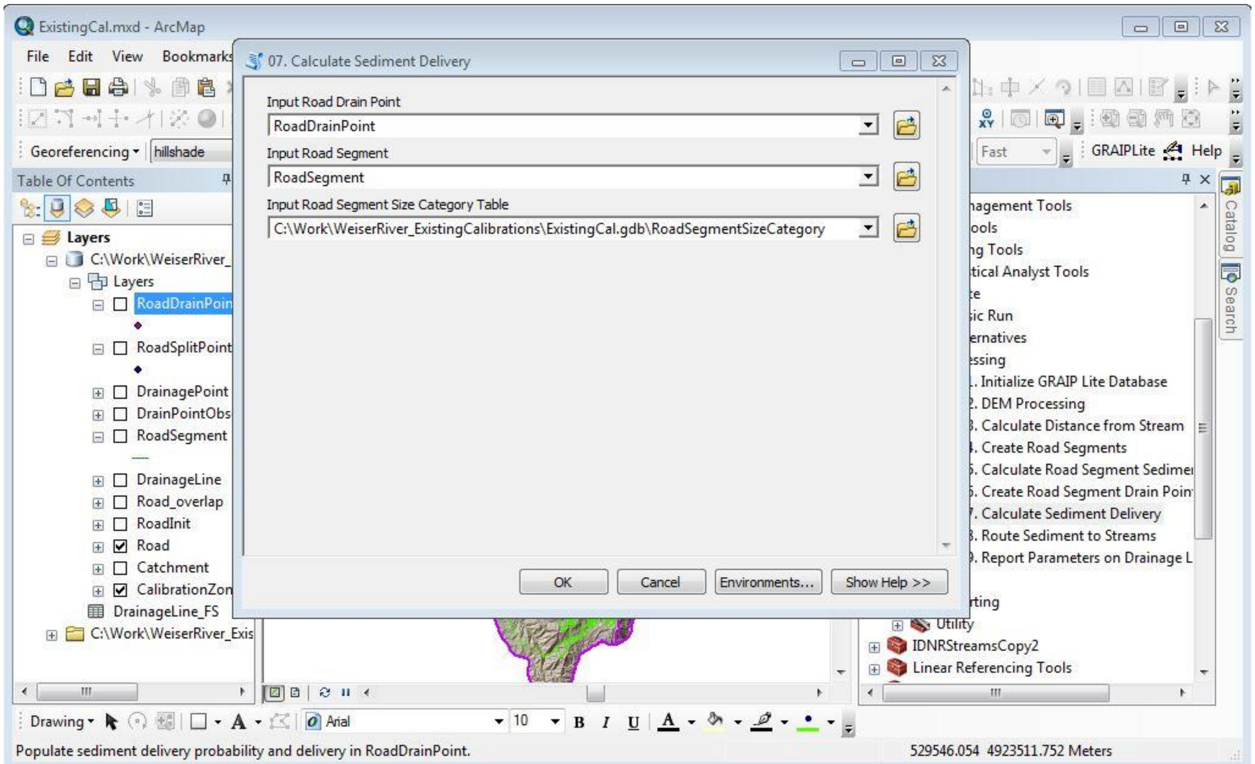


Figure 27: Calculate Sediment Delivery tool.

The *08. Route Sediment to Streams* tool (Figure 28) is next on the list. This tool uses some of the rasters created by the DEM Processing tool to route sediment downhill from the drainpoints to the stream network and then add up the total amount of expected road sediment in the stream network. It also routes and sums the connected road length to create a tally of how much road has affected the stream network. It also normalizes both the accumulated sediment data and the accumulated connected road length data by the contributing area to produce rasters describing specific sediment (accumulated sediment divided by contributing area) and connected road density.

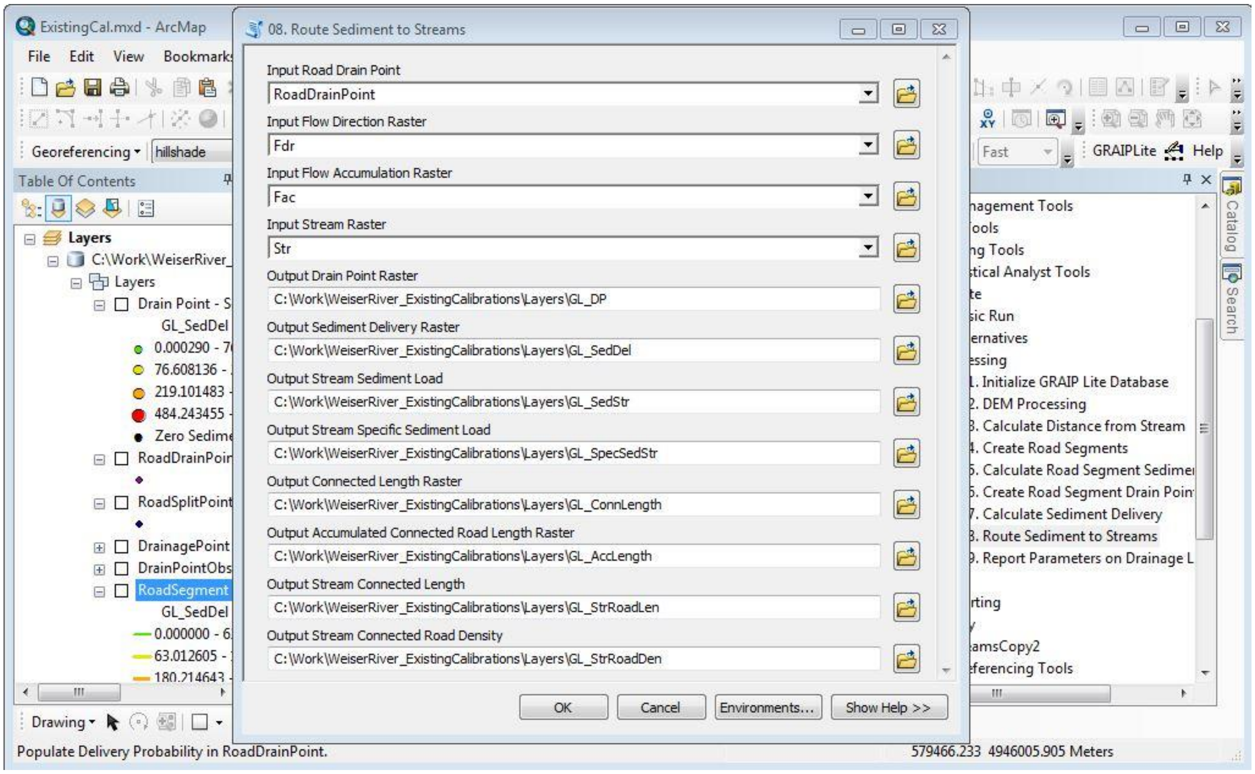


Figure 28: Route Sediment to Streams tool.

The *09. Report Parameters of Drainage Line* tool (Figure 29) takes the data recorded in the rasters created in the previous step and appends that data to the features in the Drainage Line feature class, which stores the stream network data. This makes it much easier to present the data in map form, and allows the data to more easily be summarized.

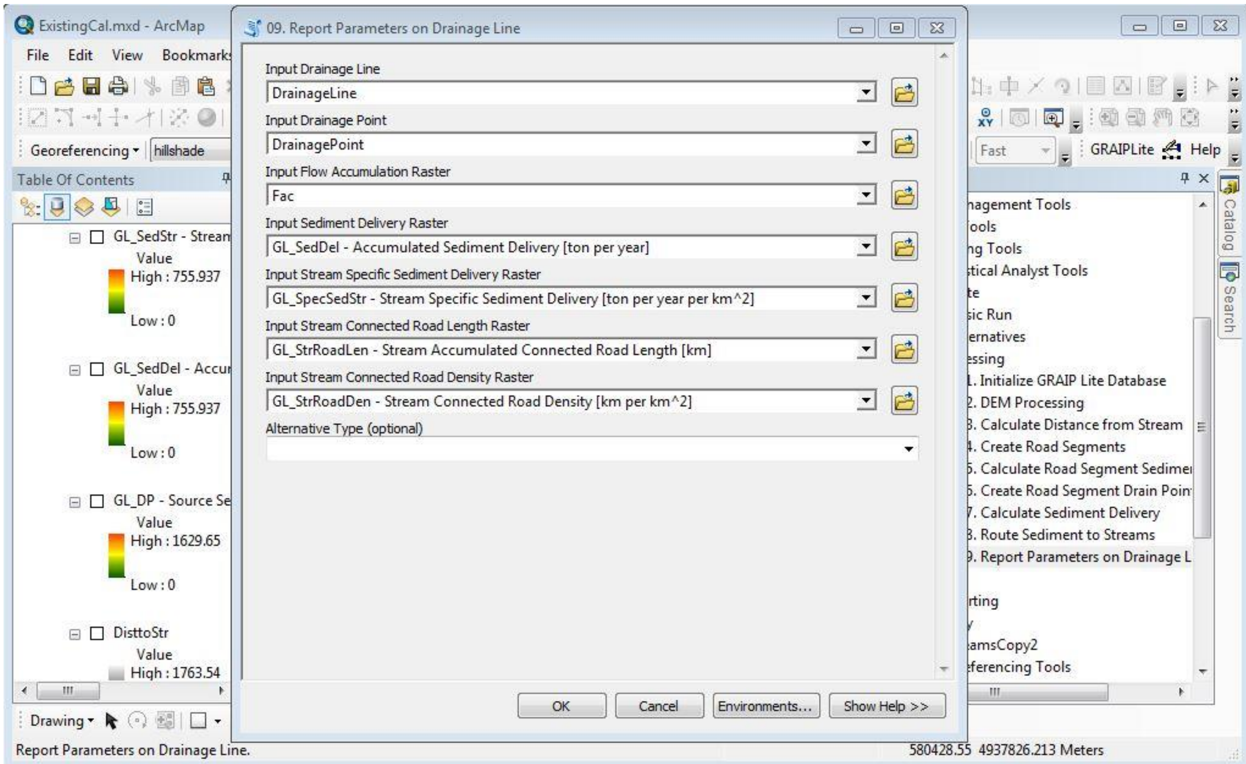


Figure 29: Report Parameters on Drainage Line tool.

At this point, the Basic Report can be run, which will provide the same set of maps as those produced for the Basic Run.

Alternatives

GRAIP_Lite is also designed as a tool for analyzing different potential treatment options. In order to do this, it provides a way of analyzing different alternative at three time steps. Each alternative is modeled at the initial condition time step, a disturbed time step, and a recovered time step. GRAIP_Lite has a dialog box that is used to create each alternative and set the treatments applied with that alternative; multiple alternatives can be created and run as part of a GRAIP_Lite model. This tutorial is intended to highlight the main ways in which treatments are specified for the GRAIP_Lite model.

There are also a few additional data considerations when modeling alternatives that are not as big a deal when just modeling current conditions. Since road treatments may only be applied to portions of certain roads, those portions need to be separate from the untreated portions of the road network. Since in many cases these treatment portions are defined based on intersections with other roads, one easy way to deal with this is to planarize the road network prior to beginning the model run; this method is demonstrated in this tutorial. If a treatment boundary does not correspond to an intersection, the road section must be split at the appropriate point in order to correctly model the differing sections.

As always, the first step is to save the map document in the project folder, in this case as EFWR.mxd (Figure 30). It is also a good idea to save the map document frequently.

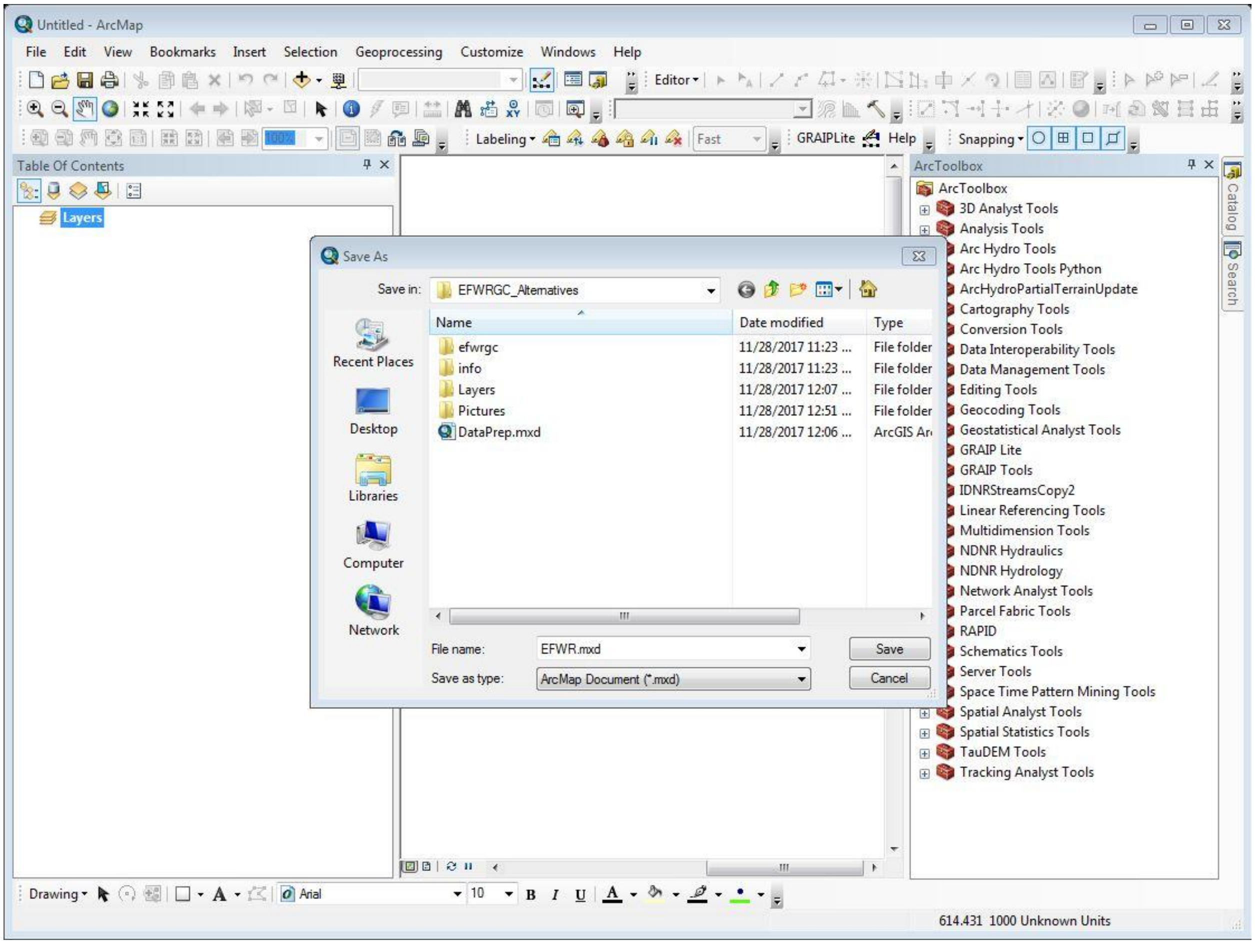


Figure 30: Saving the map document.

The next step is to add the INFRA.shp file to the map document (Figure 31). This file is the shapefile containing the road information for the project. Click on the Add Data button to access the dialogue box and add the shapefile.

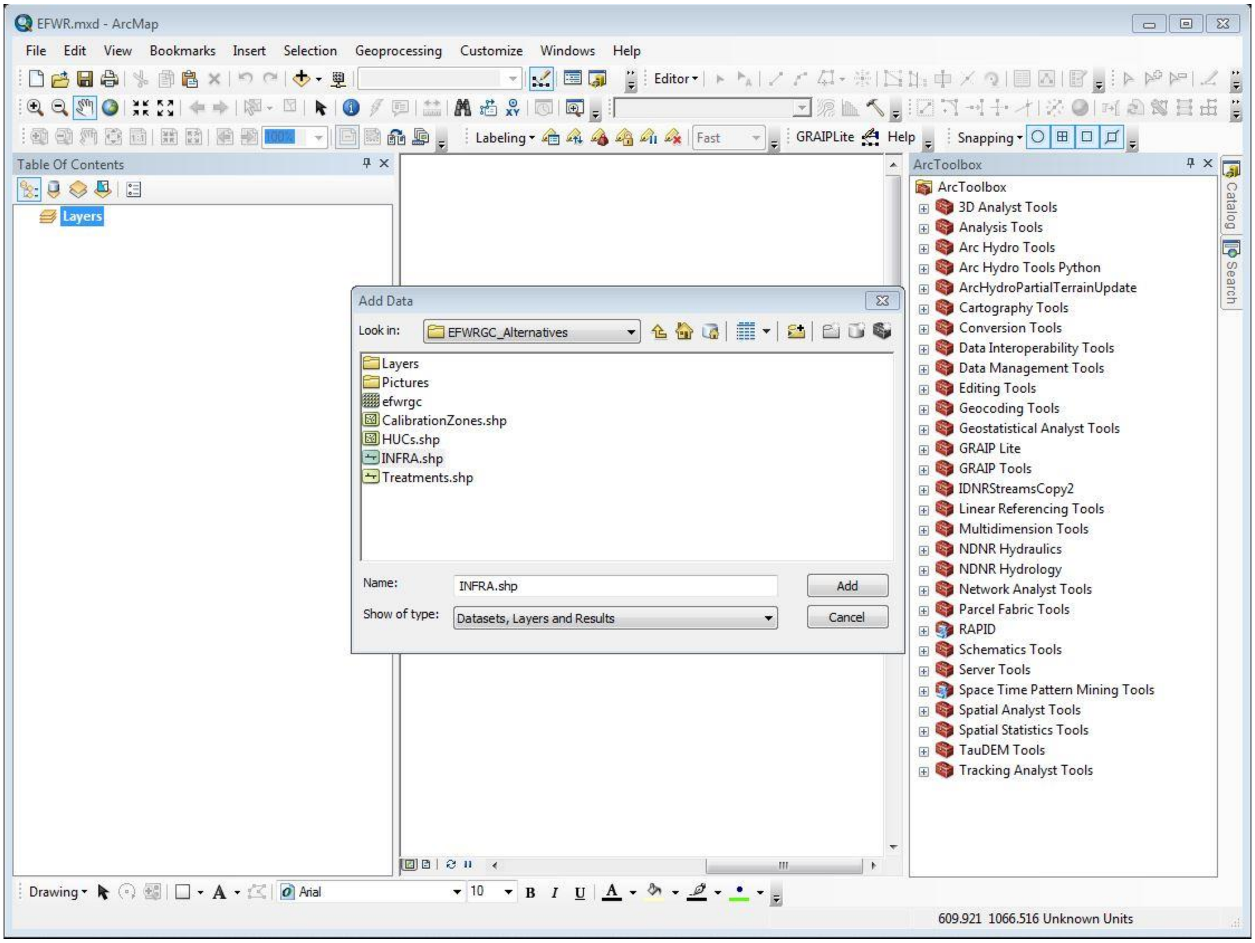


Figure 31: Add INFRA shapefile.

Next, make sure the Editor toolbar is visible, click on Editor to open the menu, and then click on Start Editing. This will activate all of the tools in the Editor and Advanced Editing toolbars (Figure 32).

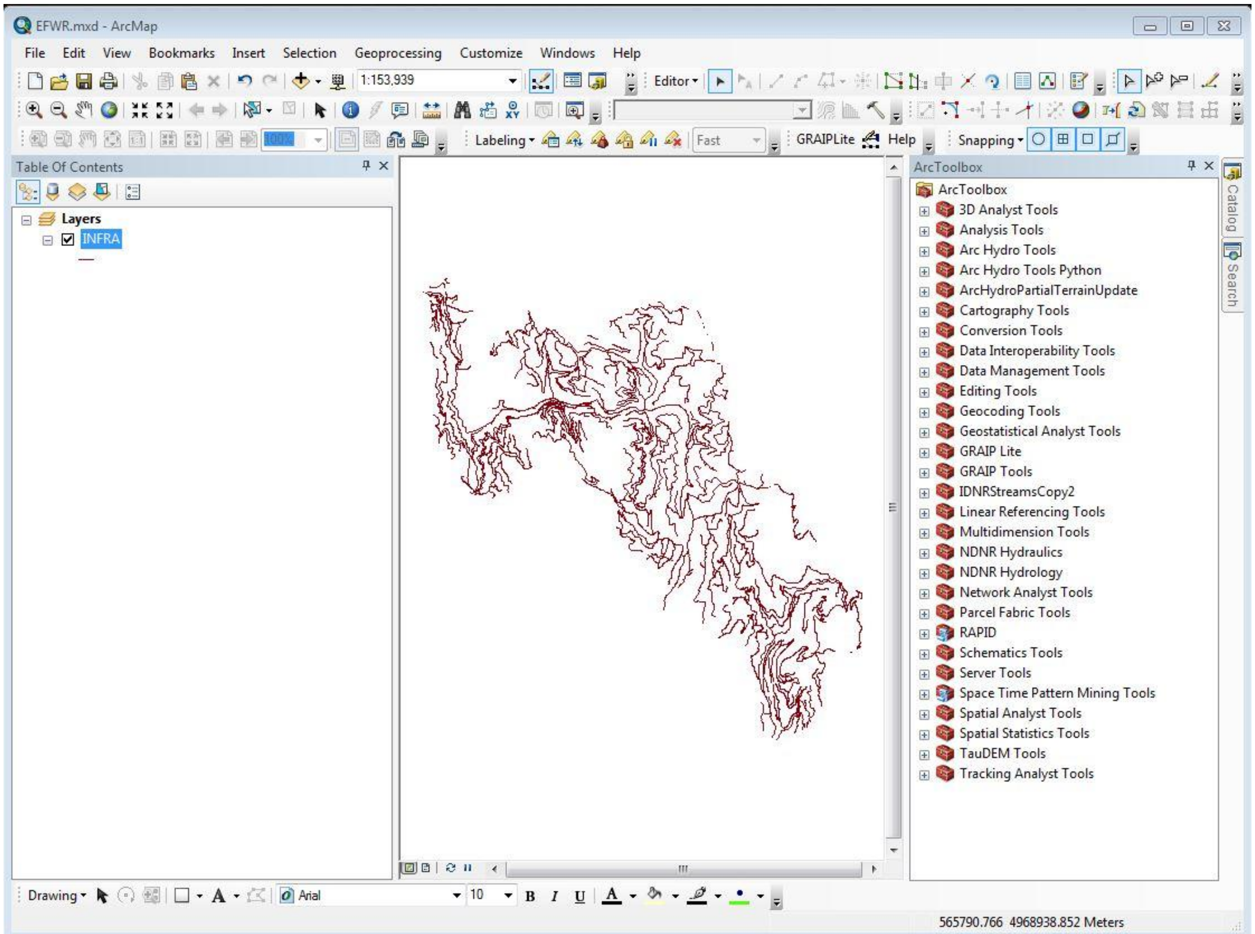


Figure 32: Start Editing.

Next, use the Selection tool to select all roads in the INFRA shapefile (Figure 33). The easiest way to do this is to click and drag a box around all of the roads shown in the map window.

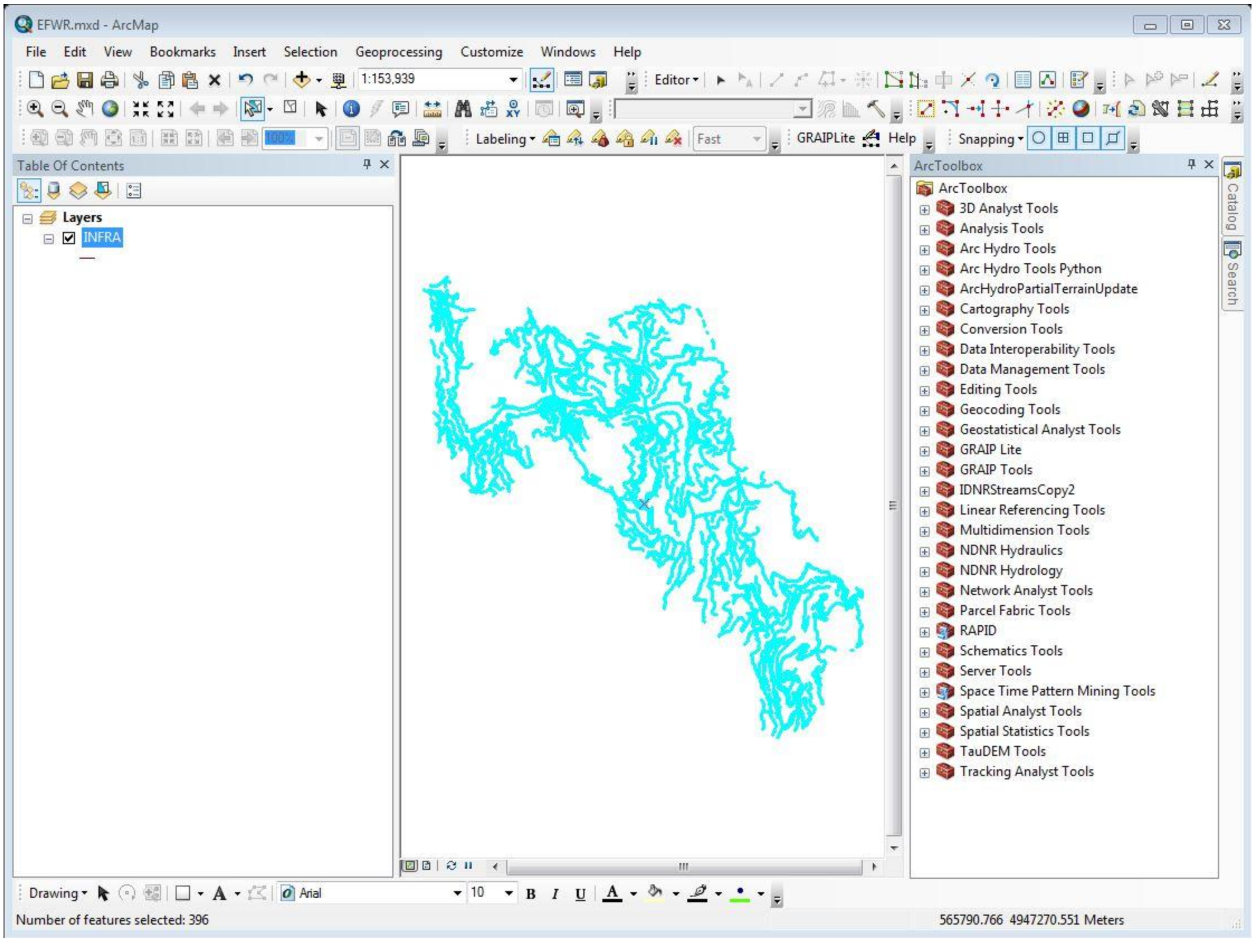


Figure 33: Select all road features.

Once all of the roads are selected, click on the Planarize Lines tool in the Advanced Editing toolbar (Figure 34). Specify a Cluster Tolerance of 0.001 meters, or 1 mm, and click OK. This tool splits all of the lines at each intersection point, resulting in separate features on either side of the intersection. All attributes are preserved during the process.

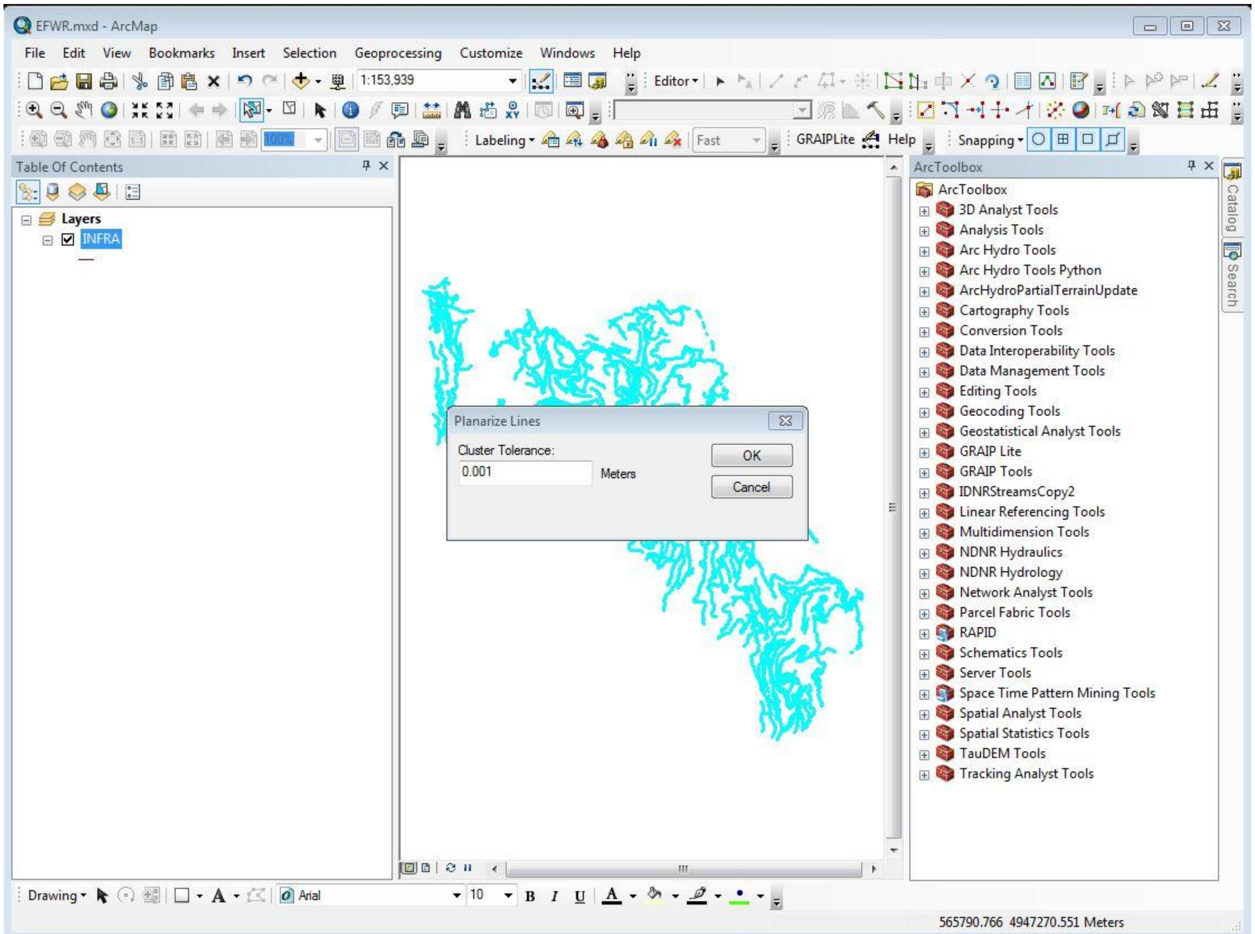


Figure 34: Planarize Lines tool.

Once the tool has finished, click on Save Edits and then Stop Editing, both located in the Editor menu (Figure 35). At this point, all road sections should be deselected. If there are places where the road needs to be split between intersections, use the Split tool, located in the main Editor toolbar, to do so while in editing mode, making sure to save your edits; in this tutorial this is not necessary.

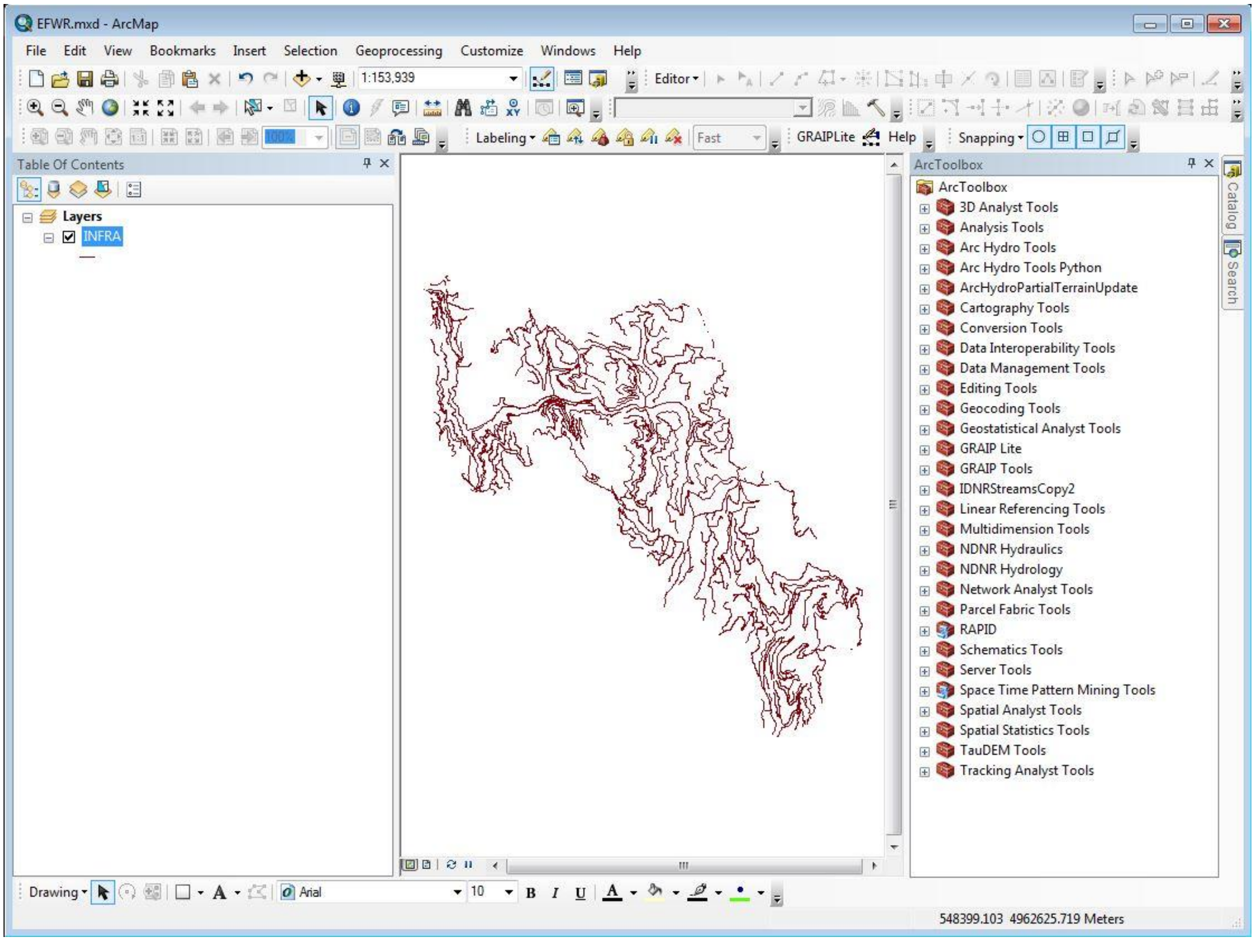


Figure 35: Save edits and stop editing.

Now that the data is in the format we need so that we can properly designate which portions of the road network will be treated, it is time to start the GRAIP_Lite model run. Before we can model the alternatives, we need to give GRAIP_Lite the underlying structure. This can be done with the Basic Run tool if there is no calibration or known drainpoints to be included, but if either or both of these are available it is best to do a full run using the Processing tools. The first step is the *01. Initialize GRAIP Lite Database* tool (Figure 36). This tool tells GRAIP_Lite where our data is and creates the geodatabase to keep track of the results.

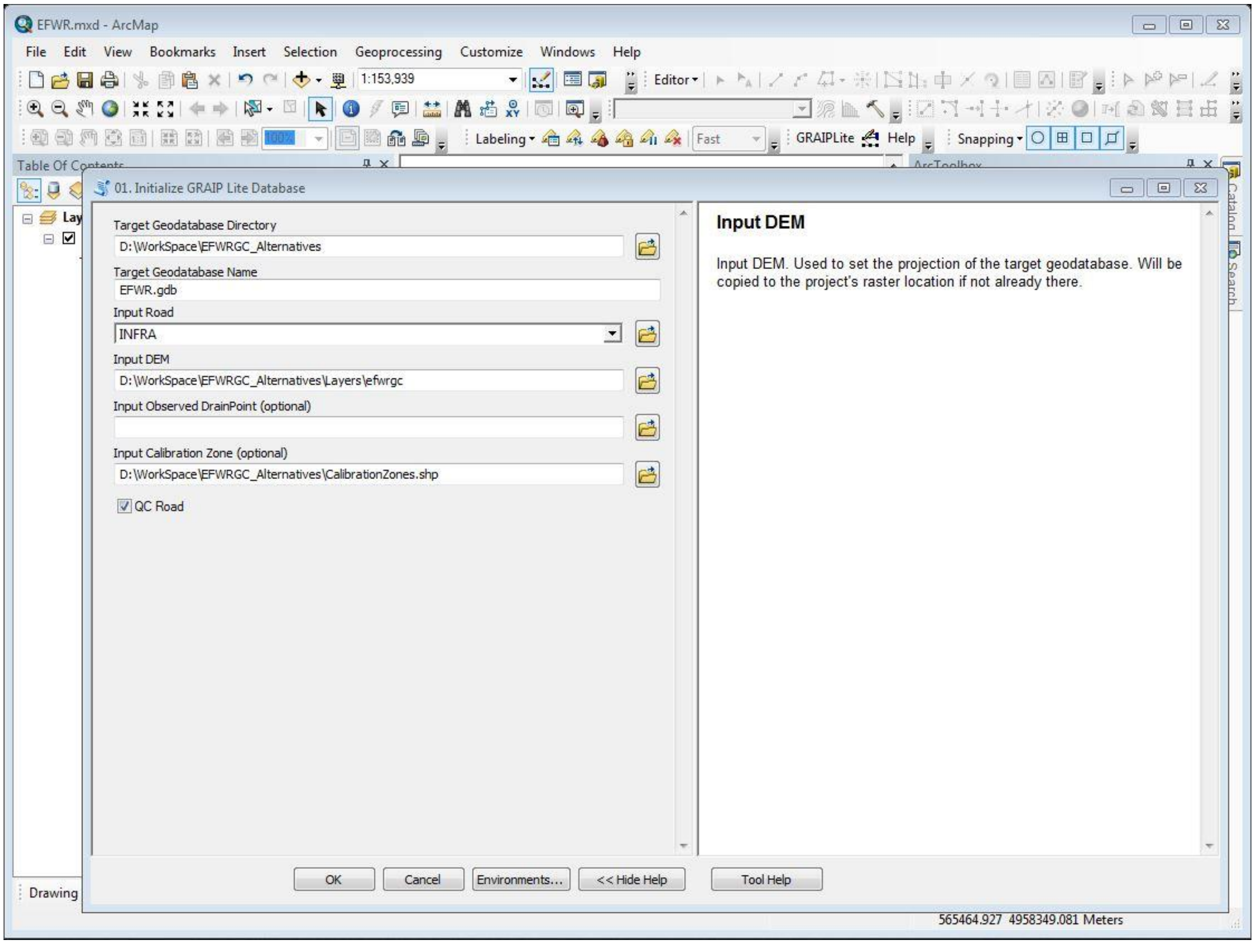


Figure 36: Initialize GRAIP Lite Database tool.

The next tool, *02. DEM Processing*, generates the stream network and the raster datasets needed for routing sediment in the GRAIP_Lite model (Figure 37).

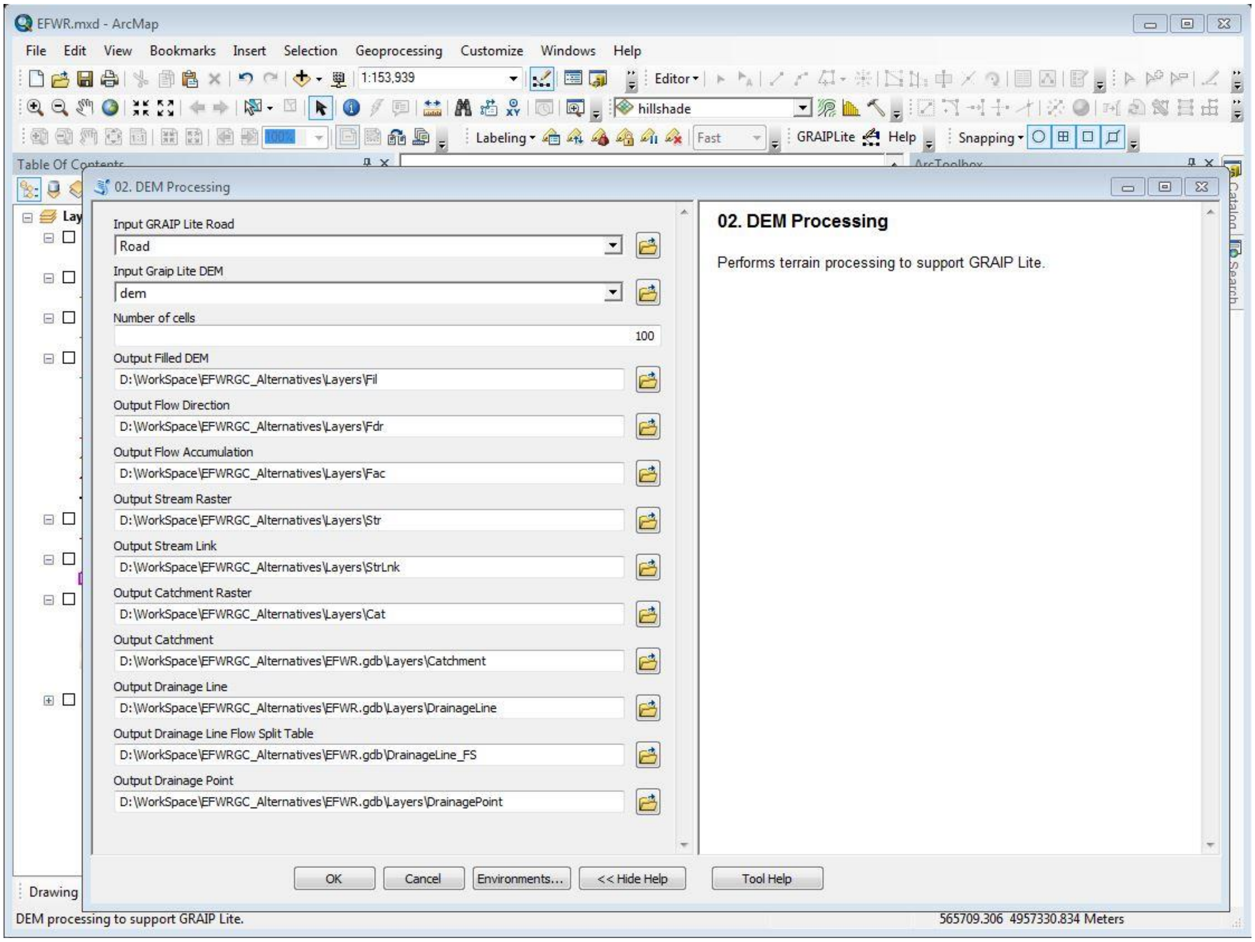


Figure 37: DEM Processing tool.

Next is the *03. Calculate Distance from Stream* tool (Figure 38), which calculates the distance along the flowpath to the nearest downhill stream.

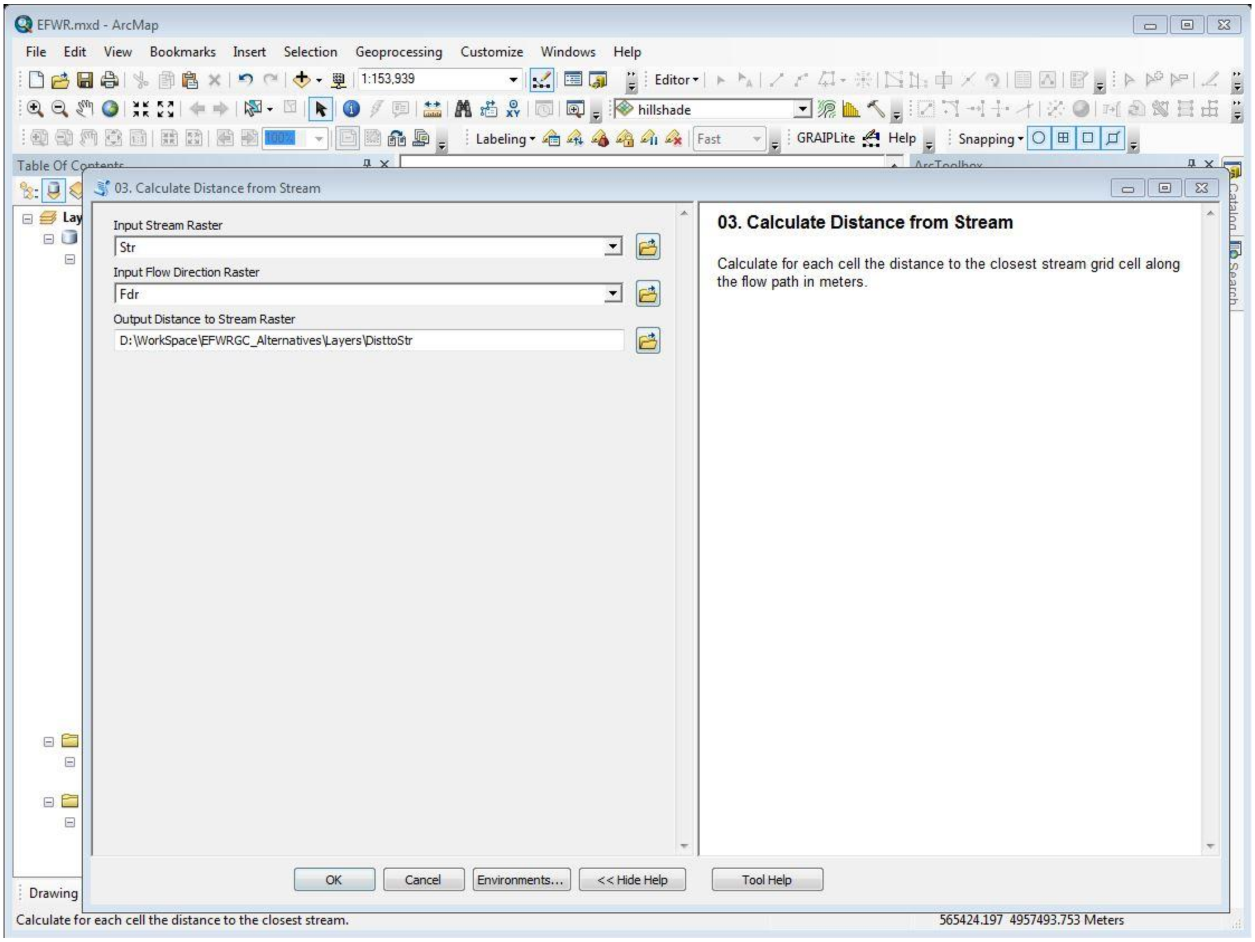


Figure 38: Calculate Distance from Stream tool.

The next tool is the *04. Create Road Segments* tool (Figure 39). This tool takes the input road layer and splits it up into GRAIP_Lite road segments based on intersections with calibration zone and catchment boundaries, streams (drainage lines), observed drainpoints, and a maximum road segment length determined by the road segment maintenance level.

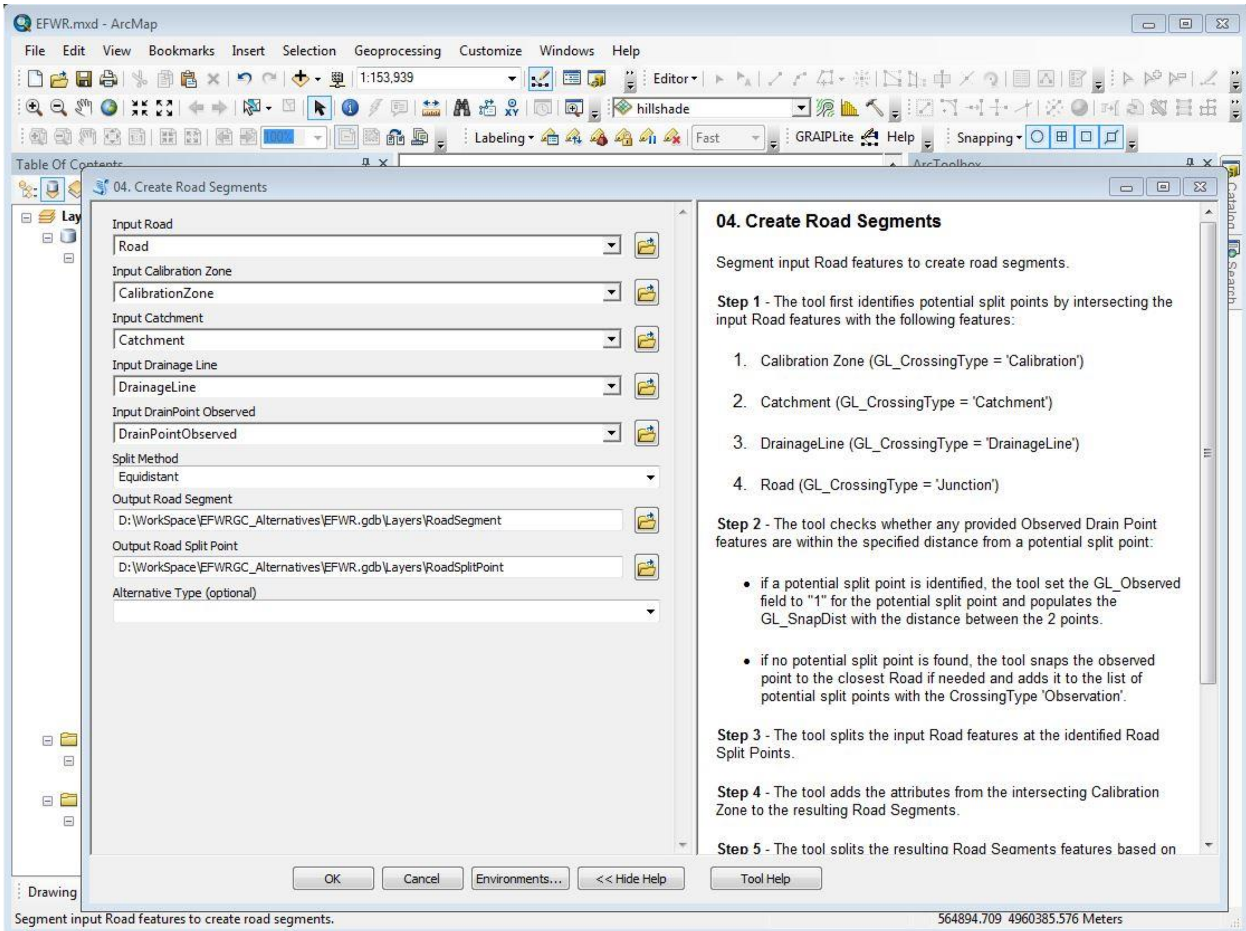


Figure 39: Create Road Segments tool.

Road-surface sediment production is then calculated using the *05. Calculate Road Segment Sediment Production* tool (Figure 40).

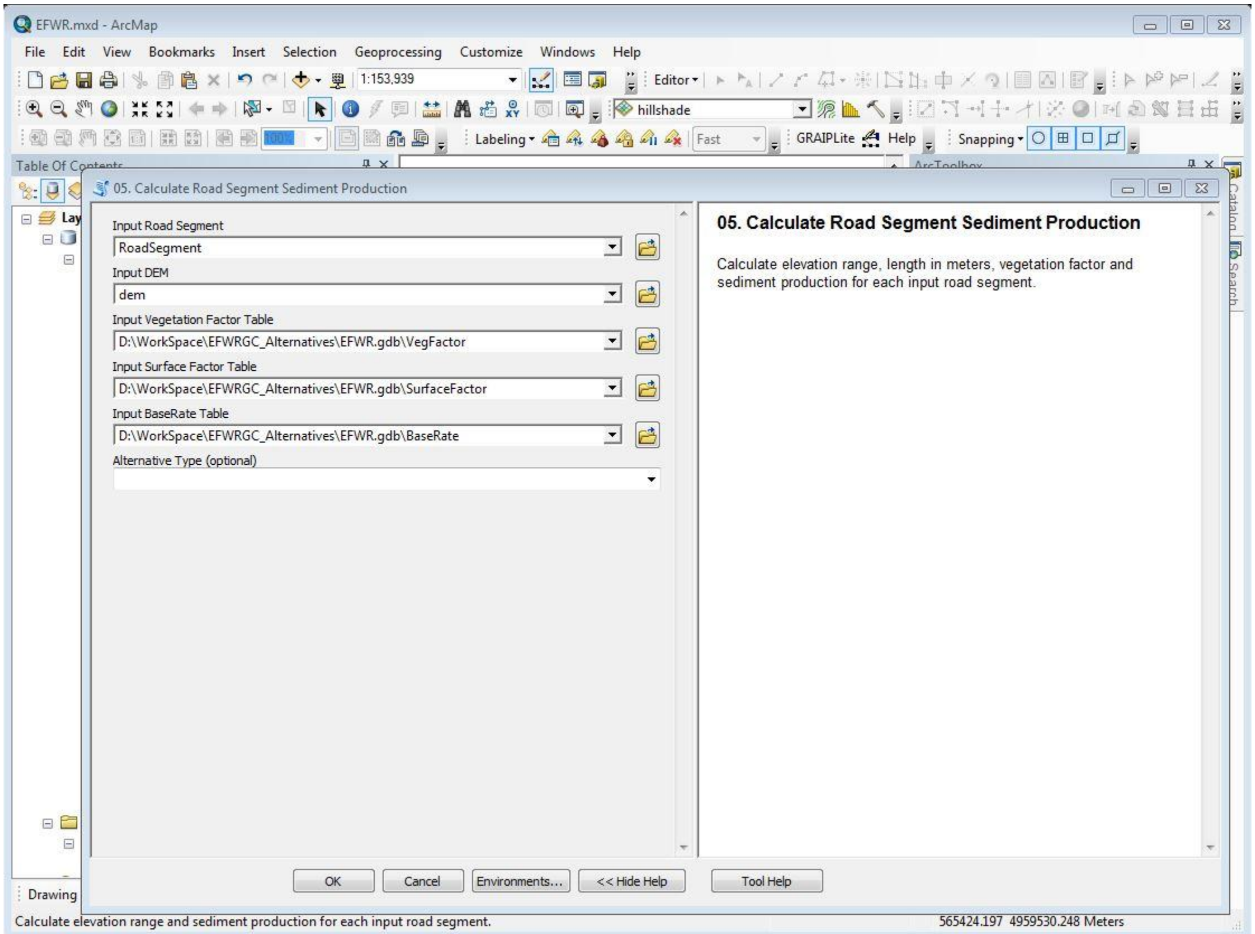


Figure 40: Calculate Road Segment Sediment Production tool.

The next tool, the *06. Create Road Segment Drain Points* tool, creates drain points at the low end of each road segment and appends the flow distance to the stream (Figure 41).

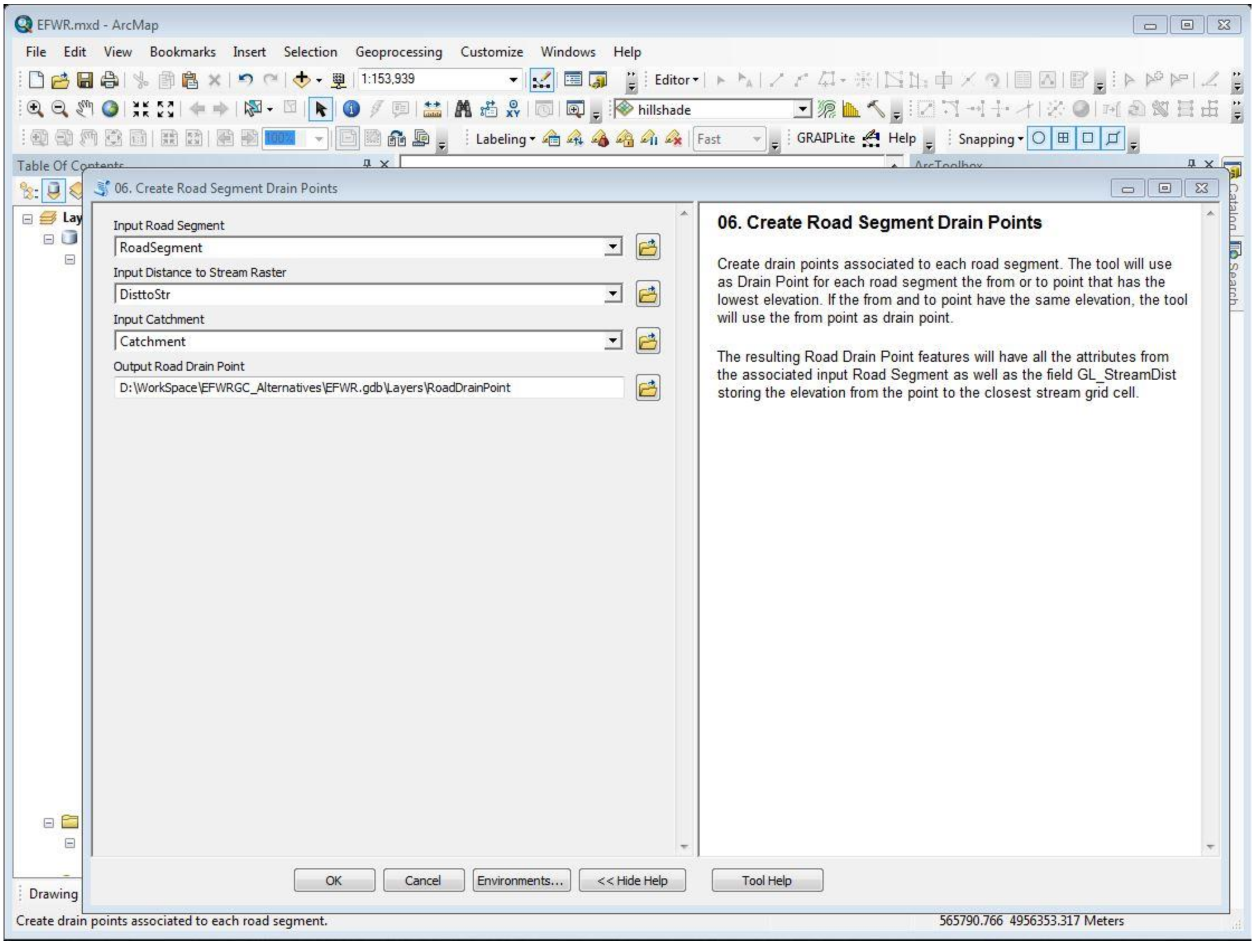


Figure 41: Create Road Segment Drain Points tool.

Next is the *07. Calculate Sediment Delivery* tool (Figure 42) that calculates how much of the produced sediment from each road segment will be delivered to the stream network.

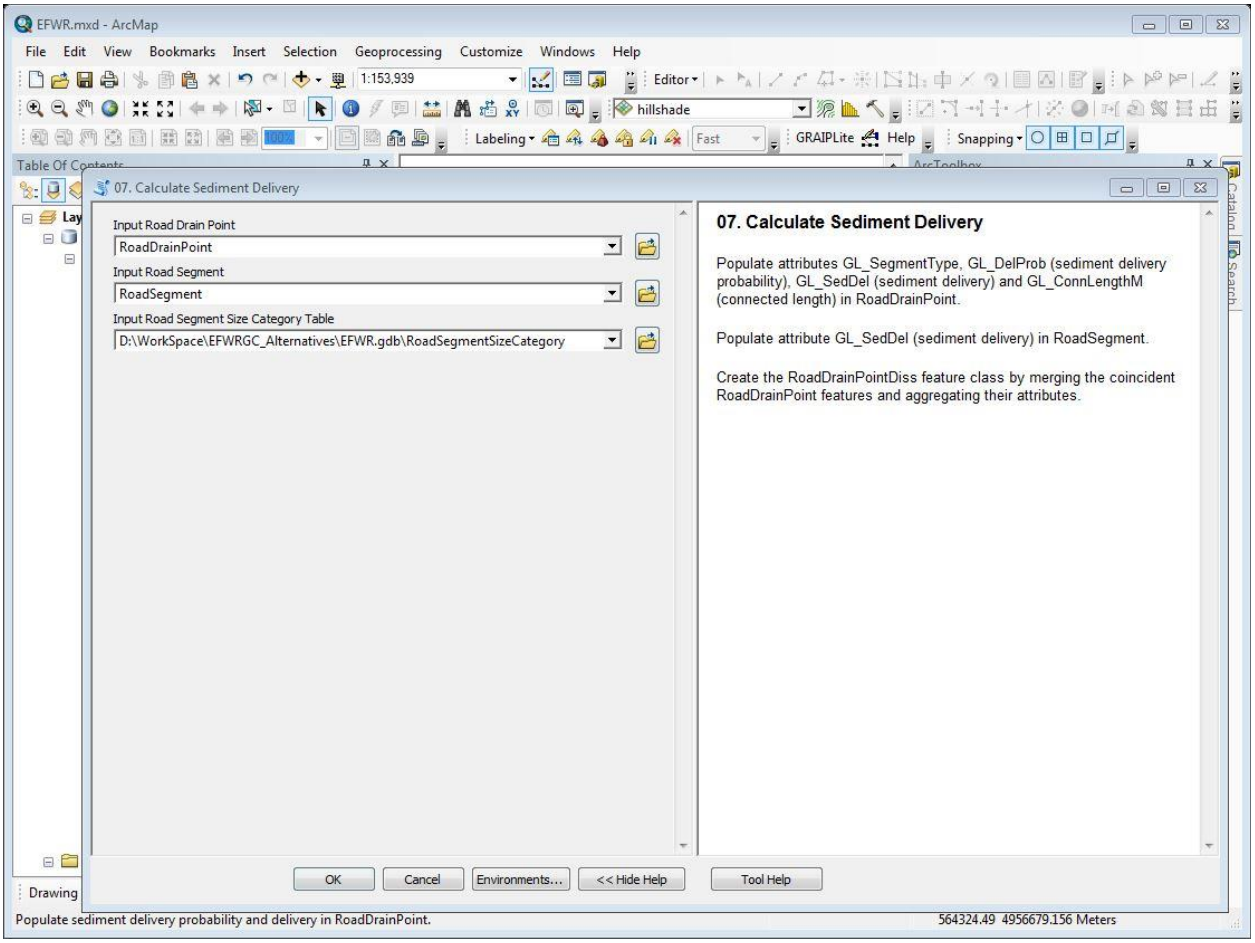


Figure 42: Calculate Sediment Delivery tool.

The next step is to route the delivered sediment into the stream network using the *08. Route Sediment to Streams* tool (Figure 43).

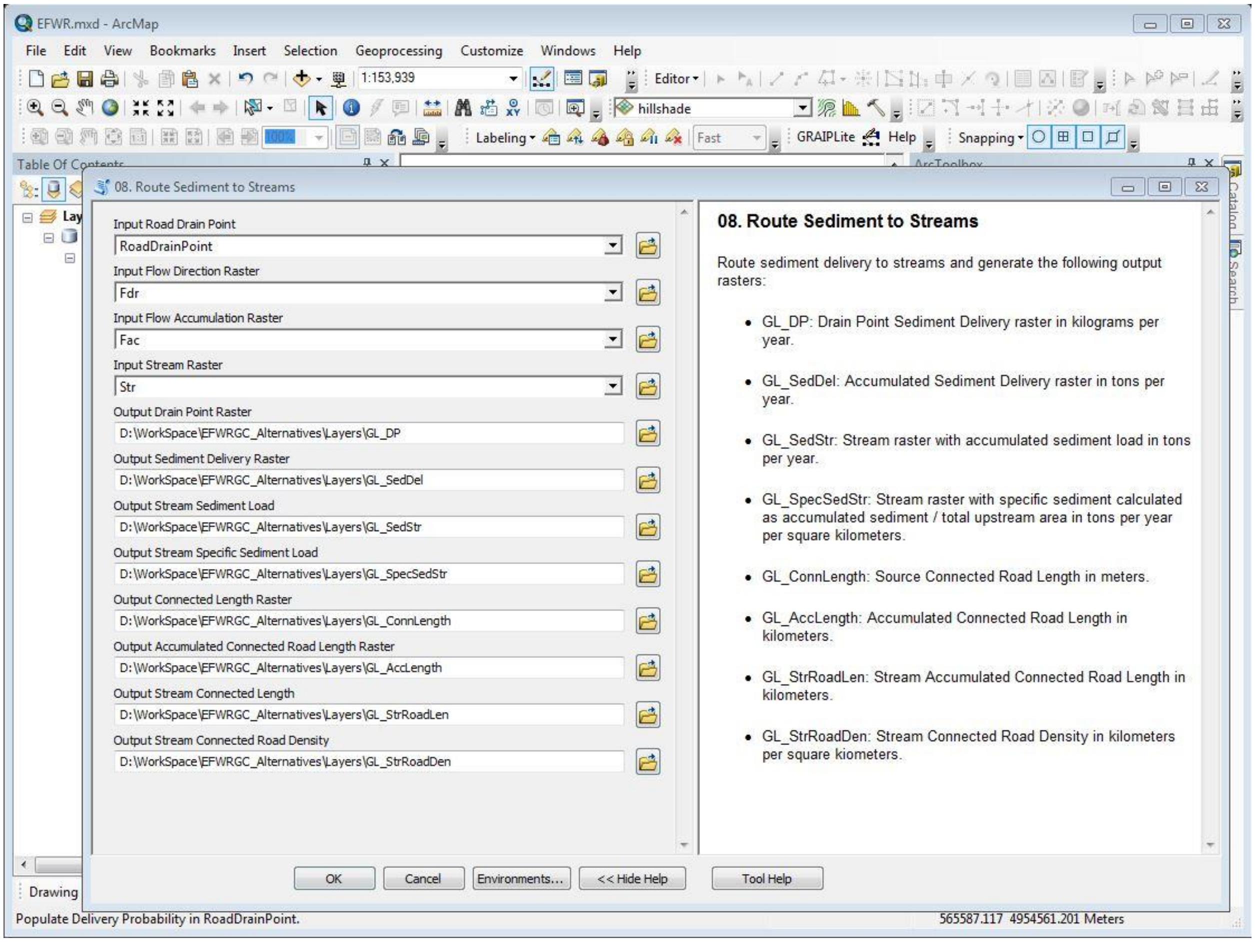


Figure 43: Route Sediment to Streams tool.

Finally, run the *09. Report Parameters on Drainage Line* tool to add the accumulated sediment metrics to the drainage line feature class (Figure 44). This completes the initial part of the model run and establishes the model parameters that will be used to model the alternatives.

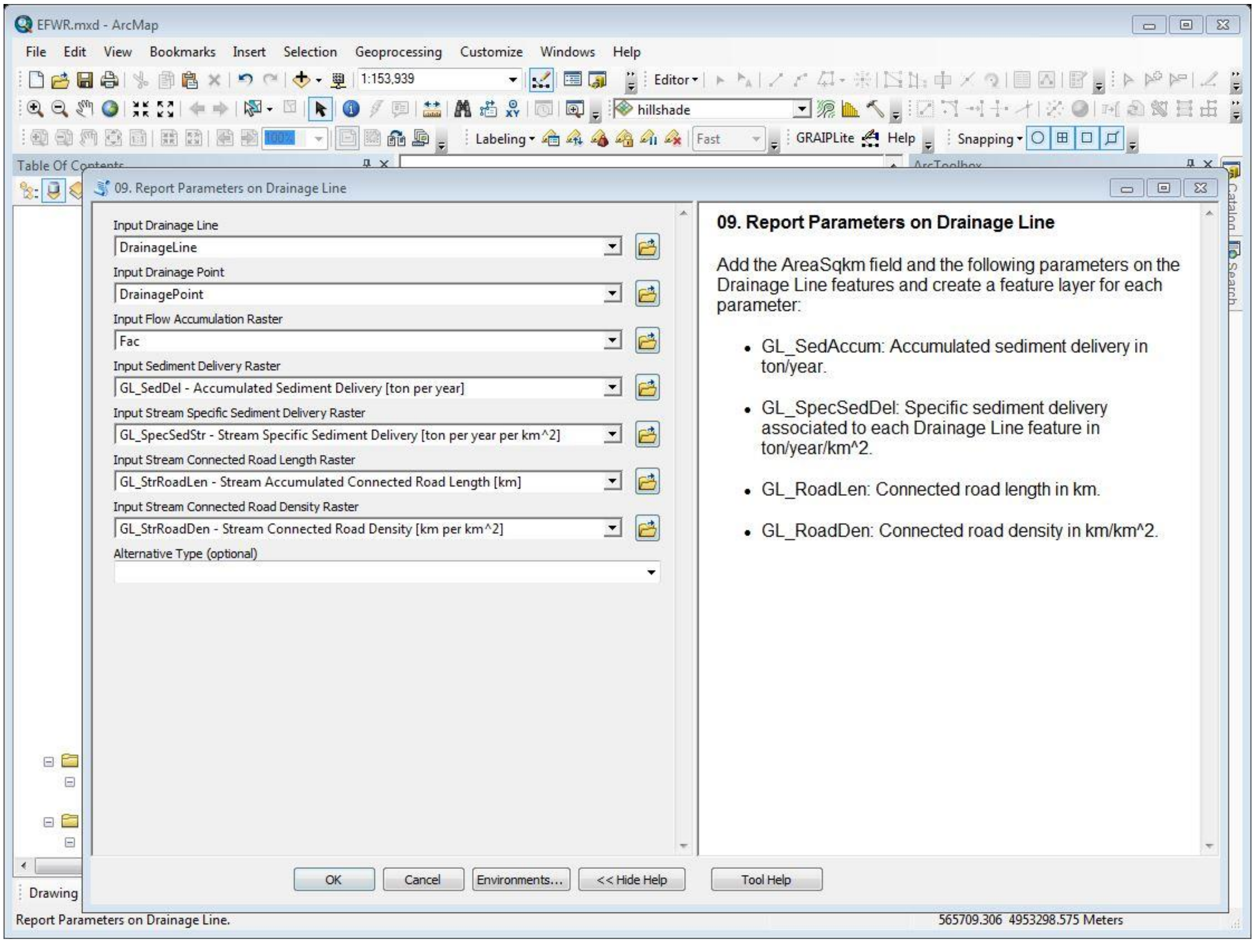


Figure 44: Report Parameters on Drainage Line tool.

Before the treatments can be modeled, GRAIP_Lite needs to know what the treatments are and what road segments are being treated. This is done using the GRAIP_Lite window, which is opened from the GRAIP_Lite toolbar by clicking on *GRAIP Lite* (Figure 45). The window can be docked or moved to a convenient location on your screen.

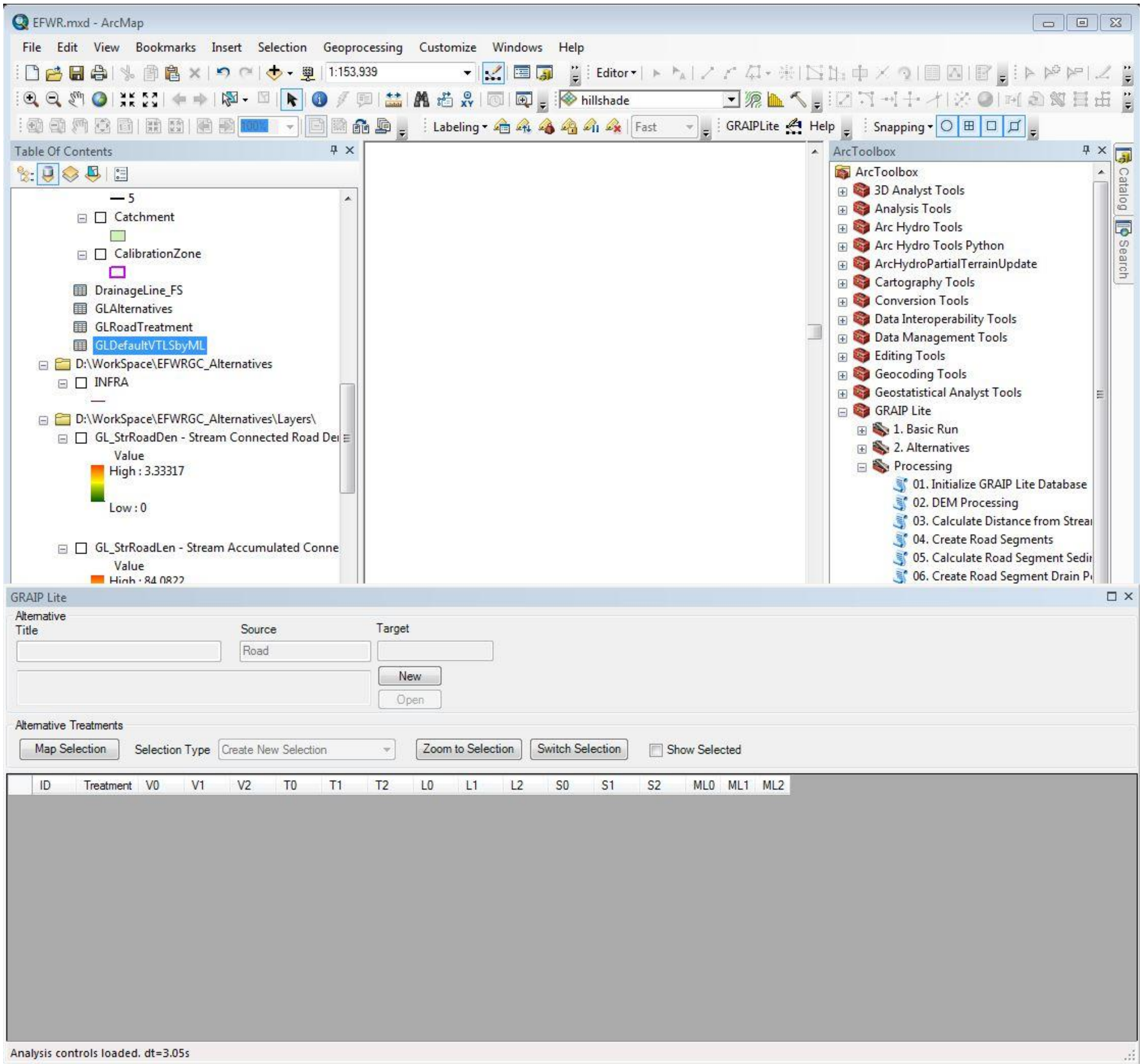


Figure 45: Open GRAIP Lite window.

Another common, and annoying, error we have been seeing involves the ApUtilities setting the target locations incorrectly, usually to one of the previously opened map documents. This results in errors when starting the GRAIP_Lite window in preparation for defining treatments to be modeled as alternatives. When the GRAIP_Lite window is opened from the GRAIP_Lite toolbar, three tables are supposed to be copied into the GRAIP_Lite project database. The red box in the Figure 46 shows the three tables; the picture shows them in the correct location, as noted by the path highlighted in blue (pointing to the project geodatabase).

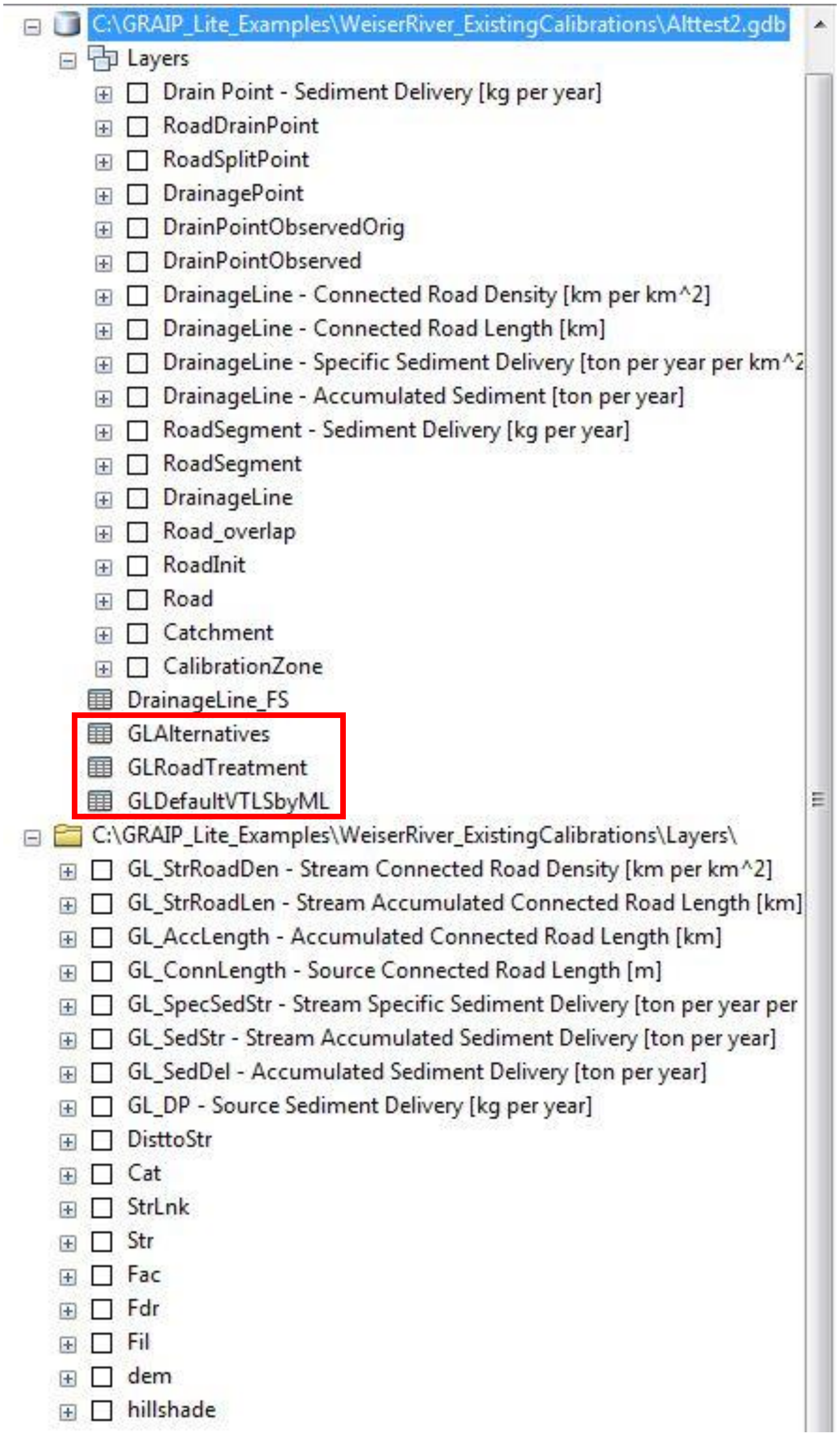


Figure 46: The tables created when opening the GRAIP_Lite window should appear in this location in your project geodatabase.

If the tables show up where they are supposed to, then all is good. If the tables show up in any other path, close ArcMap **WITHOUT** saving the document. Re-open ArcMap, then re-open the map document, and try again. In our testing, it should work at this point, but double check that the tables are being copied to the correct location before saving the map document.

One way we have found to avoid this is to save, close, and then re-open the map document after running the *Initialize GRAIP Lite Geodatabase* tool. This seems to prevent the issue, which appears to be related to ArcMap not letting go of settings for a previous map document and work space.

Once the GRAIP_Lite window is open, and the tables are in the correct location, click on New to open the options for a new alternative (Figure 47). If you have already created an alternative, you would also have the option to click on Open to access an existing alternative.

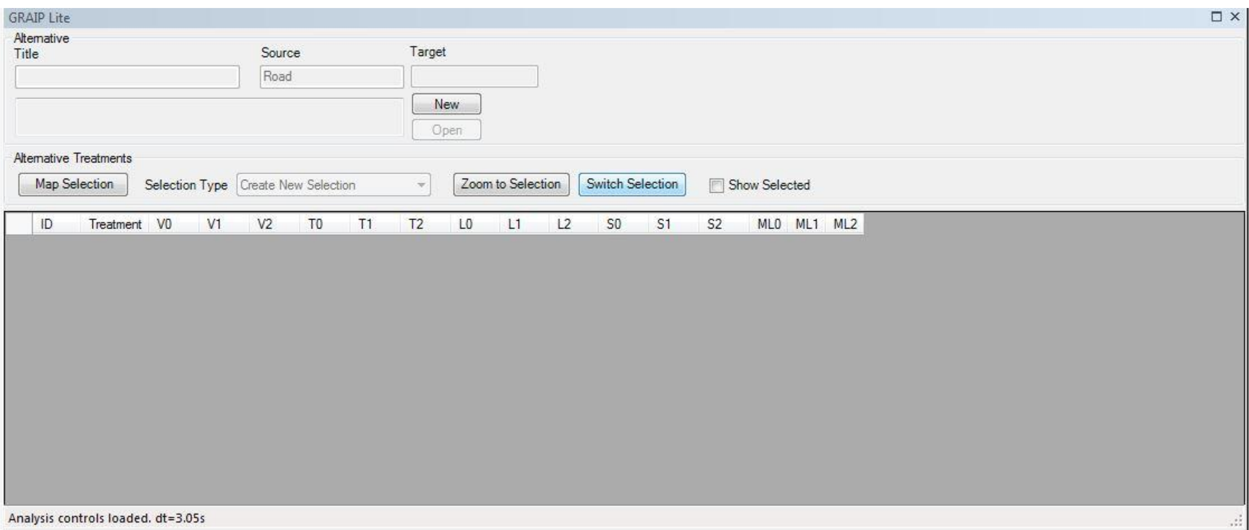


Figure 47: GRAIP Lite window; click on New to start.

After clicking *New*, the window will provide you options for setting up the alternative (Figure 48). You can use the *Title* field to name the alternative, as well as select the *Source* road layer for the alternative. For this tutorial, the defaults will be used. The road layer in this case is the *Road* feature class from the initial model run; this is the copy of the road layer created when the *01. Initialize GRAIP Lite Database* tool was run. There is also a space to enter a description of the alternative. Click *Create* and wait while the tool creates the feature classes for the alternative.

Note that you can choose a different *Source* road layer; this is most commonly used if creating multiple alternatives where there are only a few differences between them. In such a case, one alternative can be set up, and then that layer (*Alternative1_Road*) may be used as the *Source* for the other alternative with only minor changes being made to subsequent alternatives.

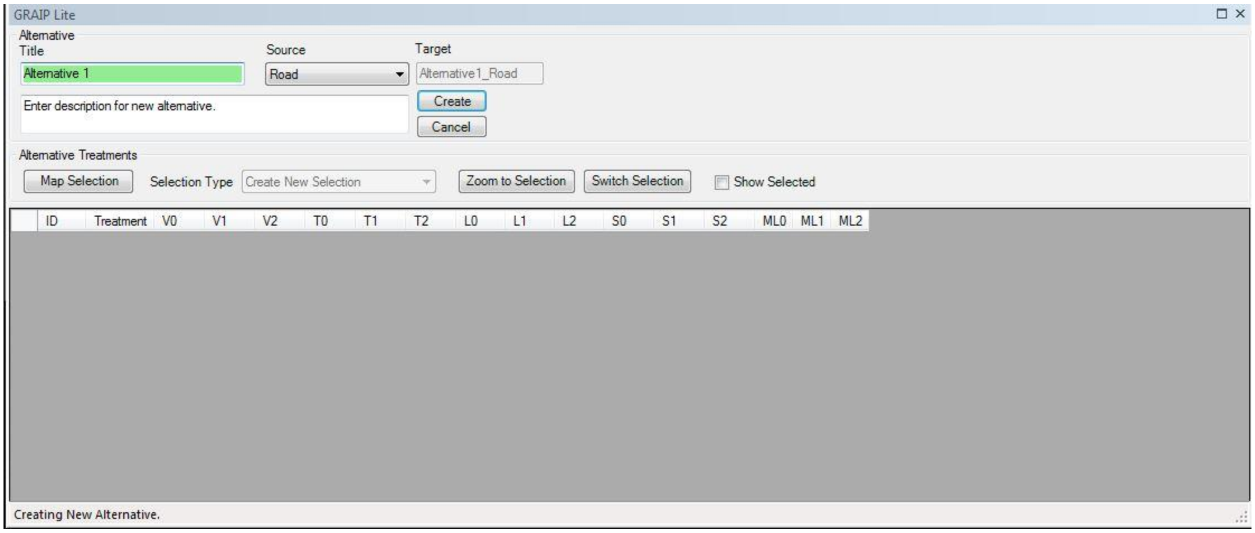


Figure 48: Create new alternative.

Once the tool has created the alternative, you will be able to see a table where you will be able to set treatment values (Figure 49). Click on *Open* to begin editing the treatments for the alternative. Notice that when the new alternative was created, a new map is added to ArcMap's Table of Contents. Save the map document.

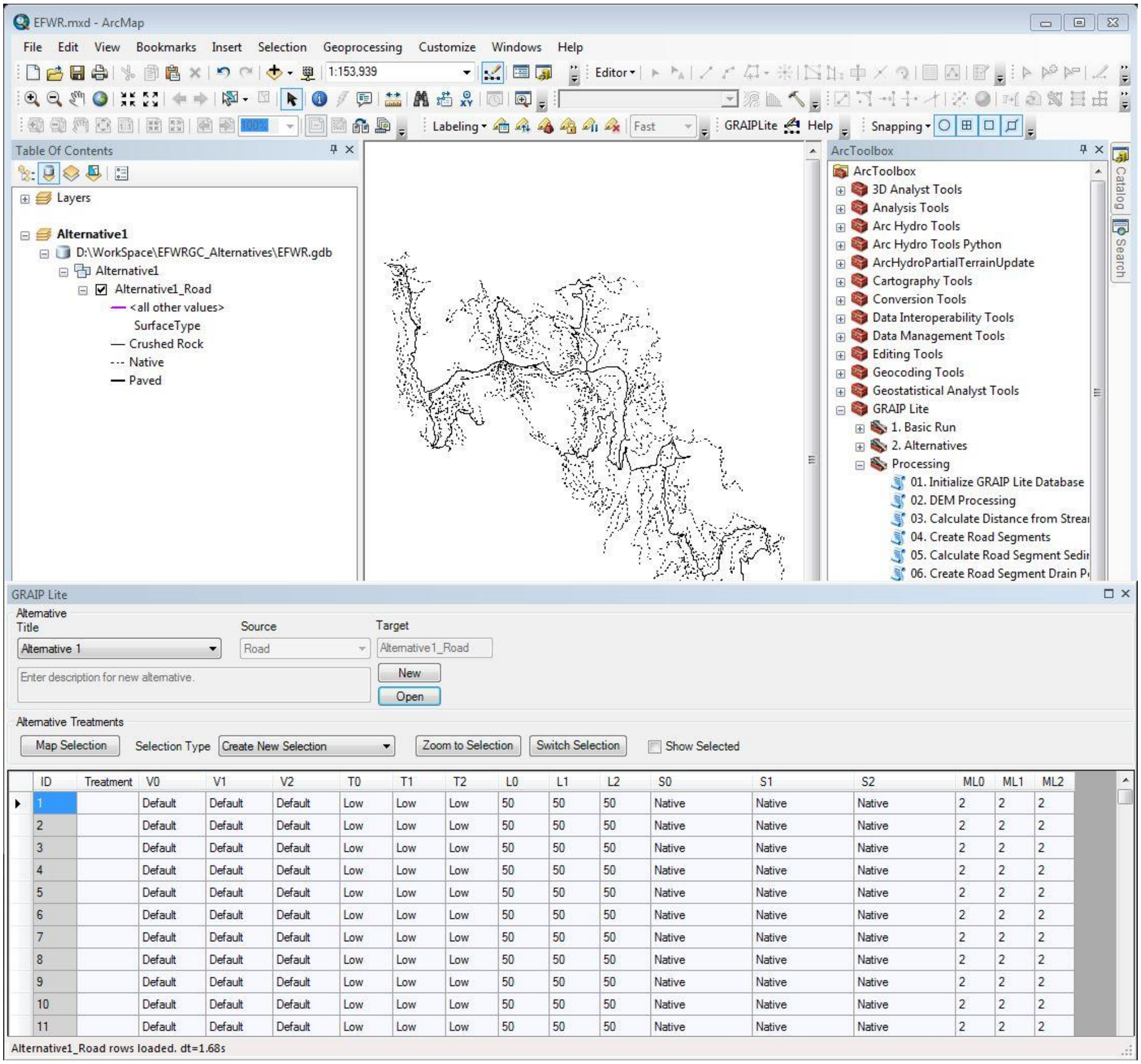


Figure 49: Newly created alternative ready to open for editing.

One way to plan treatments is using a shapefile or feature class dataset to keep track of those planned treatments. For the purposes of the tutorial, the *Treatments.shp* shapefile contains just the planned treatments. It was created from a planarized version of the *INFRA.shp* shapefile used for the tutorial. Add the Treatments.shp shapefile using the Add Data dialogue (Figure 50). A separate shapefile or feature class is not necessary; if the treatments are already recorded in columns in the road layer, that information will carry over into GRAIP_Lite which means that features can be directly selected in the *Alternative1_Road* layer using the *Select by Attributes* tool. If the treatment descriptions are already in the *Alternative1_Road* layer, the *Select by Location* tool is not necessary.

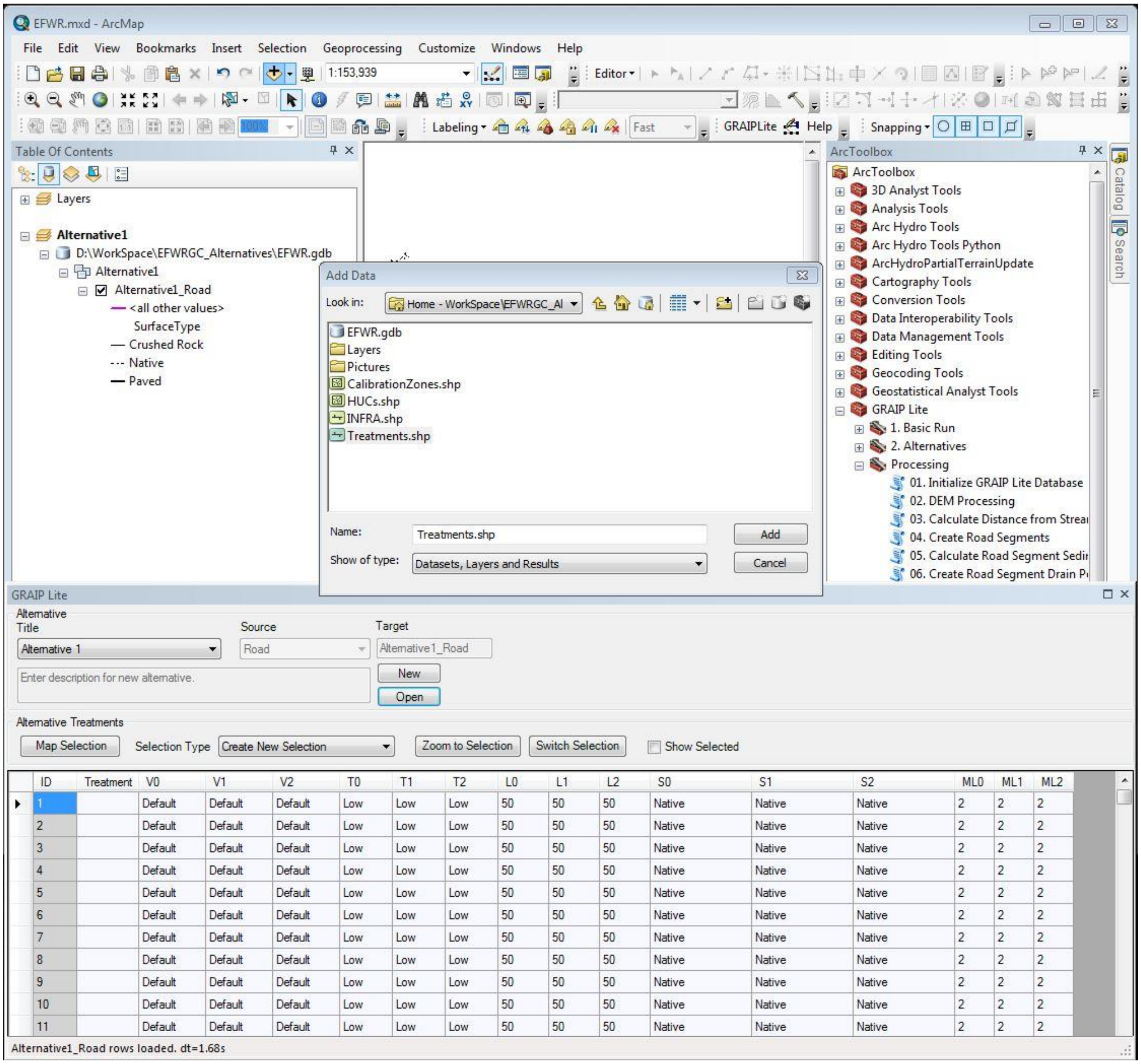


Figure 50: Add Treatments layer.

Once the treatments layer has been added, double click on it to open the Layer Properties and click on the Symbology tab (Figure 51). Select the Unique values option under the Categories menu, then select Treatment in the Value Field menu. Finally, click Add All Values. The choice for color ramp isn't important; the idea is just to be able to distinguish each treatment category. Click OK when satisfied with the symbology and turn the layer on if it is not already on.

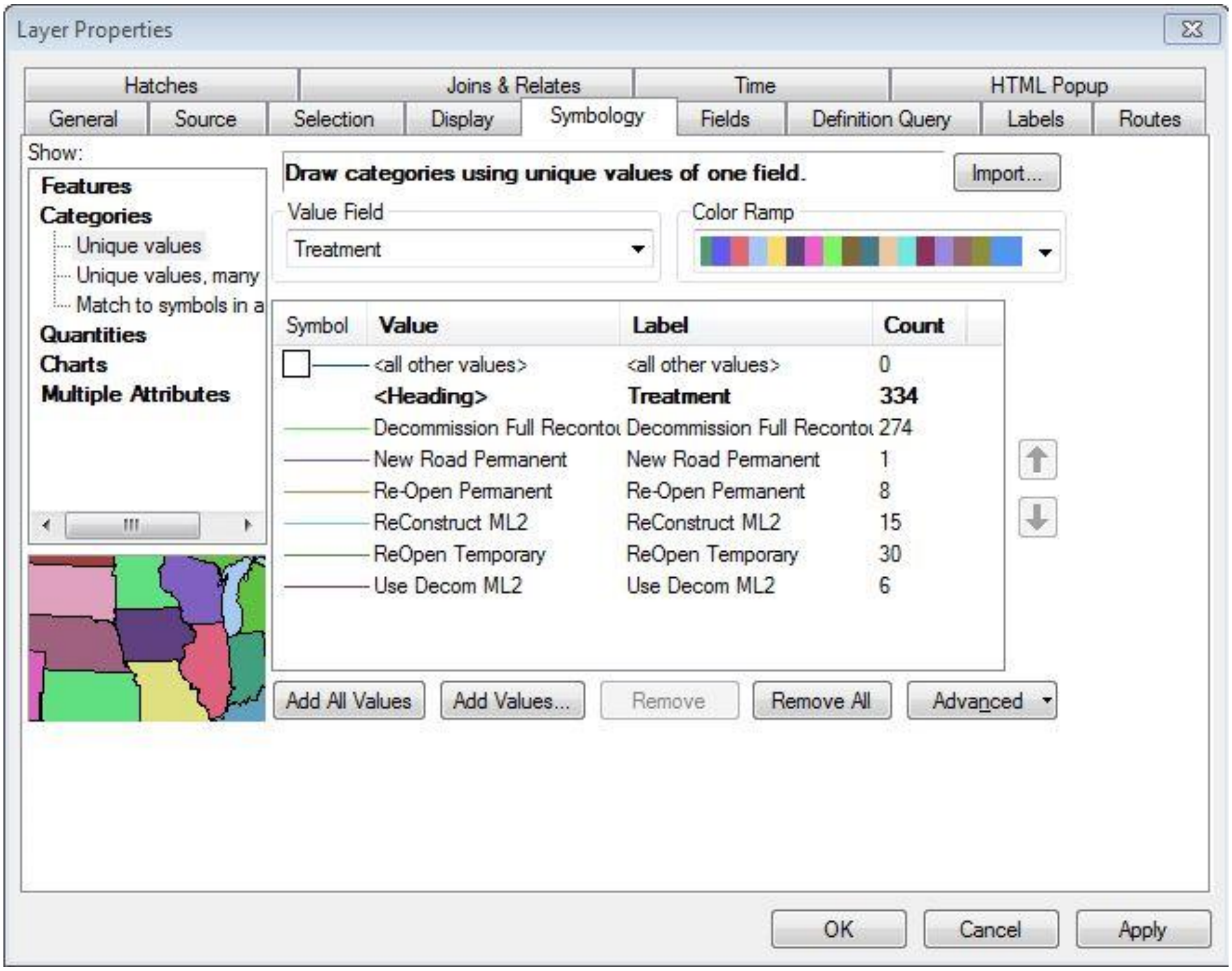


Figure 51: Treatments symbology.

It is now time to start selecting road segments and setting treatment values. In order to set the treatments, the appropriate road segments must be selected from the *Alternative1_Road* layer. There are a couple ways to do this, depending on the way the data is set up and how many road segments will receive the same treatment.

Since the *Treatments* layer in this example is derived from the *INFRA* data set used for the model, and both layers were planarized, individual road sections are geometrically identical. This means that we can select features in the *Treatments* layer using the *Select By Attributes* tool and then use the *Select By Location* tool to select the corresponding features in the *Alternative1_Road* layer. If your project has the treatments specified in your road layer, just use the *Select By Attributes* tool to directly select the features in the *Alternative1_Road* layer.

Open the *Select By Attributes* tool by clicking on *Selection* and then *Select By Attributes* in the main ArcMap menu. Make sure *Treatments* is the target *Layer*, and in the list of attribute fields, scroll to the bottom to find *"Treatment"* (Figure 52). Double click on *"Treatment"* to add it to the logic statement in the lower part of the dialogue box, then click on *Get Unique Values* to see a list of the possible values for the field *"Treatment".* Now click on the = button and then double click on *'Decommission Full*

Recontour'. You should now have a statement in the lower part of the dialogue box: *"Treatment" = 'Decommission Full Recontour'*. Click *Apply* to select all features in the *Treatments* layer where the treatment is specified to be decommissioning by fully recontouring the road.

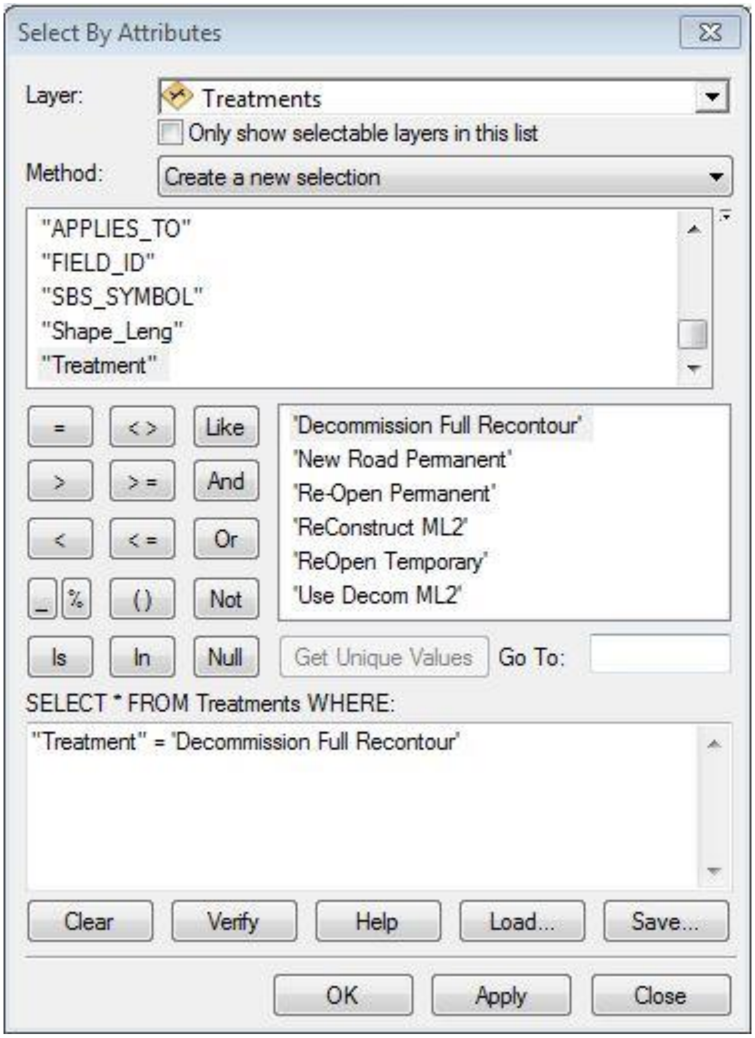


Figure 52: Select by Attributes tool.

Open the *Select By Location* tool by clicking on *Selection* and then *Select By Location* in the main ArcMap menu. This tool will be used to select the corresponding features in the *Alternative1_Road* layer. The *Select By Location* tool (Figure 53) is used to select features from the *Target layer* or layers based on their location relative to features in the *Source layer*. In the *Target layer(s):* list, make sure *Alternative1_Road* is selected. Make sure *Treatments* is the *Source layer* and click the box to *Use selected features*. There is a list of different options for *Spatial selection method for target layer feature(s):*; use the option *are identical to the source layer feature*. This selects the features in the *Alternative1_Road* layer that are geometrically identical to the features selected from the *Treatments* layer during the previous step.

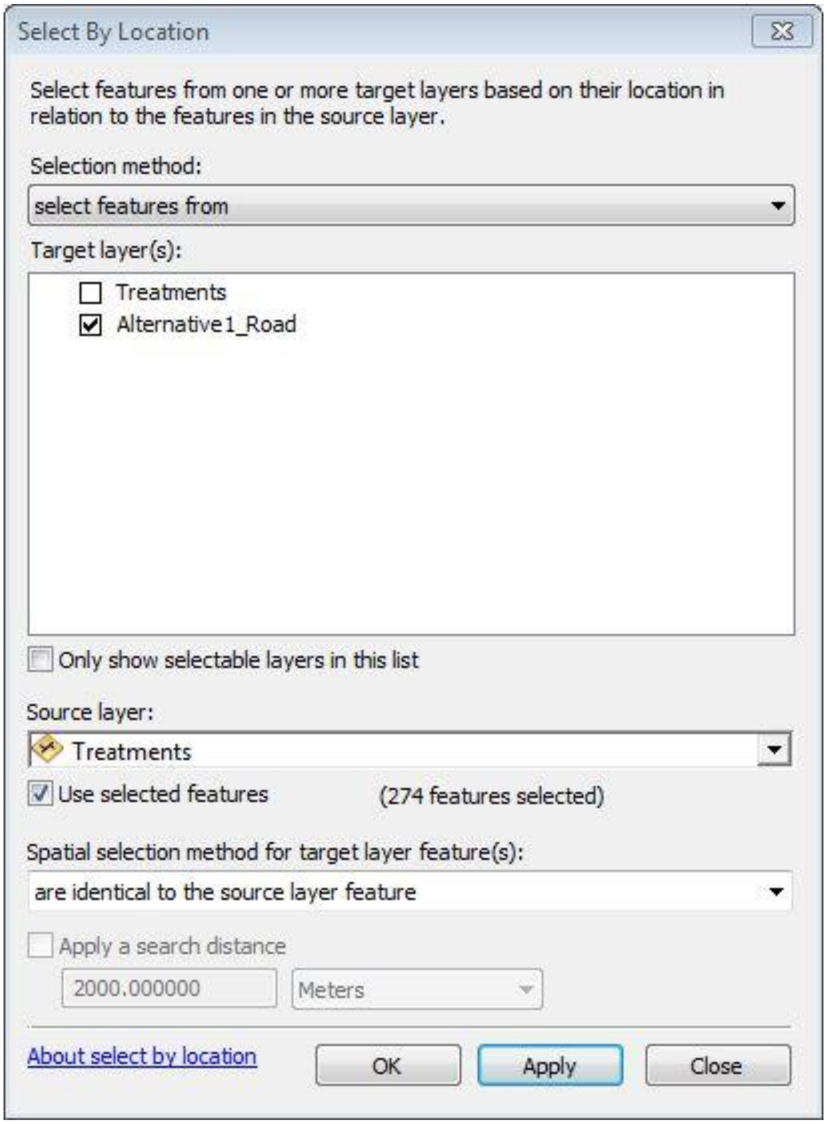
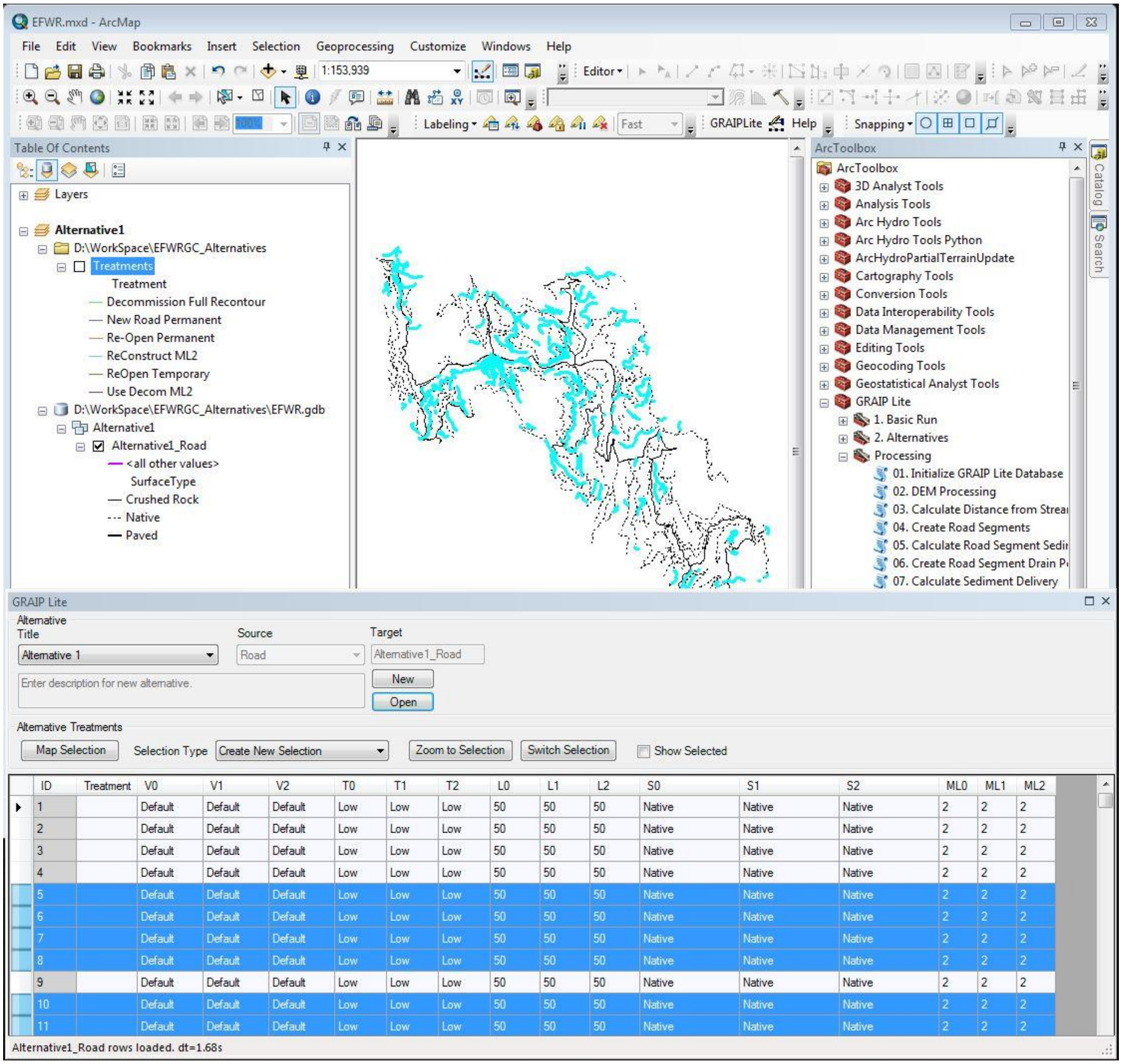


Figure 53: Select by Location tool.

The selected features will appear highlighted in both the map window and the GRAIP Lite dialogue box (Figure 54). You can check that the correct features were selected by turning on and off the *Treatments* layer and comparing the selected features on the map.



ID	Treatment	V0	V1	V2	T0	T1	T2	L0	L1	L2	S0	S1	S2	ML0	ML1	ML2
1		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
2		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
3		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
4		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
5		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
6		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
7		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
8		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
9		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
10		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2
11		Default	Default	Default	Low	Low	Low	50	50	50	Native	Native	Native	2	2	2

Figure 54: Selected features.

In the GRAIP Lite window, click on the box for Show Selected to show only the selected road sections (Figure 55).

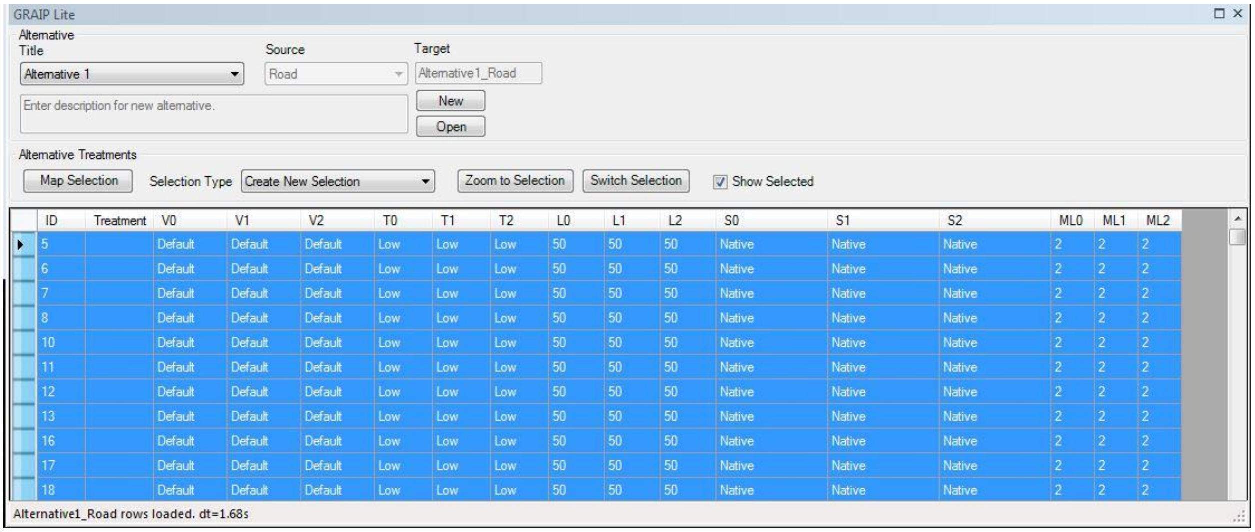


Figure 55: Showing only selected features.

Click on the top row of the table in the Treatment column. It will probably take a couple clicks before the treatment menu appears, but since the tool is doing things each time you click, wait for it to be done between clicks. You will see a drop-down menu when it is ready (Figure 56). If you click too fast, it will end up selecting only the top row as a subselection to apply the chosen treatment to; if you let the program catch up between clicks, you will be able to apply the treatment to all selected features at once.

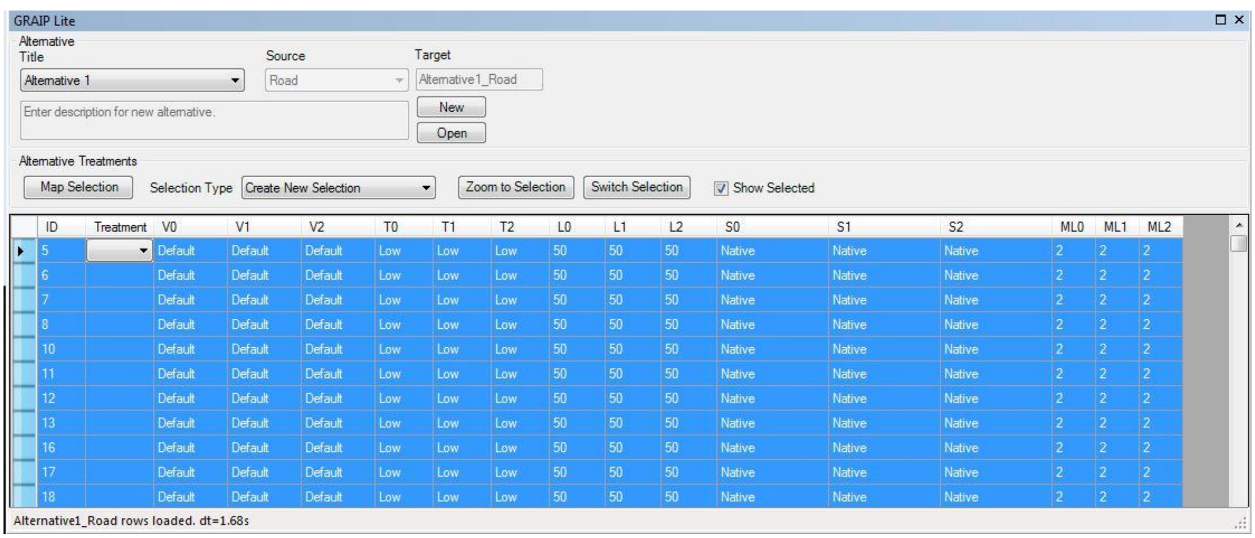


Figure 56: Treatment column showing dropdown menu ready to be accessed.

When the menu opens, select "Decommission – Full Recontour" and wait while GRAIP_Lite sets the treatment values in the table. When it is done, it should look like Figure 57. Notice that the many of the values in the table have now changed to reflect conditions at the disturbed and recovered conditions based on the treatment specified.

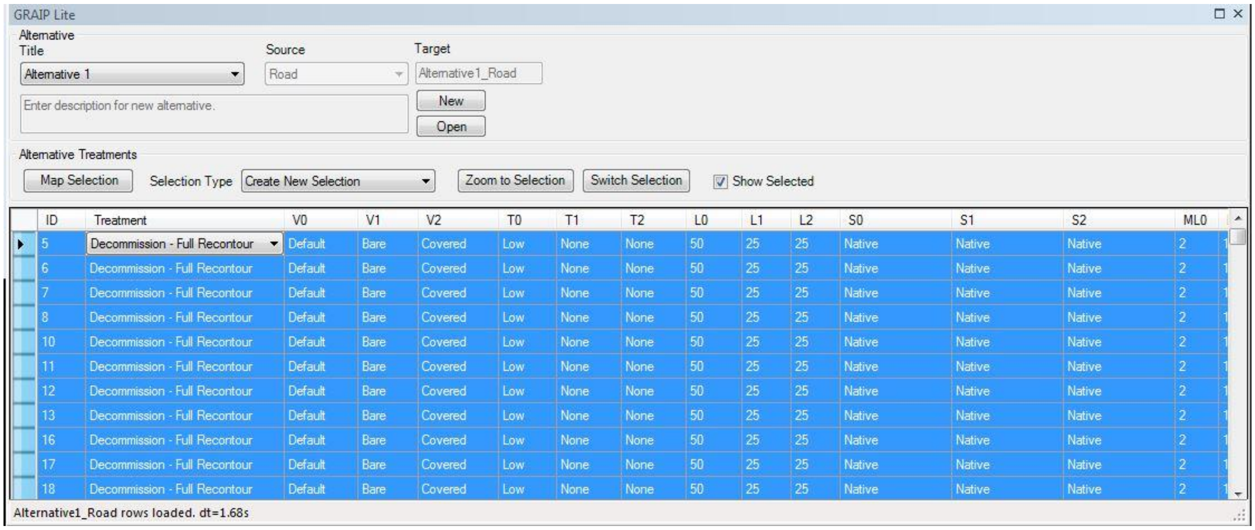


Figure 57: Treatment selected and applied to features.

When the tool has finished, uncheck the box by *Show Selected* and then *Clear Selected Features* (in the *Tools* toolbar) before making a new selection.

Repeat this process to select and set treatments for those road sections with the specified treatments of “Reconstruct ML2”, “ReOpen Temporary”, and “Use Decom ML2” before moving on to the next part of the tutorial.

Another tool used to select roads is the *Select Features* tool (also in the *Tools* toolbar), which allows you to select visible features by clicking on them. This tool is more useful when there are only a few road sections receiving a given treatment. Use the *Zoom In* tool to zoom in on the area of the roads listed for “Re-Open Permanent” and “New Road Permanent” so that they roughly fill the map window (Figure 58); this tool is also in the *Tools* toolbar. This will make it easier to select the road sections that will be re-opened.

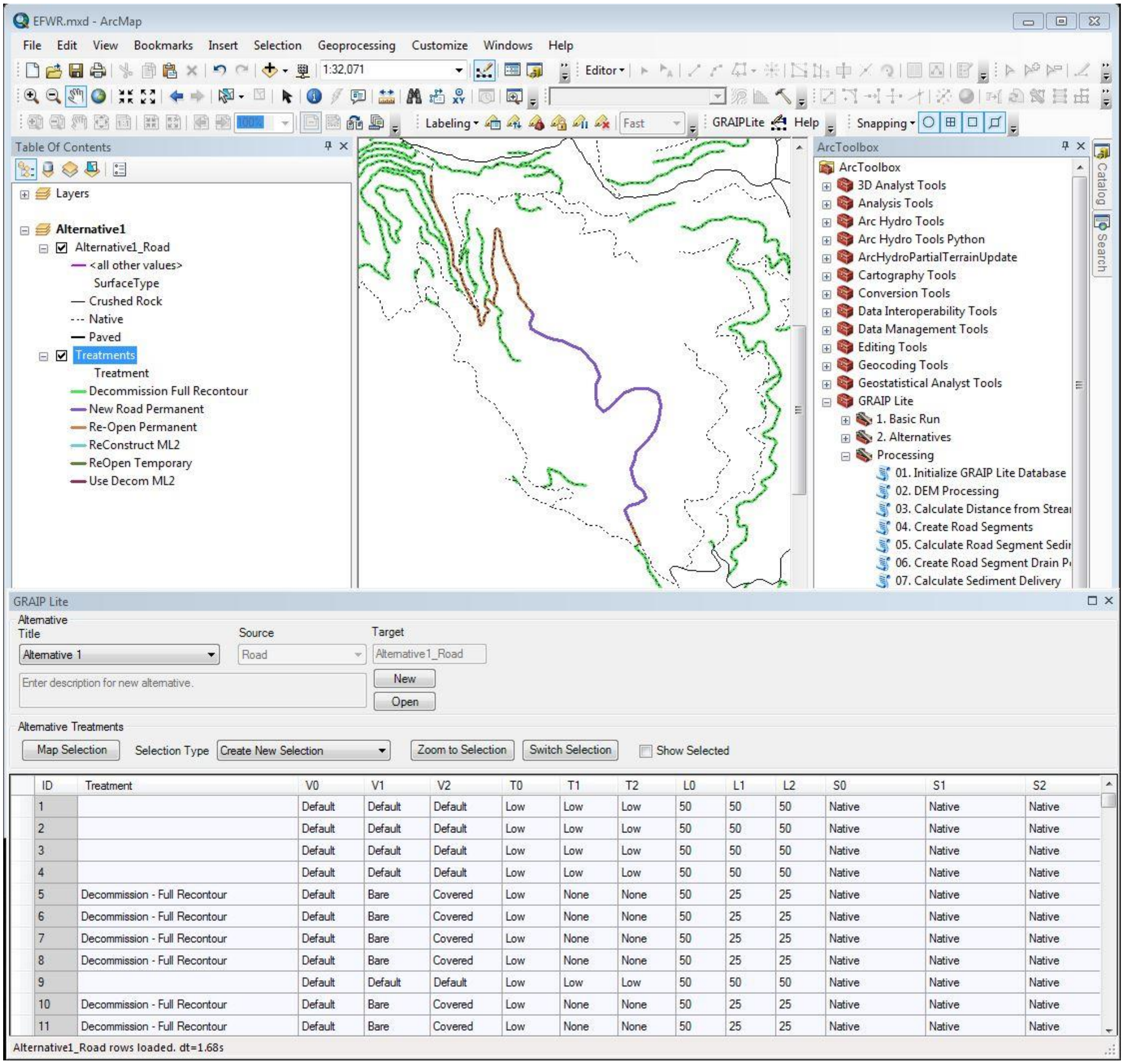


Figure 58: Map window zoomed in to show "Re-Open Permanent" and "New Road Permanent" features.

Making sure both the *Treatments* and *Alternative1_Road* layers are visible, use the *Select Features* tool to select the features marked “Re-Open Permanent” (Figure 59); the features will be selected in both layers.

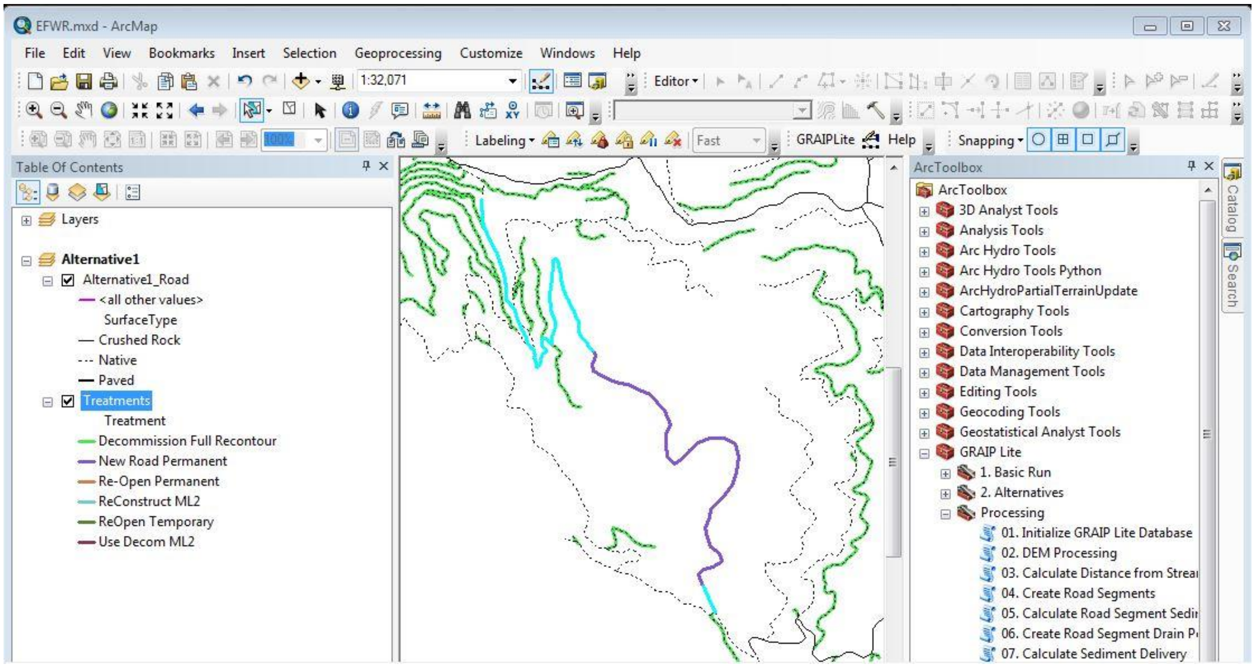


Figure 59: Select Features tool used to select the "Re-Open Permanent" features.

In the GRAIP Lite window, click on *Show Selected* so that only the eight selected features are displayed (Figure 60).

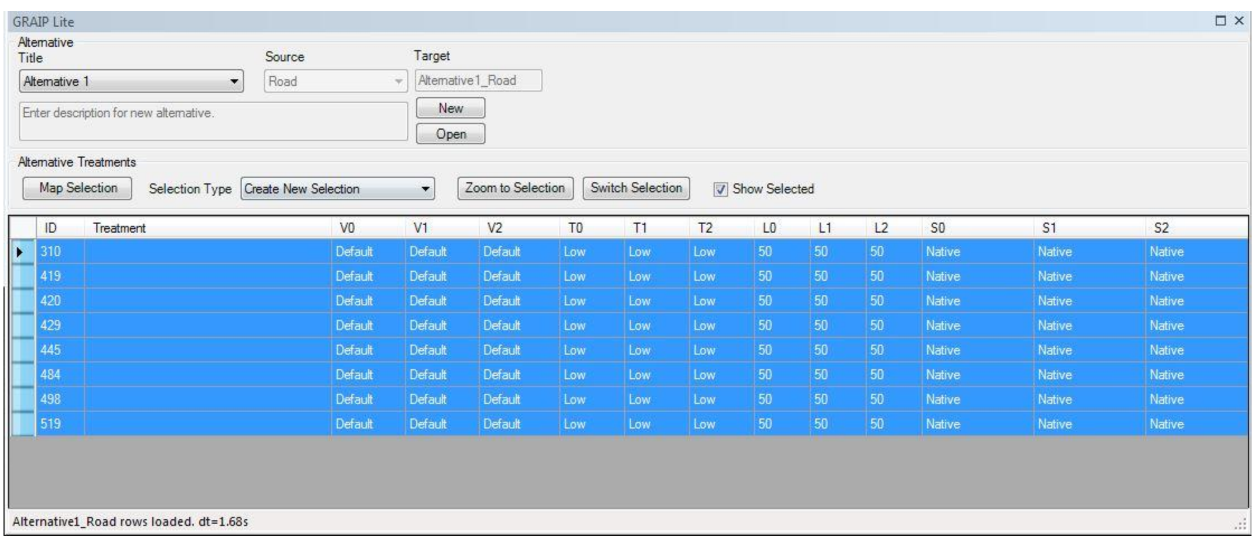


Figure 60: Showing only selected features.

Next select the treatment to be applied to these road segments (Figure 61).

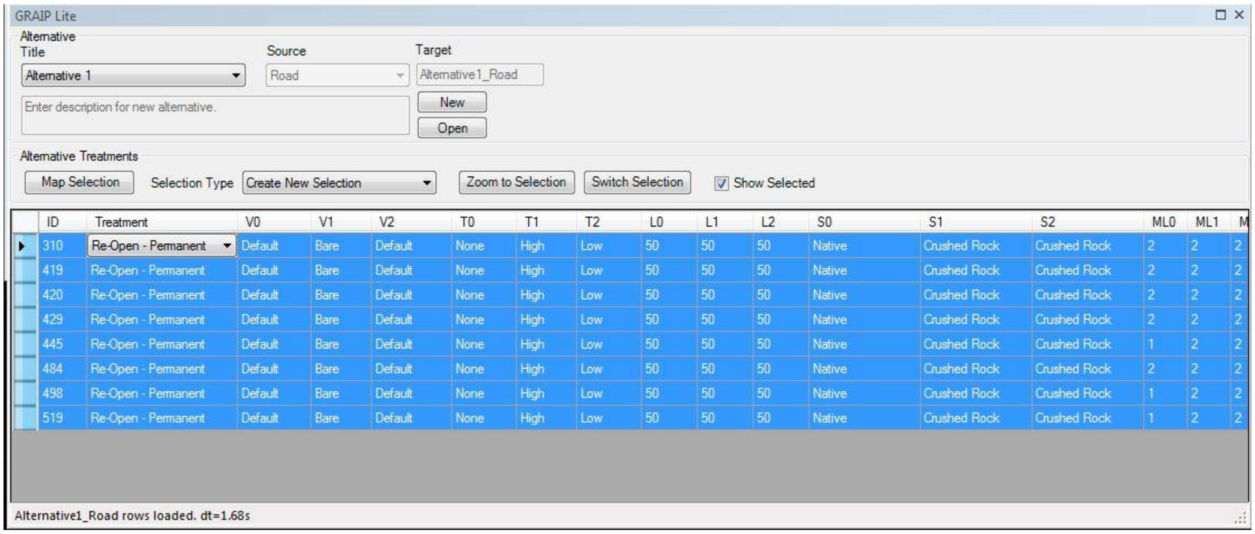


Figure 61: Treatment selected and applied.

Once the treatments are set, uncheck the box by *Show Selected* and then *Clear Selected Features*.

There is one road section listed in the *Treatments* layer that does not yet exist in the *Alternatives1_Road* layer. This is the new road with the specified treatment "New Road Permanent". Use the *Create New Road* tool from the GRAIP Lite toolbar to draw in the new road following the one shown in the *Treatments* layer (Figure 62).

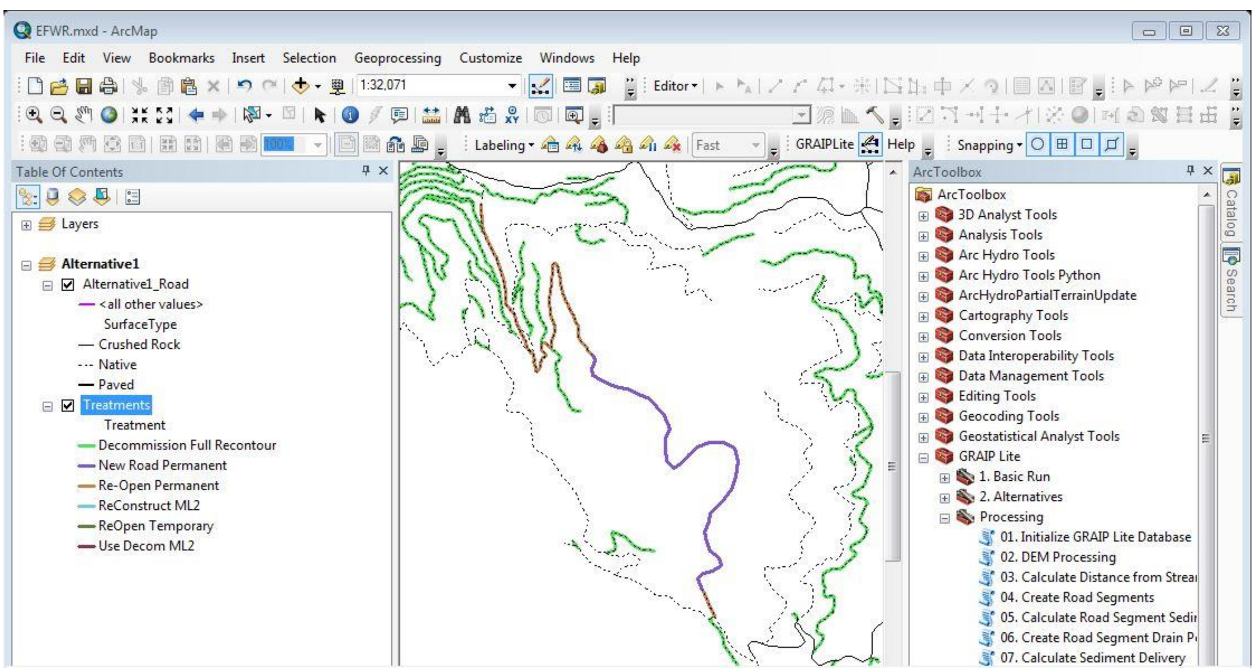


Figure 62: The GRAIP Lite Create New Road tool.

The tool appears in the map as a crosshair, and places vertices for the new road line at the center of the crosshair with each click. Start at one end and double click to end the feature when you get to the other end (Figure 63). Notice that the newly created feature is selected in the GRAIP Lite window.

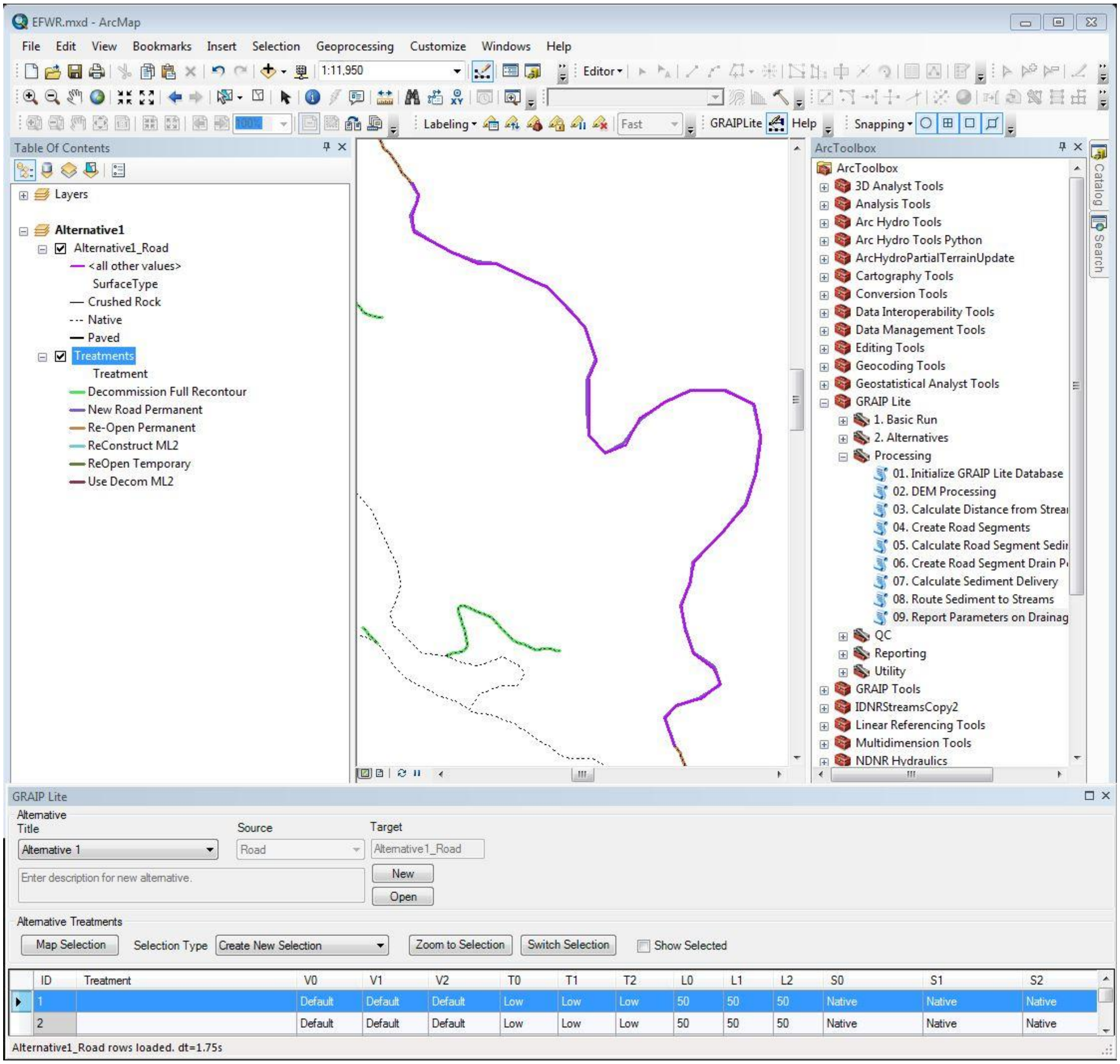


Figure 63: Draw new road following feature in Treatments layer.

Click on *Show Selected* (Figure 64). Notice that the new road has all default values including a native surface type and maintenance level 2. These are the defaults for any time the surface type and maintenance level are not defined.

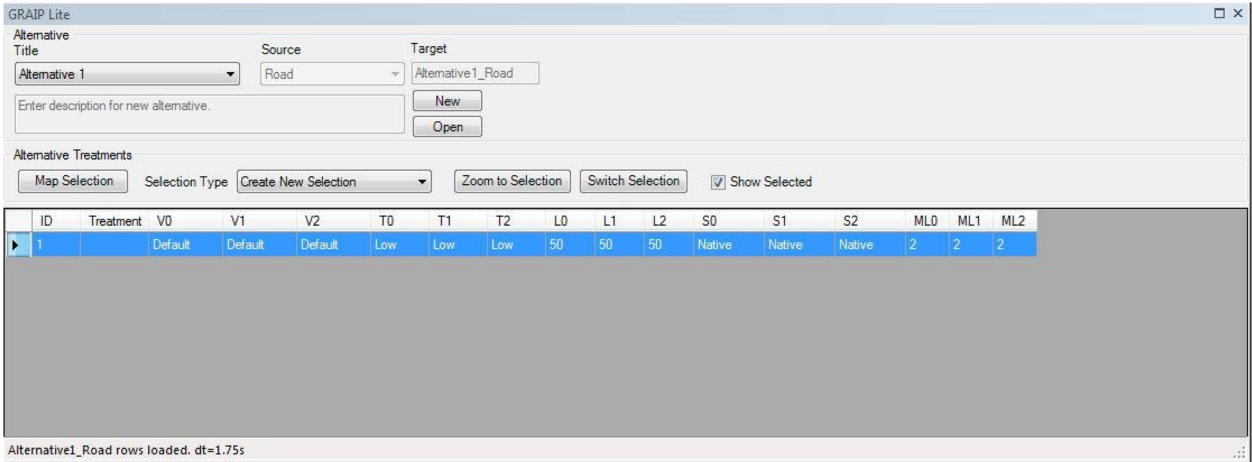


Figure 64: Show Selected.

Set the *Treatment* to "New Road – Permanent" and notice the change in values, specifically for *S0*, which is set to "Not a road" (Figure 65). This means the road will not produce sediment during the initial condition run because it does not yet exist.

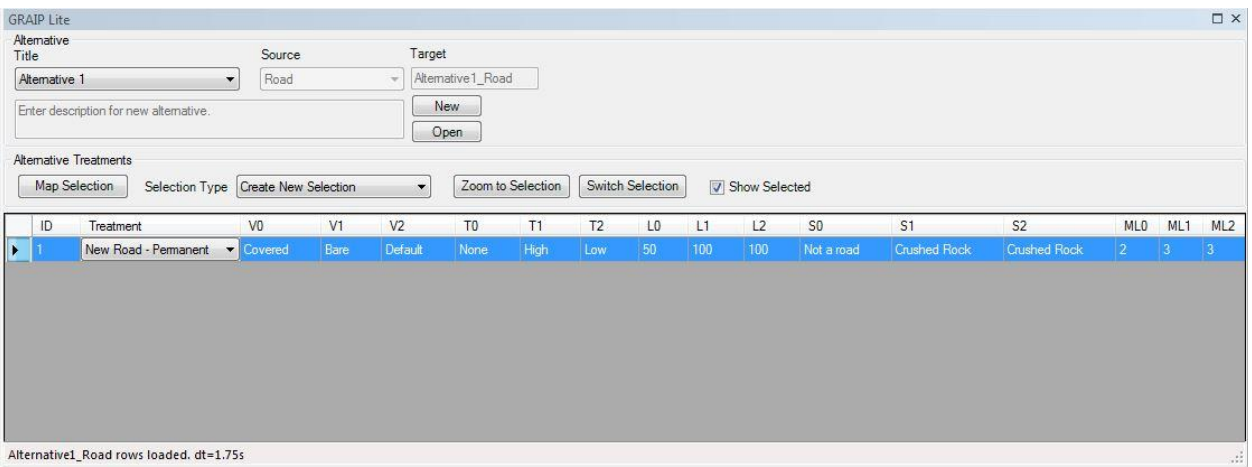


Figure 65: Assign treatment; note that S0, the surface factor for the initial condition, is set to "Not a road".

At this point, GRAIP_Lite now knows what treatments to model and where they will be applied. Save changes to the map document, close the GRAIP Lite window, and clear all selected features.

Often, more than one alternative needs to be analyzed in order to determine which alternative represents the best course of action. In such cases, the above process of creating an alternative and specifying treatments would be repeated for each alternative to be analyzed.

The next step runs the model for each time step in the alternative. Open the *01. Run Alternative* tool in the *Alternatives* toolbox (Figure 66). The *Input Road Alternative Feature Class* should be set to

Alternative1_Road; click *OK* to run the tool. This tool may take a while to run, especially with larger data sets and increasing amounts of road treated.

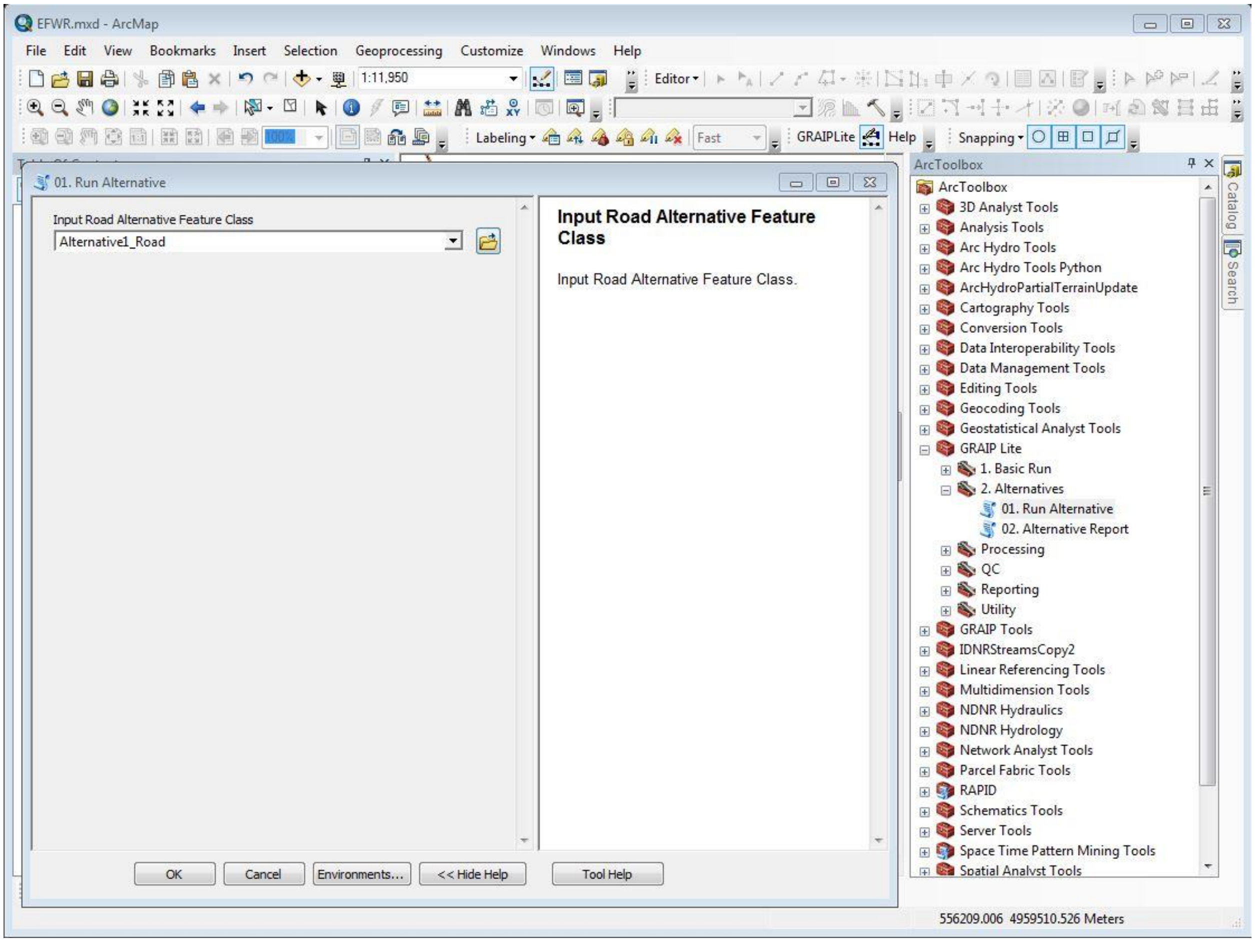


Figure 66: The Run Alternative tool.

The last tool to run is the *02. Alternative Report* tool (Figure 67), also in the *Alternatives* toolbox. This tool creates the same set of reports as the Basic Report tool, but it does so for each time step for the alternative. It also produces two maps showing the change in specific sediment at the disturbed and recovered conditions relative to the initial condition; these are helpful for highlighting where road related sediment impacts are expected to change, and in which direction and at what time frame, during the course of the alternative. Make sure the location of the *Input GRAIP Lite Database* is correct, and set the *Input Alternative Name* to *Alternative1*. Click *OK* to run the tool.

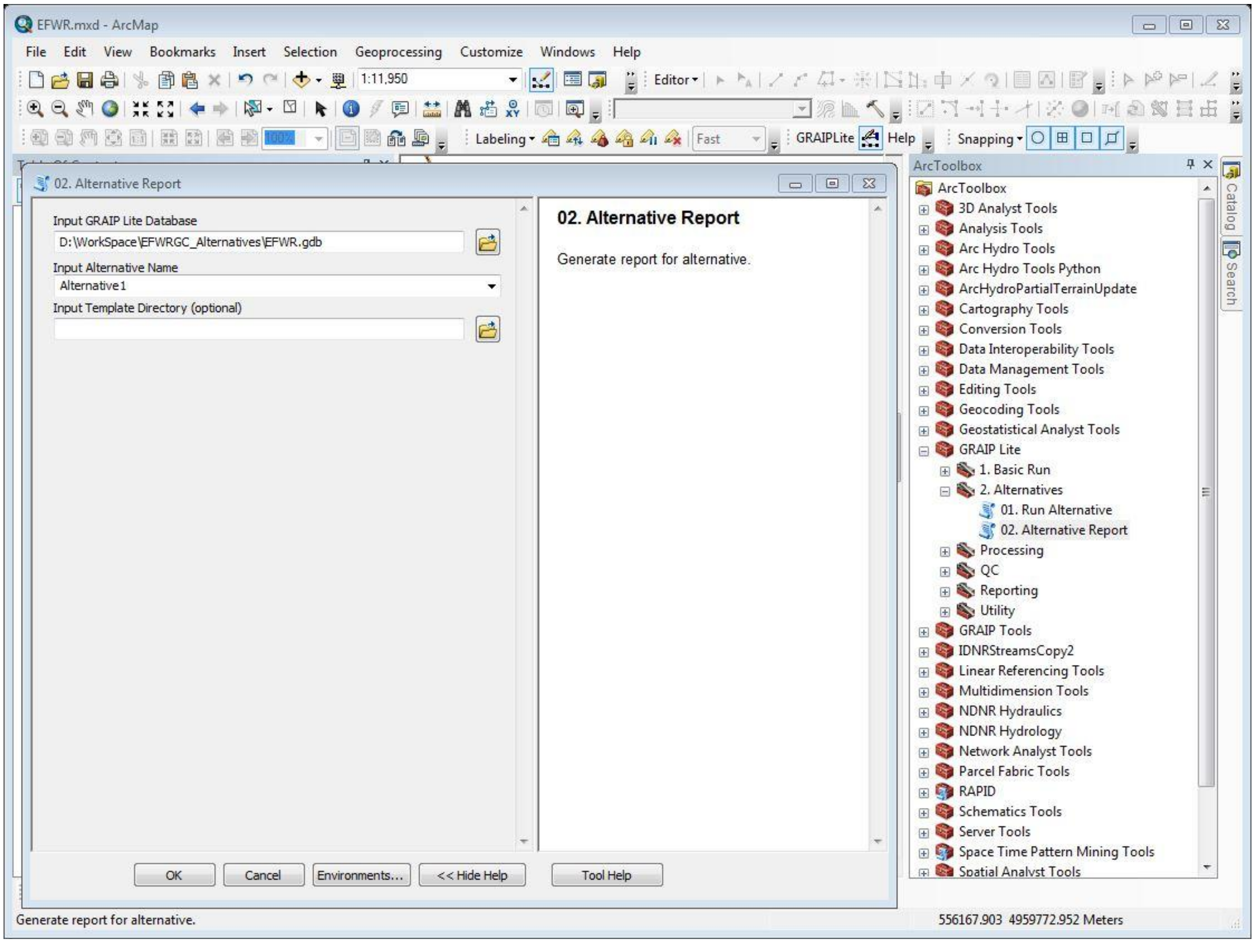


Figure 67: The Alternative Report tool.

If you are analyzing multiple alternatives, the *01. Run Alternative* and *02. Alternative Report* tools will need to be run separately for each alternative.

Post Processing

One additional tool is the Create Summary Statistics by Area tool (Figure 68) that aggregates several metrics by catchment area. This is especially useful because it calculates the specific sediment delivery to the catchment areas (Figure 69), which is effectively a measure of road-related sediment impact in each catchment. This highlights both the stream segments and the direct contributing area where the roads are having the greatest impacts on the stream network.

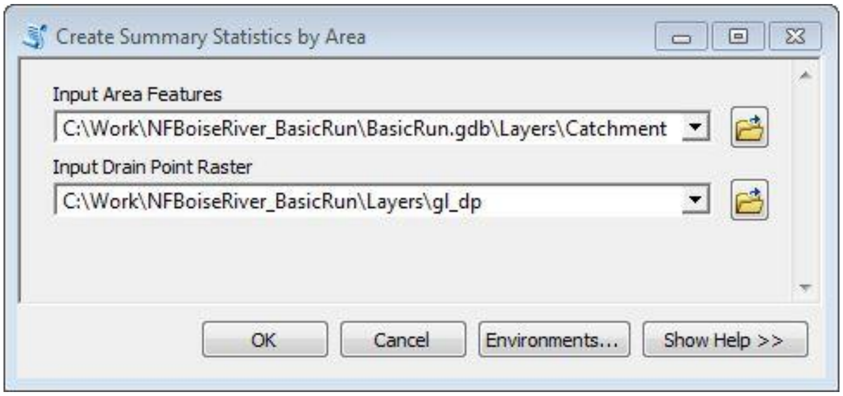


Figure 68: The Create Summary Statistics by Area tool, ready to be run on the Basic Run tutorial dataset.

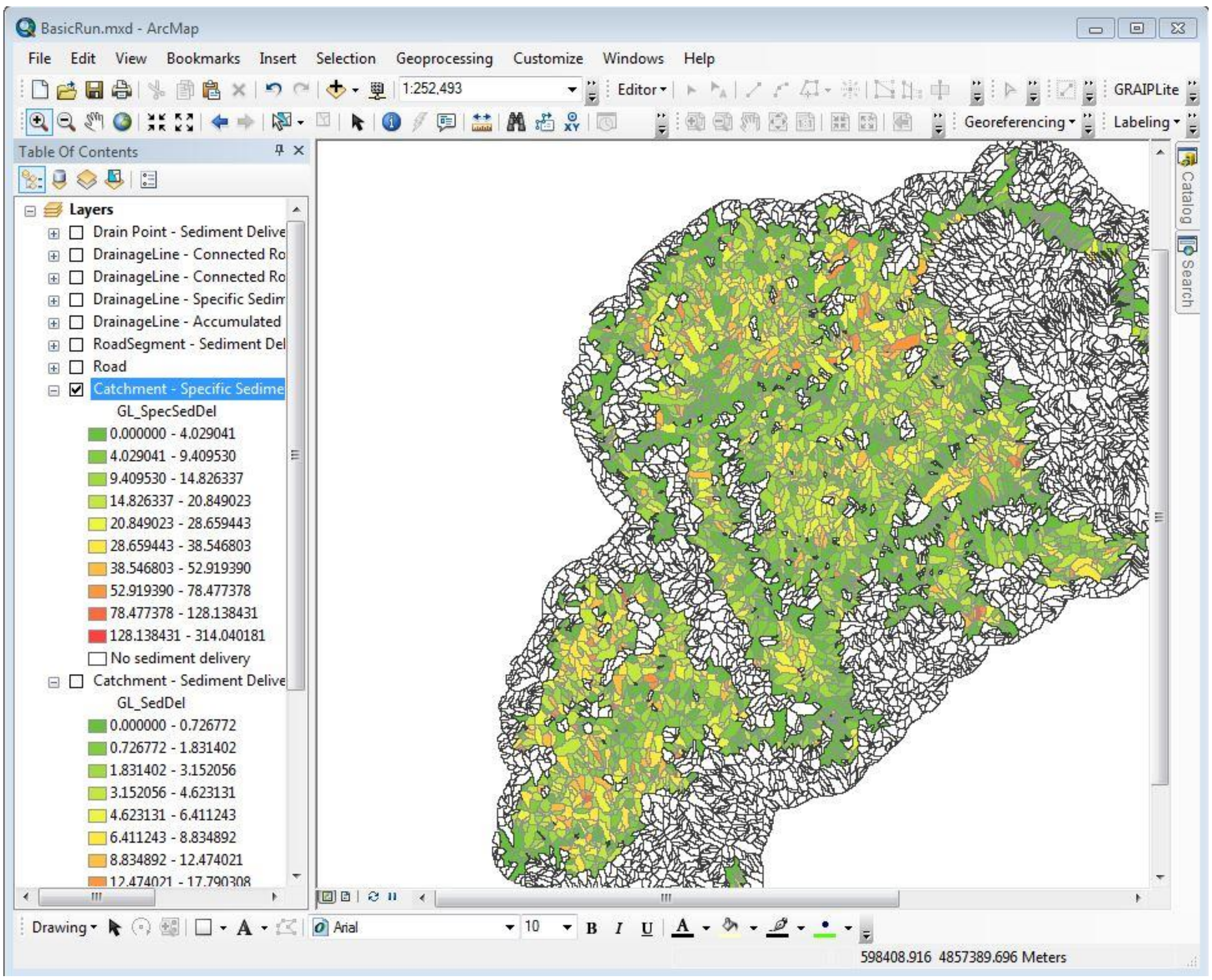


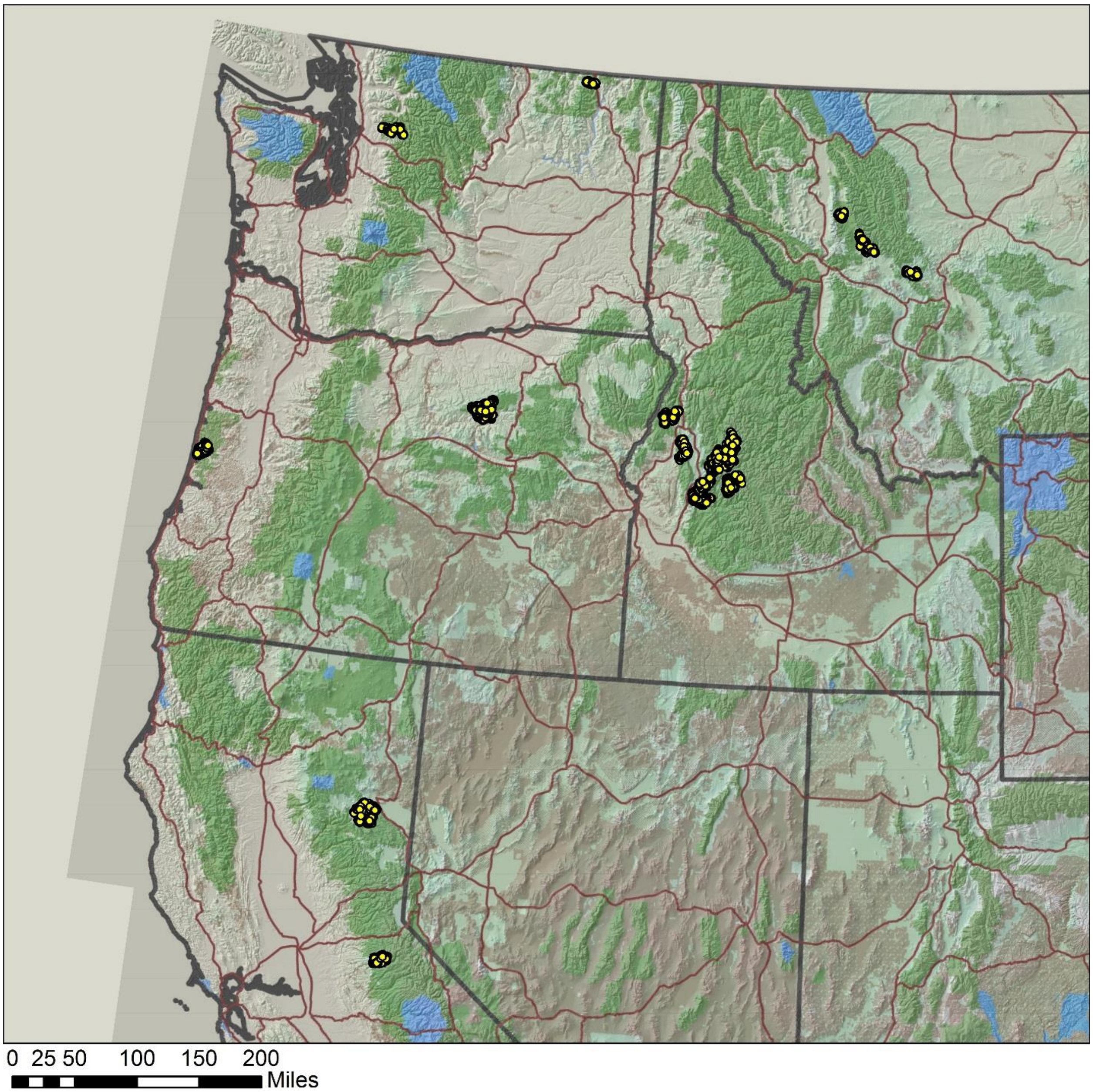
Figure 69: Specific Sediment Delivery (Mg/yr/km²) aggregated to hydrologic catchments.

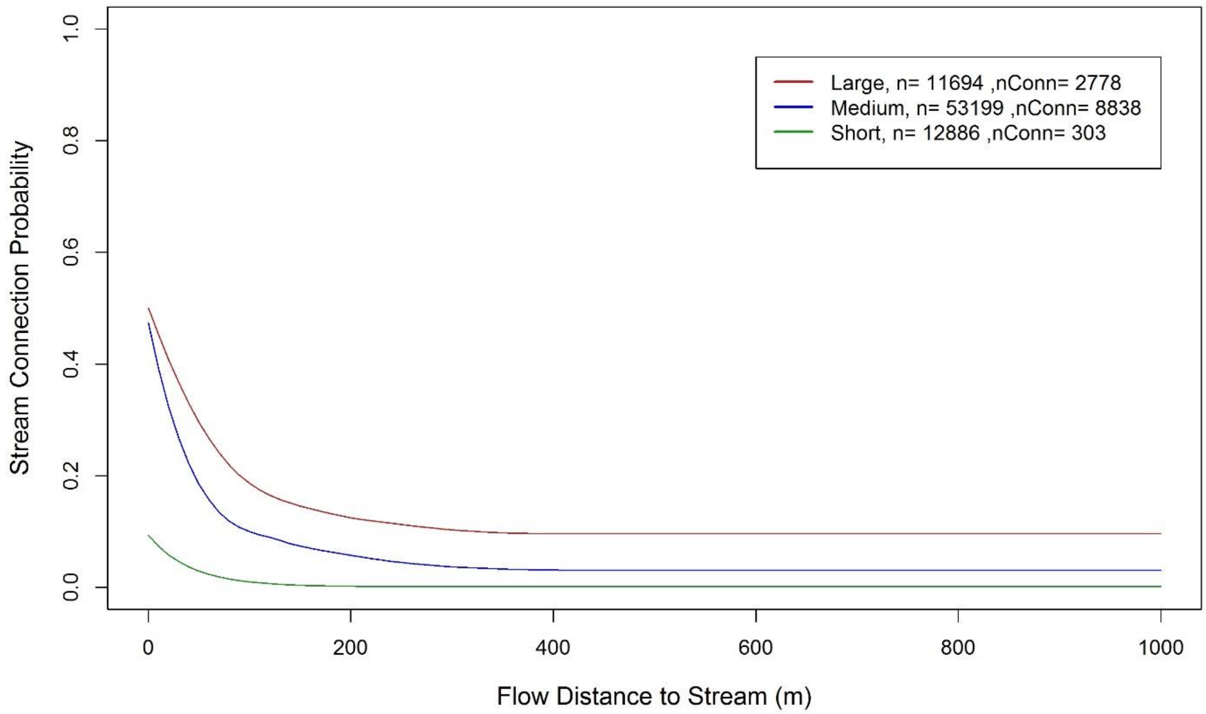
In some cases, it may be necessary to manually aggregate the data. One way to do this is to use the Intersect tool and then summarize the data based on a column in the resulting data; start by intersecting the RoadDrainPoint layer with the layer that has the features you wish to aggregate the data to. Next, summarize the table based on a unique identifier for the features you are aggregating the data. Finally, join the summary table back to the aggregate features. Summary tables can also be created using columns in the original data, for instance, road number/name/ID or jurisdiction. Most often, the data to be aggregated will be the sums of road lengths and the sediment production and delivery values.

Appendix A: Description of Existing Calibration Data Sets

Default: This calibration set consists of the other calibration sets merged into a single calibration set. It totals 77,779 observations from 5,374 km of roads and has an observed stream connection rate of 15 percent. The mean flow distance from the observed calibration points to the stream network modelled by ArcHydro for GRAIP_Lite (stream distance) was 166 m and the standard deviation was 164 m.

The baserate used with the default calibration set is 79 kg/yr/m vertical drop along the road, and comes from the data in Luce and Black, 1999. This default baserate is also the default for the more detailed, inventory-based GRAIP model.

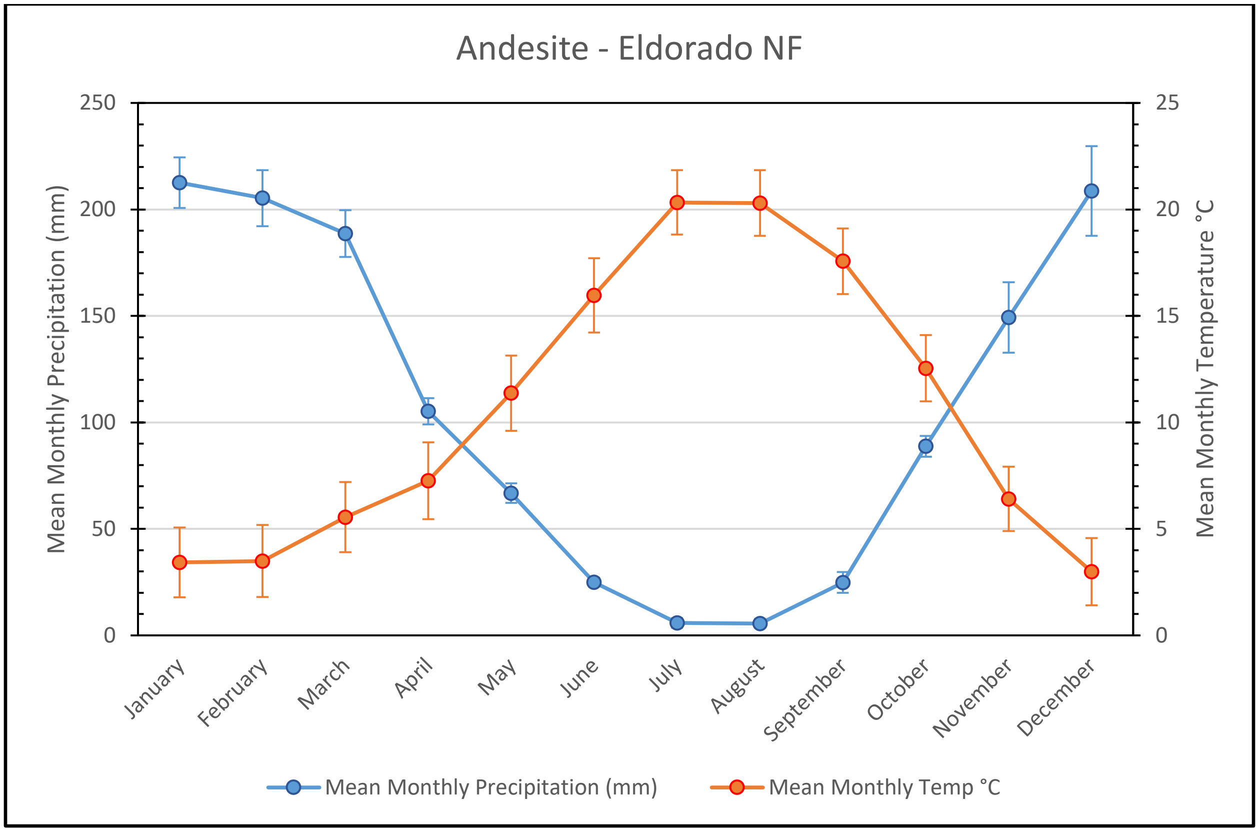


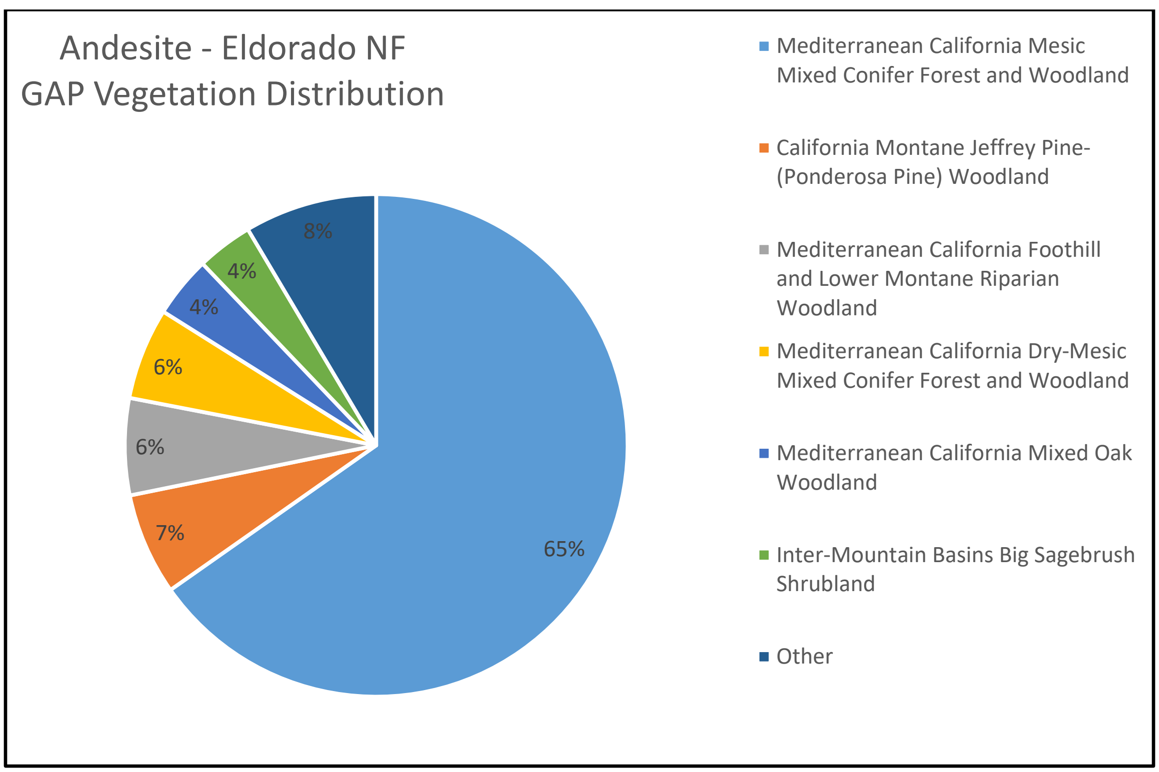


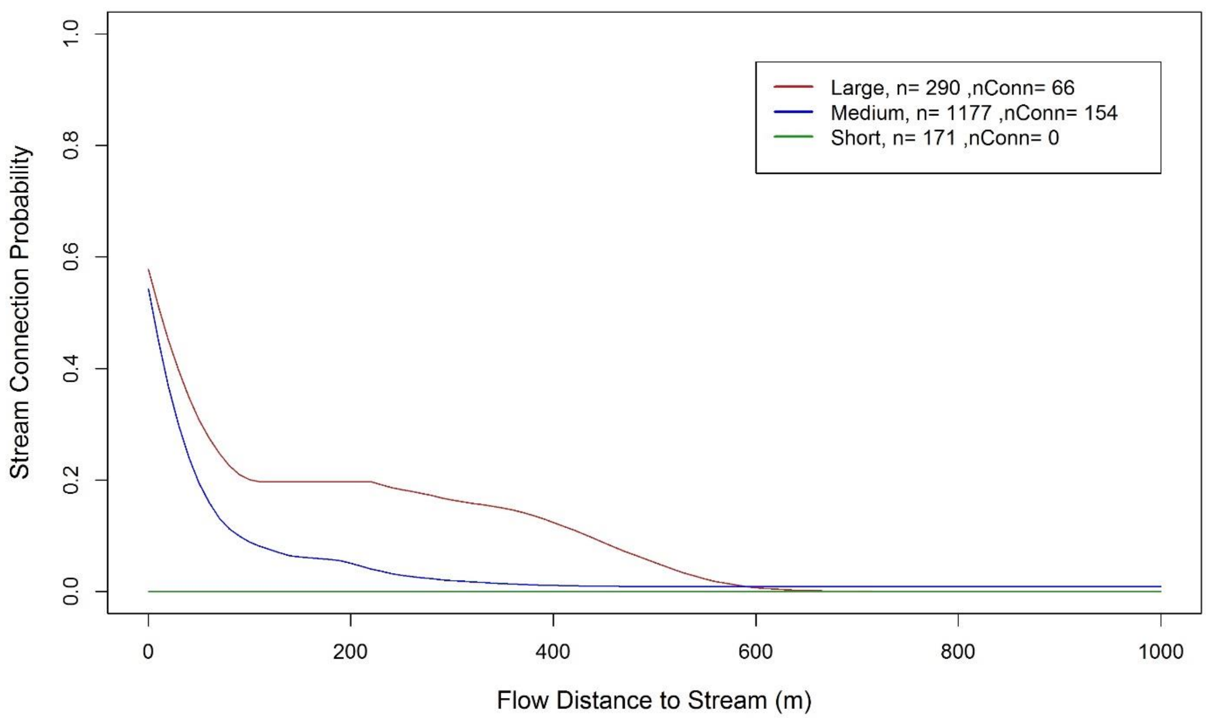
Large, n= 11694 ,nConn= 2778
Medium, n= 53199 ,nConn= 8838
Short, n= 12886 ,nConn= 303
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

Andesite – Eldorado NF: This calibration set was collected as part of a GRAIP inventory conducted as part of restoration work associated with the Power Fire on the Eldorado National Forest. It consists of 1,638 calibration points collected from 124 km of road. The observed stream connection rate was 13 percent. The mean stream distance was 210 m with a standard deviation of 162 m. Elevations range from 1,117 m to 2,431 m, with a mean of 1,718 m and standard deviation of 273 m. Mean annual precipitation is 1,287 mm with a standard deviation across the calibration set of 83 mm.

The baserate used with this calibration set is 53 kg/yr/m vertical drop along the road, and comes from three sediment monitoring plots utilizing a main settling tank, tipping bucket flow gage, and a flow splitter leading to a fines collection tank. These plots were installed in 2015.

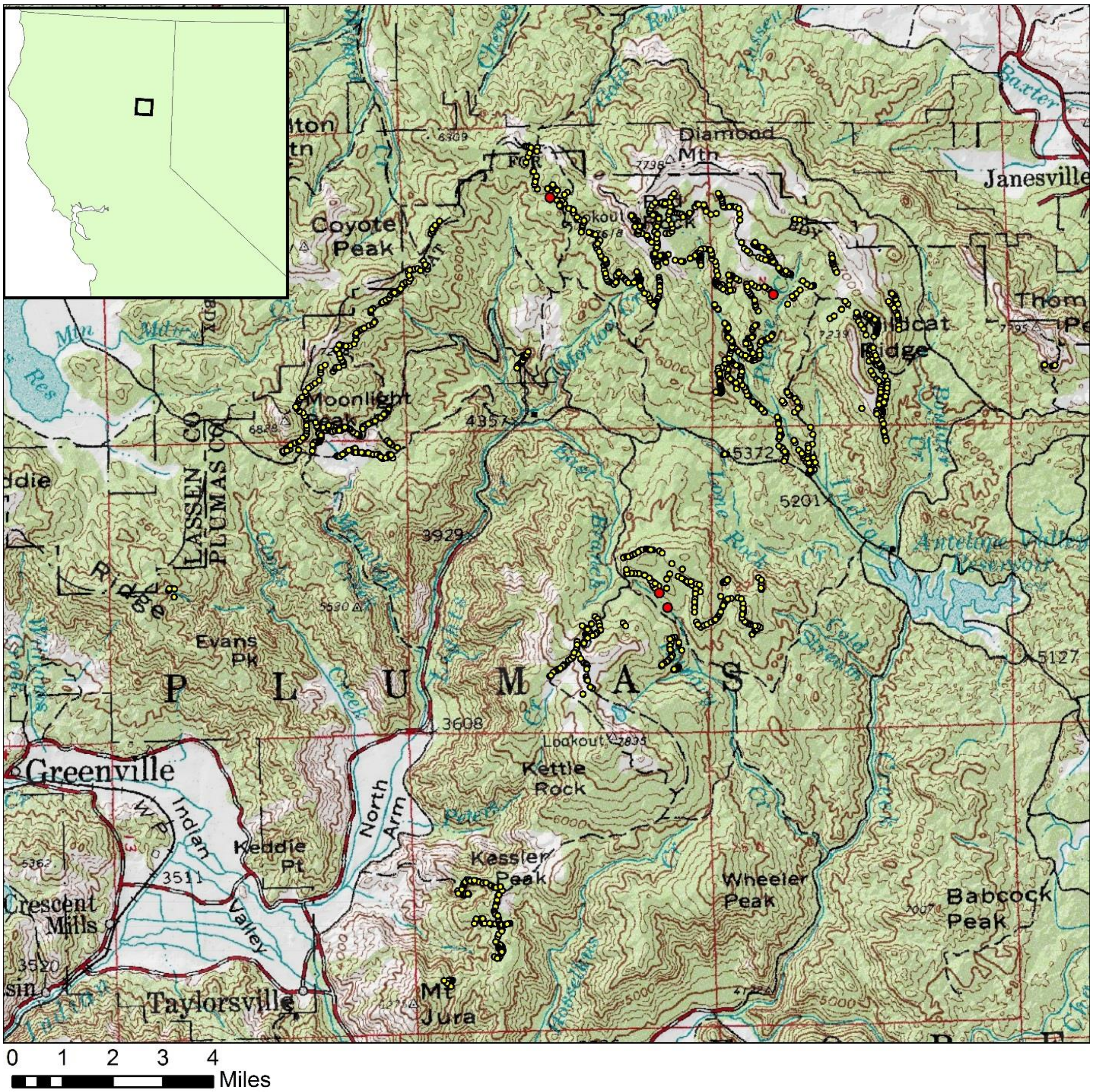

Andesite - Eldorado NF
Mean Monthly Precipitation (mm)
Mean Monthly Temperature °C
0
50
100
150
200
250
0
5
10
15
20
25
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C

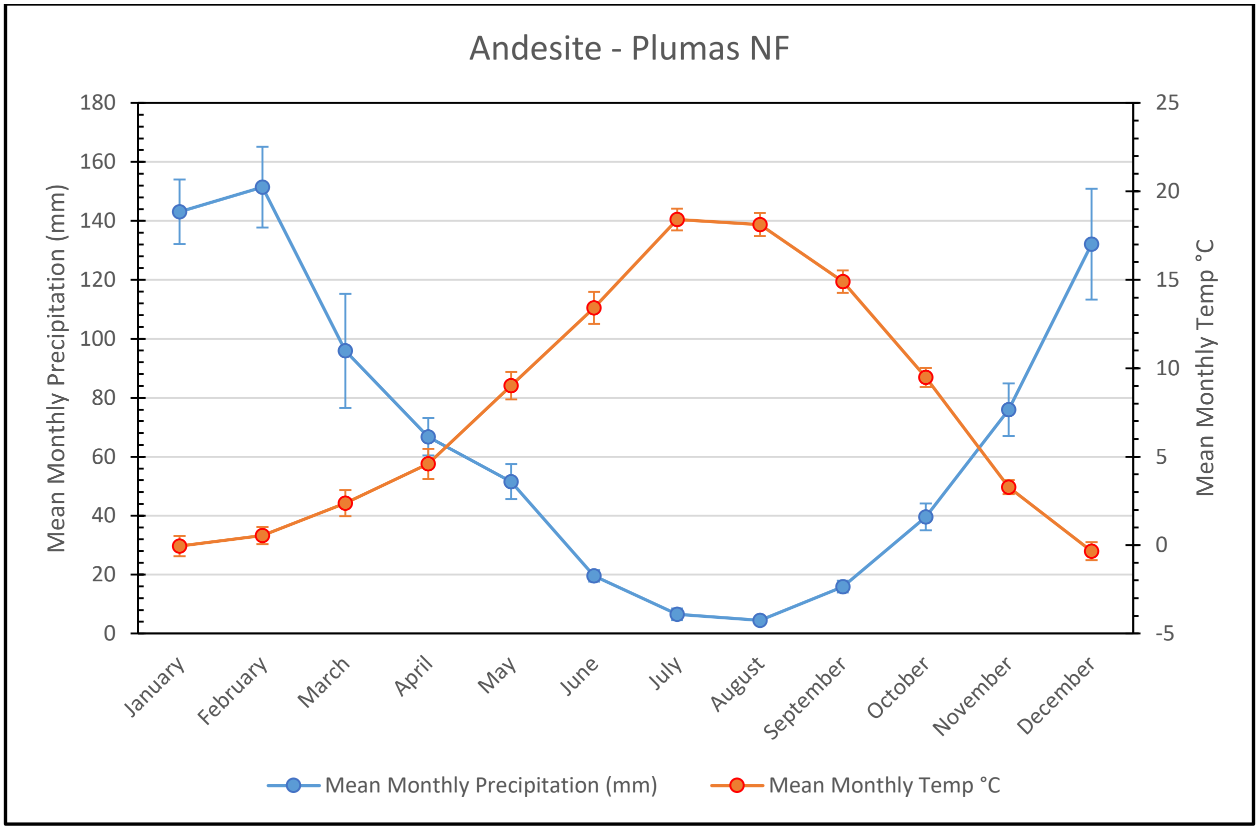

Andesite - Eldorado NF
GAP Vegetation Distribution
65%
7%
6%
6%
4%
4%
8%
Mediterranean California Mesic Mixed Conifer Forest and Woodland
California Montane Jeffrey Pine-(Ponderosa Pine) Woodland
Mediterranean California Foothill and Lower Montane Riparian Woodland
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
Mediterranean California Mixed Oak Woodland
Inter-Mountain Basins Big Sagebrush Shrubland
Other

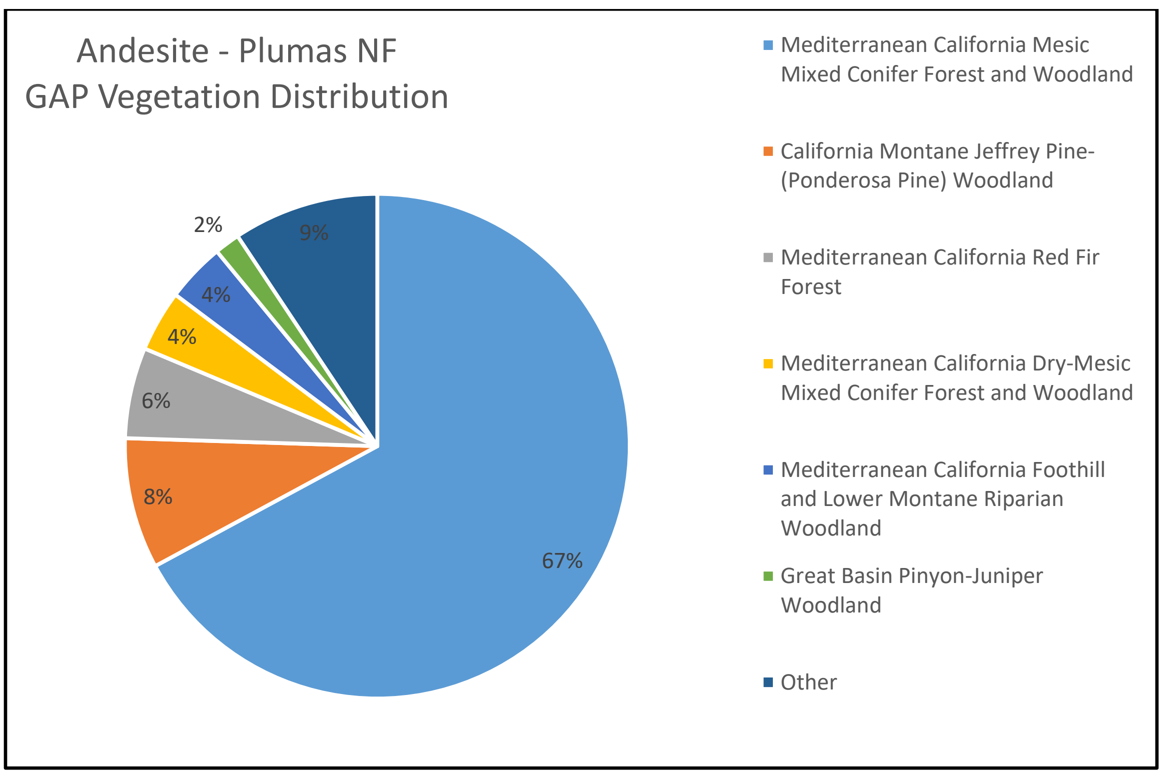

Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
Large, n= 290 ,nConn= 66
Medium, n= 1177 ,nConn= 154
Short, n= 171 ,nConn= 0
0
200
400
600
800
1000
Flow Distance to Stream (m)

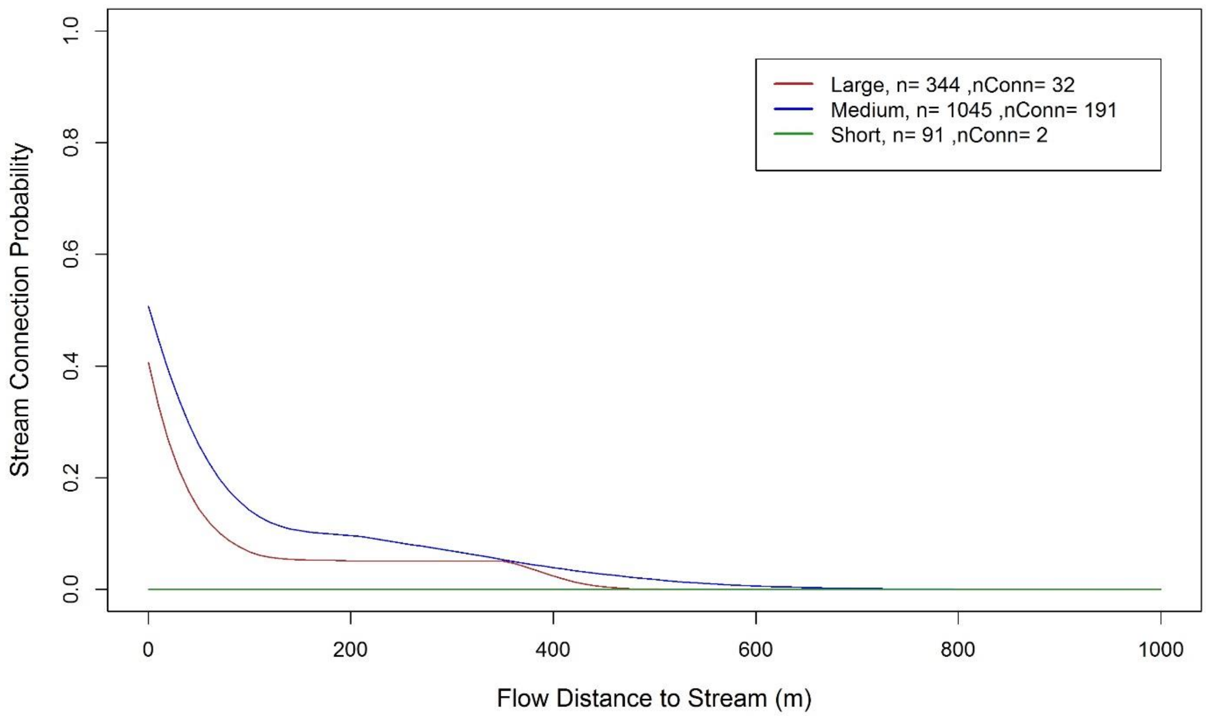
Andesite – Plumas NF: This calibration set was collected as part of a GRAIP inventory conducted as part of restoration work associated with the Moonlight Fire on the Plumas National Forest. It consists of 1,480 calibration points collected from 111 km of road. The observed stream connection rate was 15 percent. The mean stream distance was 189 m with a standard deviation of 158 m. Elevations range from 1,483 m to 2,182 m, with a mean of 1,906 m and standard deviation of 164 m. Mean annual precipitation is 803 mm with a standard deviation across the calibration set of 56 mm.

The baserate used with this calibration set is 77.6 kg/yr/m vertical drop along the road, and comes from four sediment monitoring plots utilizing a main settling tank, a flow splitter, and a second tank to collect fines. These plots were installed in 2014.



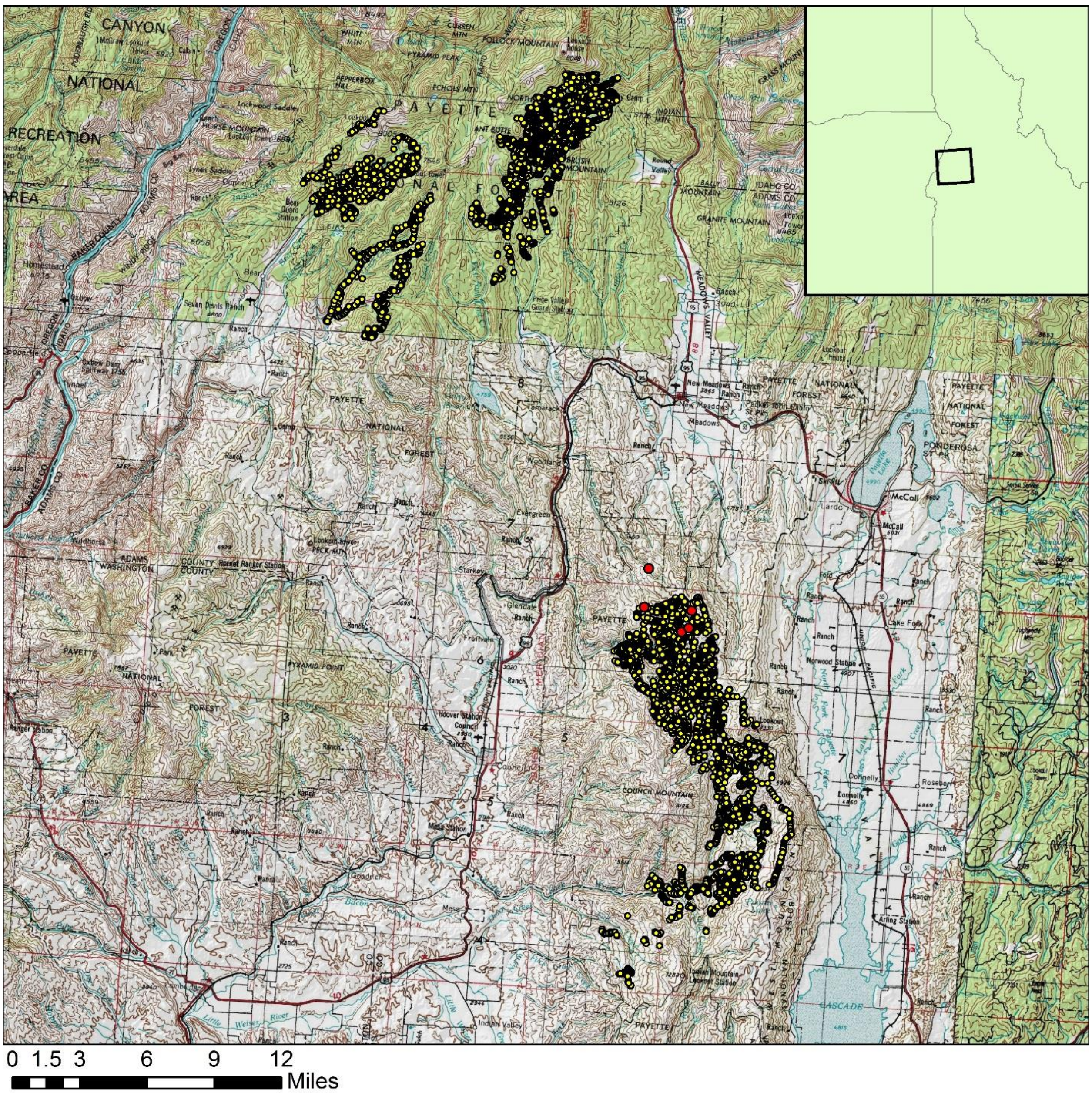

Andesite - Plumas NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
0
20
40
60
80
100
120
140
160
180
-5
0
5
10
15
20
25
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C

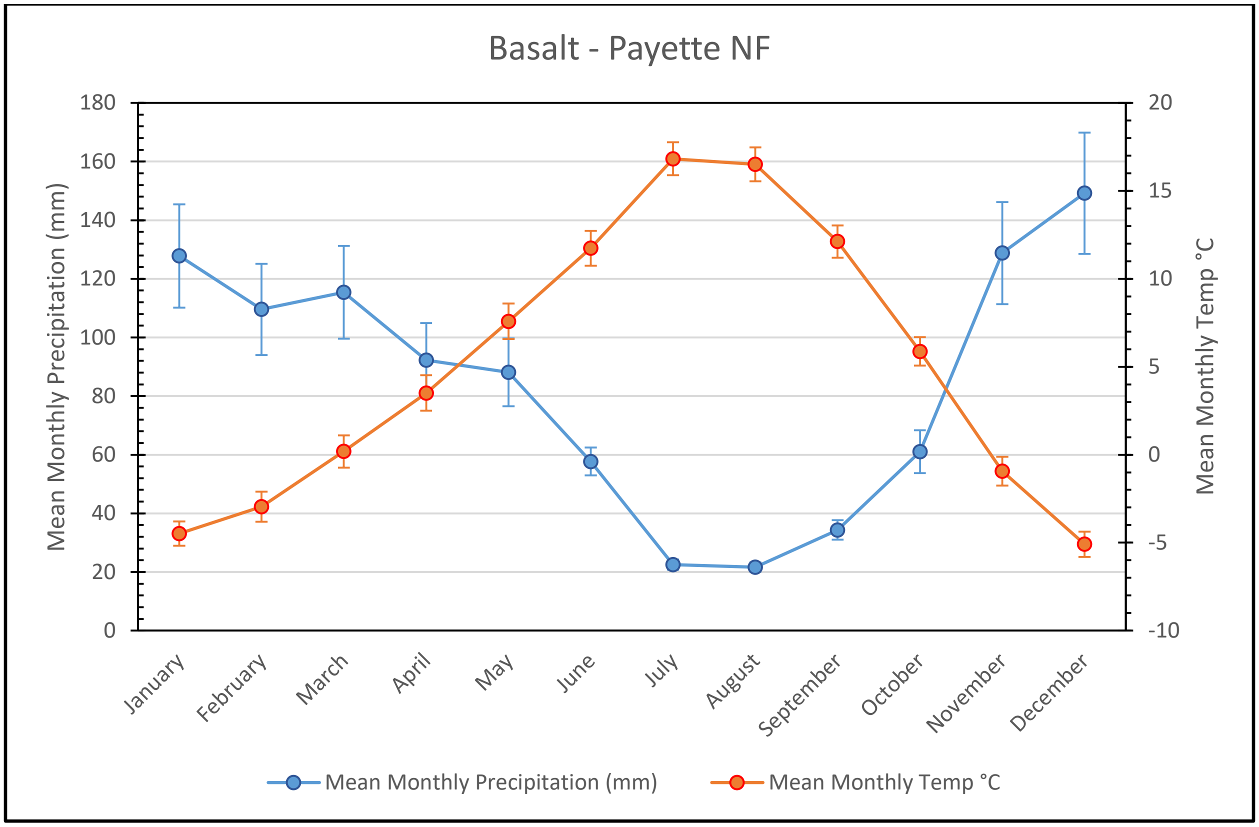

Andesite - Plumas NF
GAP Vegetation Distribution
67%
8%
6%
4%
4%
2%
9%
Mediterranean California Mesic Mixed Conifer Forest and Woodland
California Montane Jeffrey Pine-(Ponderosa Pine) Woodland
Mediterranean California Red Fir Forest
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
Mediterranean California Foothill and Lower Montane Riparian Woodland
Great Basin Pinyon-Juniper Woodland
Other

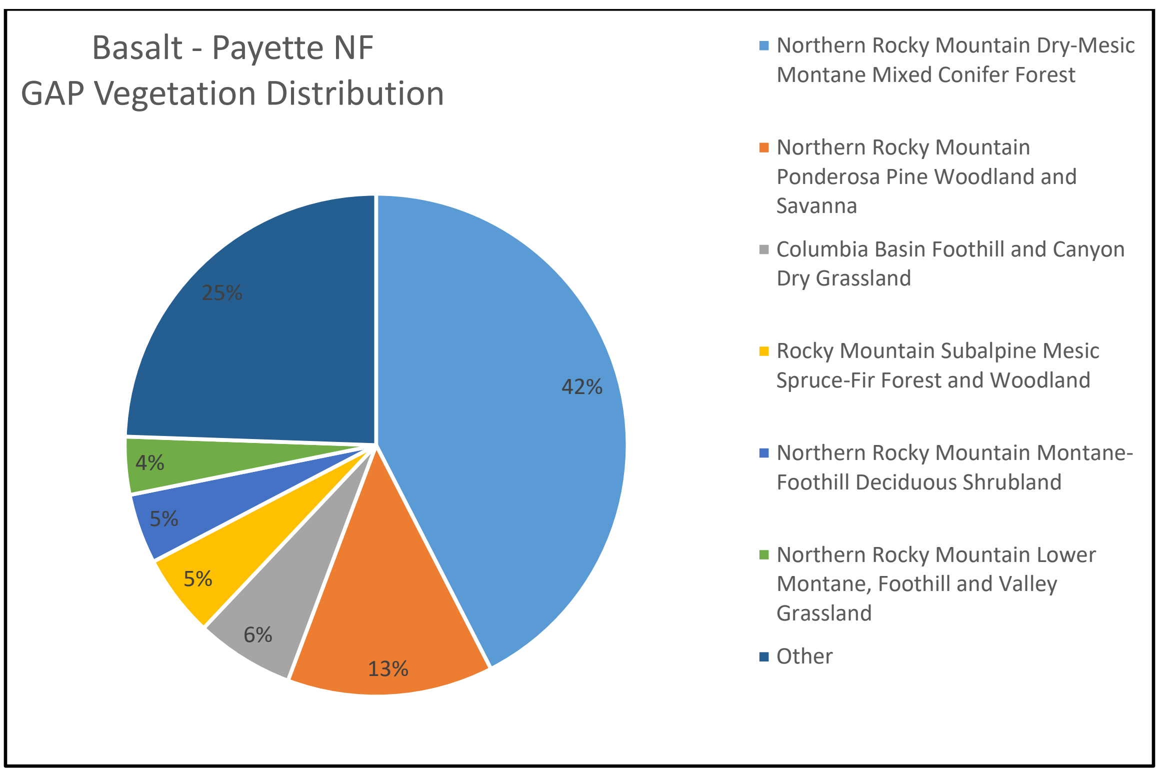

Large, n= 344 ,nConn= 32
Medium, n= 1045 ,nConn= 191
Short, n= 91 ,nConn= 2
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

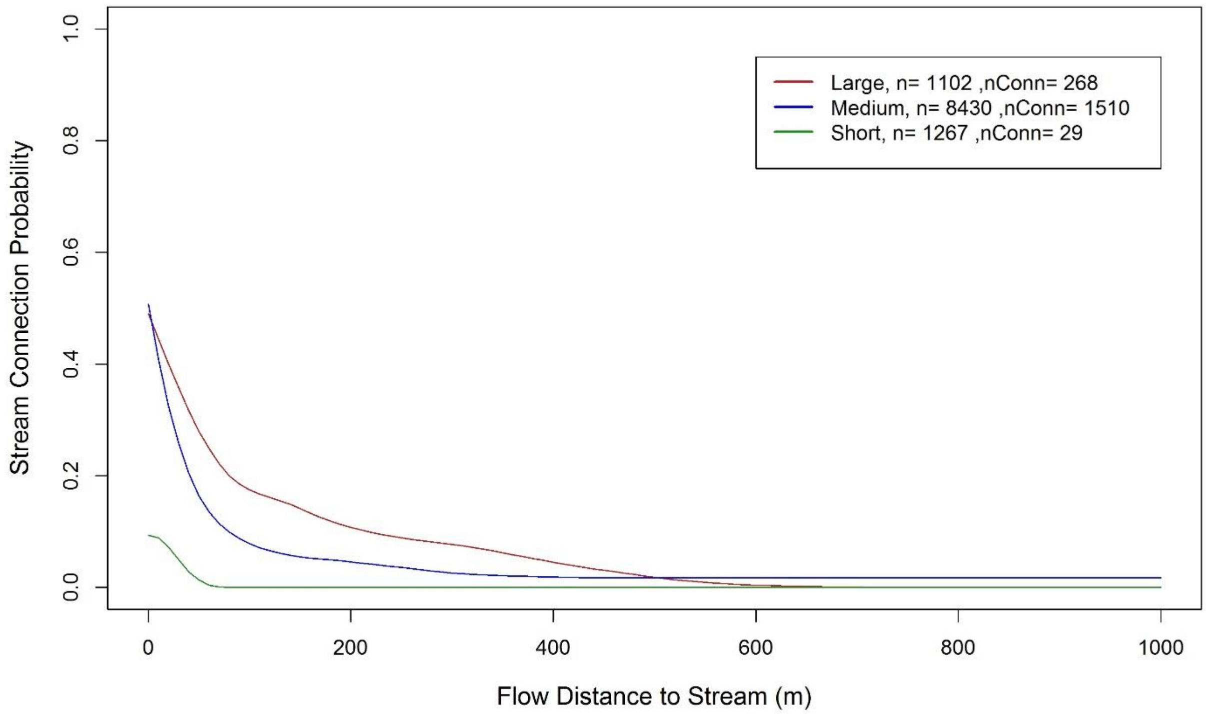
Basalt – Payette NF: This calibration set consists of GRAIP inventories collected between 2013 and 2015 as part of watershed assessment and project planning operations on the Payette National Forest. It consists of 10,799 calibration points collected from 806 km of road. The observed stream connection rate was 17 percent. The mean stream distance was 135 m with a standard deviation of 139 m. Elevations range from 1,279 m to 2,295 m, with a mean of 1,722 m and standard deviation of 158 m. Mean annual precipitation in 1,009 mm with a standard deviation across the calibration set of 118 mm.

The base rate is 27.2 kg/yr/m and was derived from 5 sediment plots measured twice a year starting in 2013. These five sediment plots all include tipping buckets and splitters feeding into fine sediment recovery tanks.



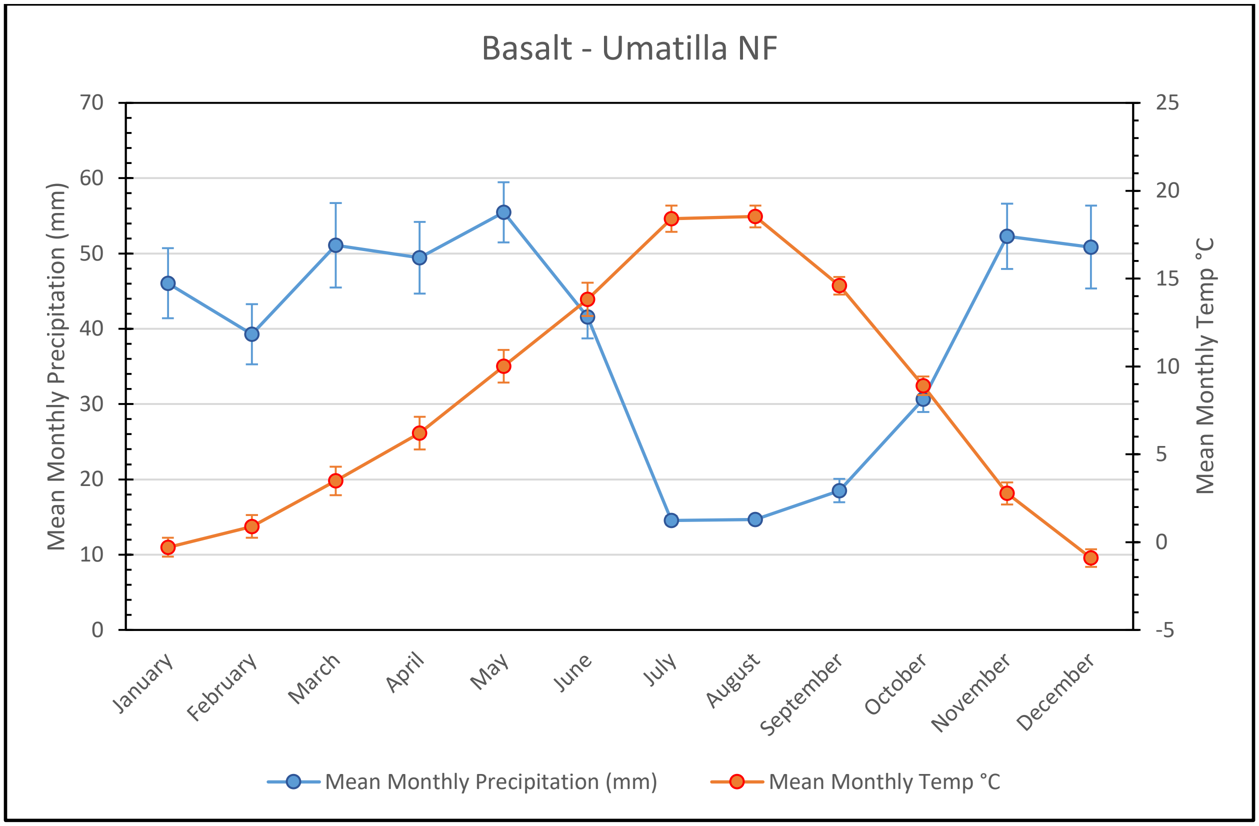

Basalt - Payette NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
180
160
140
120
100
80
60
40
20
0
20
15
10
5
0
-5
-10
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C


Basalt - Payette NF
GAP Vegetation Distribution
42%
13%
6%
5%
5%
4%
25%
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
Columbia Basin Foothill and Canyon Dry Grassland
Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
Northern Rocky Mountain Montane-Foothill Deciduous Shrubland
Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland
Other

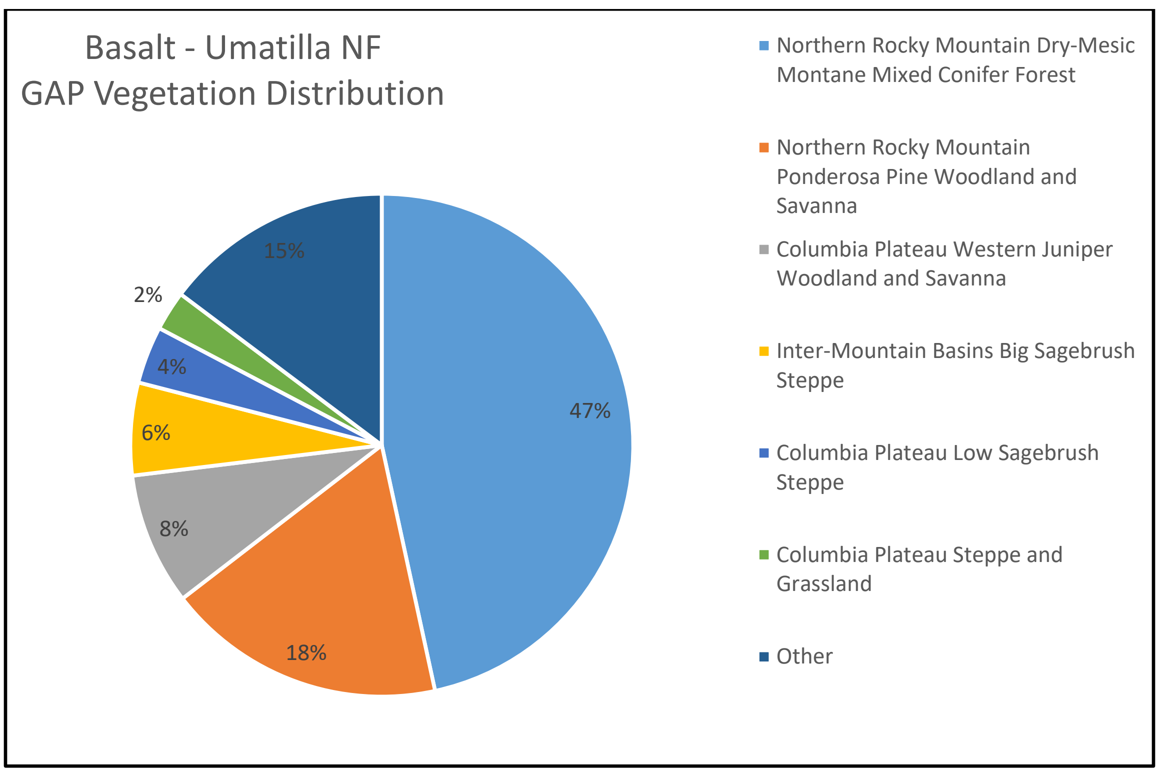

Large, n= 1102 ,nConn= 268
Medium, n= 8430 ,nConn= 1510
Short, n= 1267 ,nConn= 29
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

Basalt – Umatilla NF: This calibration set consists of a GRAIP inventory collected in support of TMDL analysis in the Wall Creek watershed on the Umatilla National Forest. It consists of 6,473 calibration points collected from 725 km of road. The observed stream connection rate was 26 percent. The mean stream distance was 104 m with a standard deviation of 128 m. Elevations range from 684 m to 1,530 m, with a mean of 1,178 m and standard deviation of 142 m. Mean annual precipitation in 464 mm with a standard deviation across the calibration set of 38 mm.

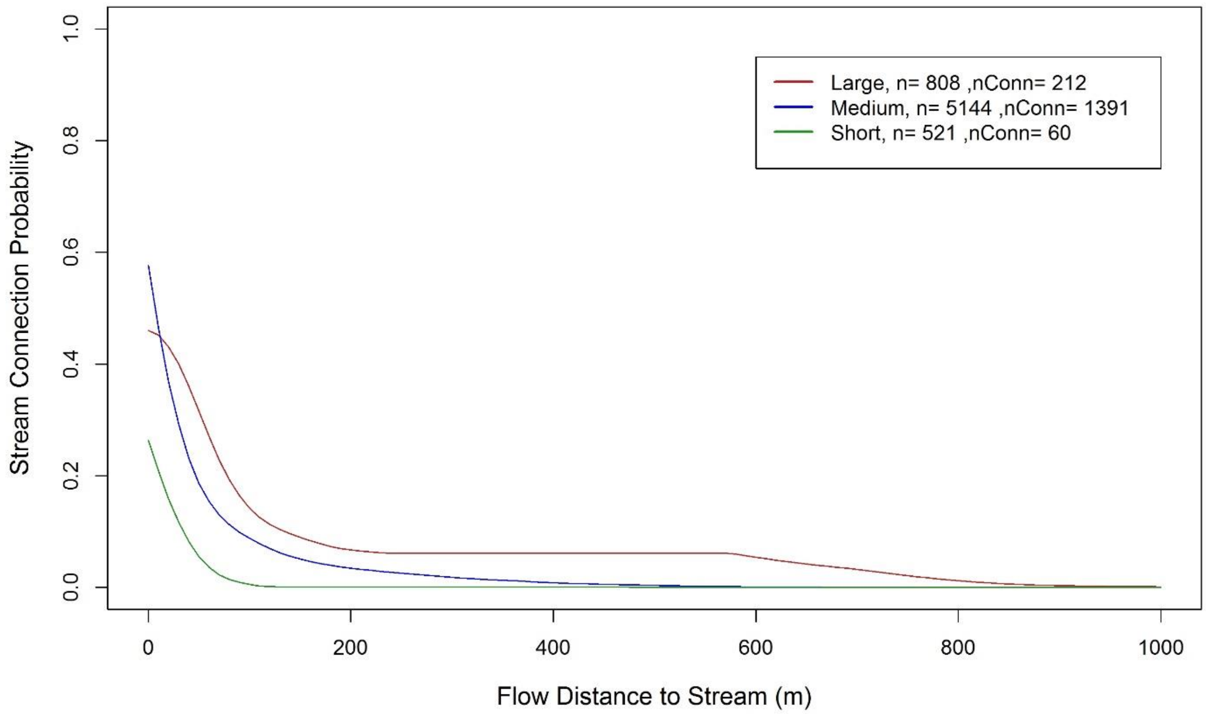
The base rate is 1.5 kg/yr/m and was assumed for the Wall Creek watershed inventory based on three years of data from nine native and aggregate surfaced roads near Klamath Falls, Oregon. For more information, see the Wall Creek Watershed GRAIP Roads Assessment.



Basalt - Umatilla NF
70
60
50
40
30
20
10
0
Mean Monthly Precipitation (mm)
25
20
15
10
5
0
-5
Mean Monthly Temp °C
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C



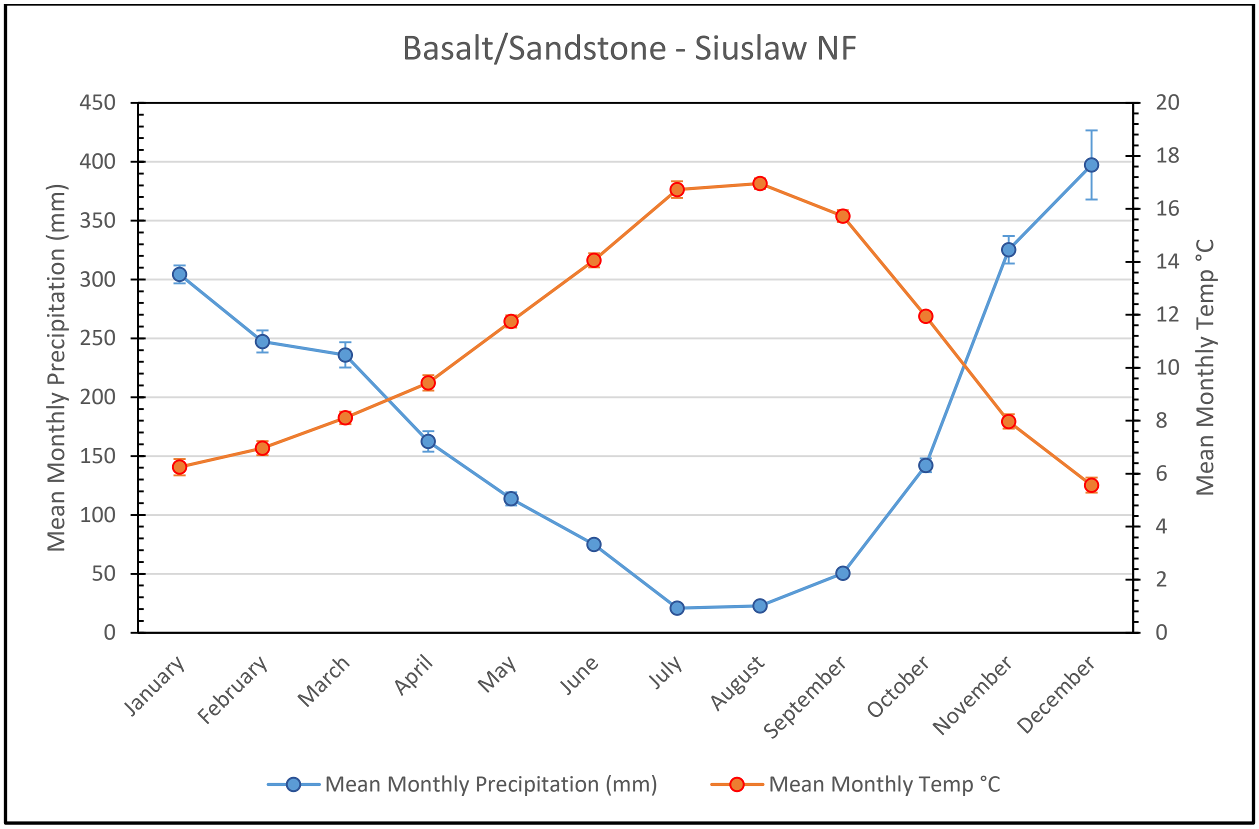
Basalt - Umatilla NF
GAP Vegetation Distribution
47%
18%
8%
6%
4%
2%
15%
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
Columbia Plateau Western Juniper Woodland and Savanna
Inter-Mountain Basins Big Sagebrush Steppe
Columbia Plateau Low Sagebrush Steppe
Columbia Plateau Steppe and Grassland
Other



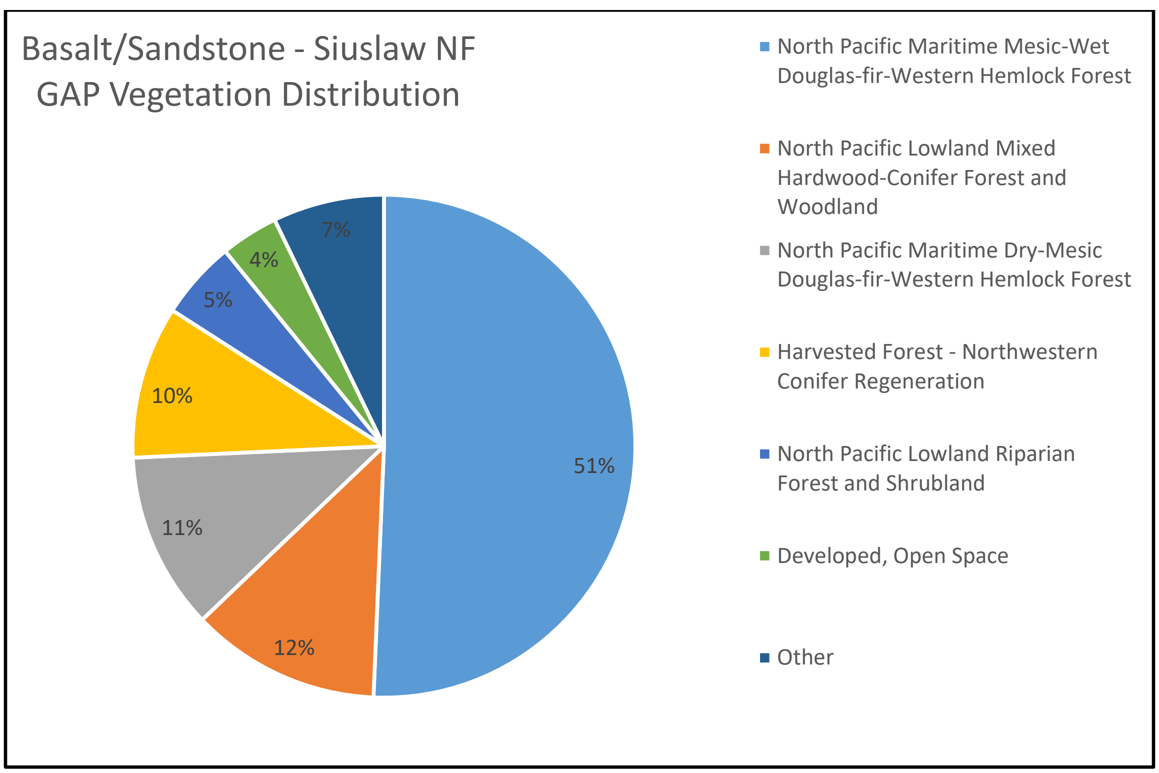
Large, n= 808 ,nConn= 212
Medium, n= 5144 ,nConn= 1391
Short, n= 521 ,nConn= 60
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

Basalt/Sandstone – Siuslaw NF: This calibration set consists of a GRAIP inventory collected during 2010 and 2011 in the North Fork Siuslaw River watershed on the Siuslaw National Forest. It consists of 5,273 calibration points collected from 261 km of road. The observed stream connection rate was 4 percent. The mean stream distance was 271 m with a standard deviation of 124 m. Elevations range from 41 m to 583 m, with a mean of 200 m and standard deviation of 74 m. Mean annual precipitation in 2,096 mm with a standard deviation across the calibration set of 79 mm.

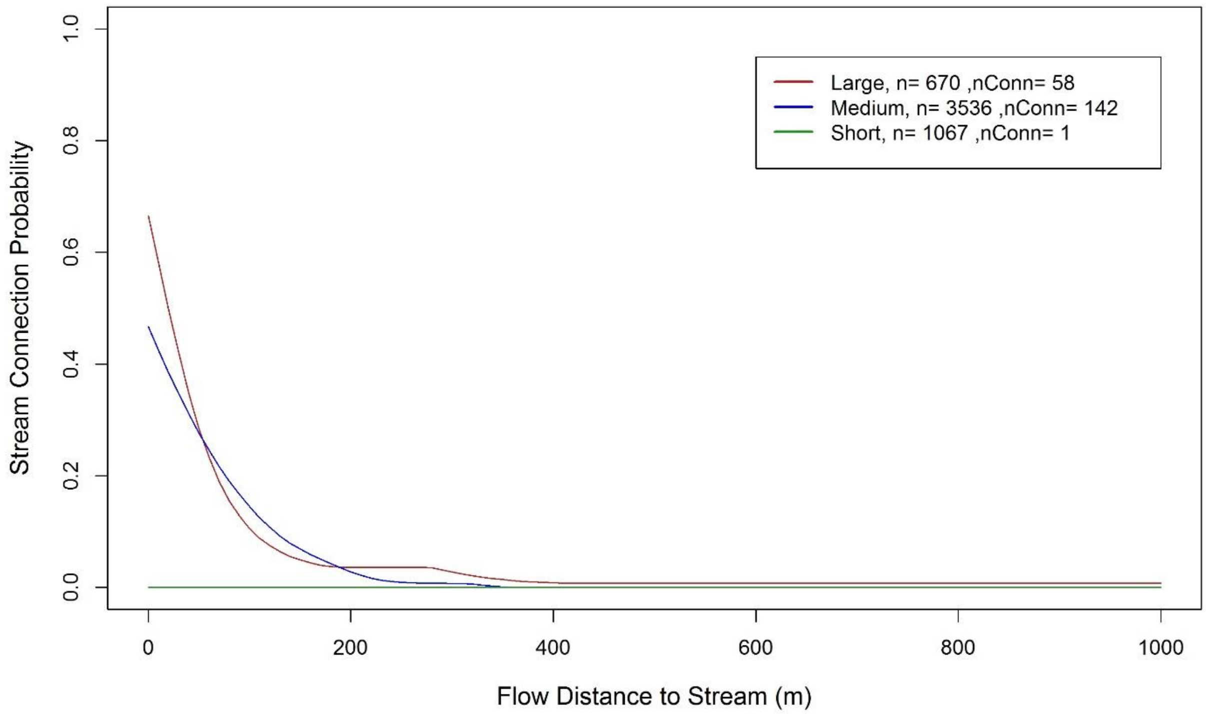
This calibration set uses the default baserate, which was developed nearby.



Basalt/Sandstone - Siuslaw NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C

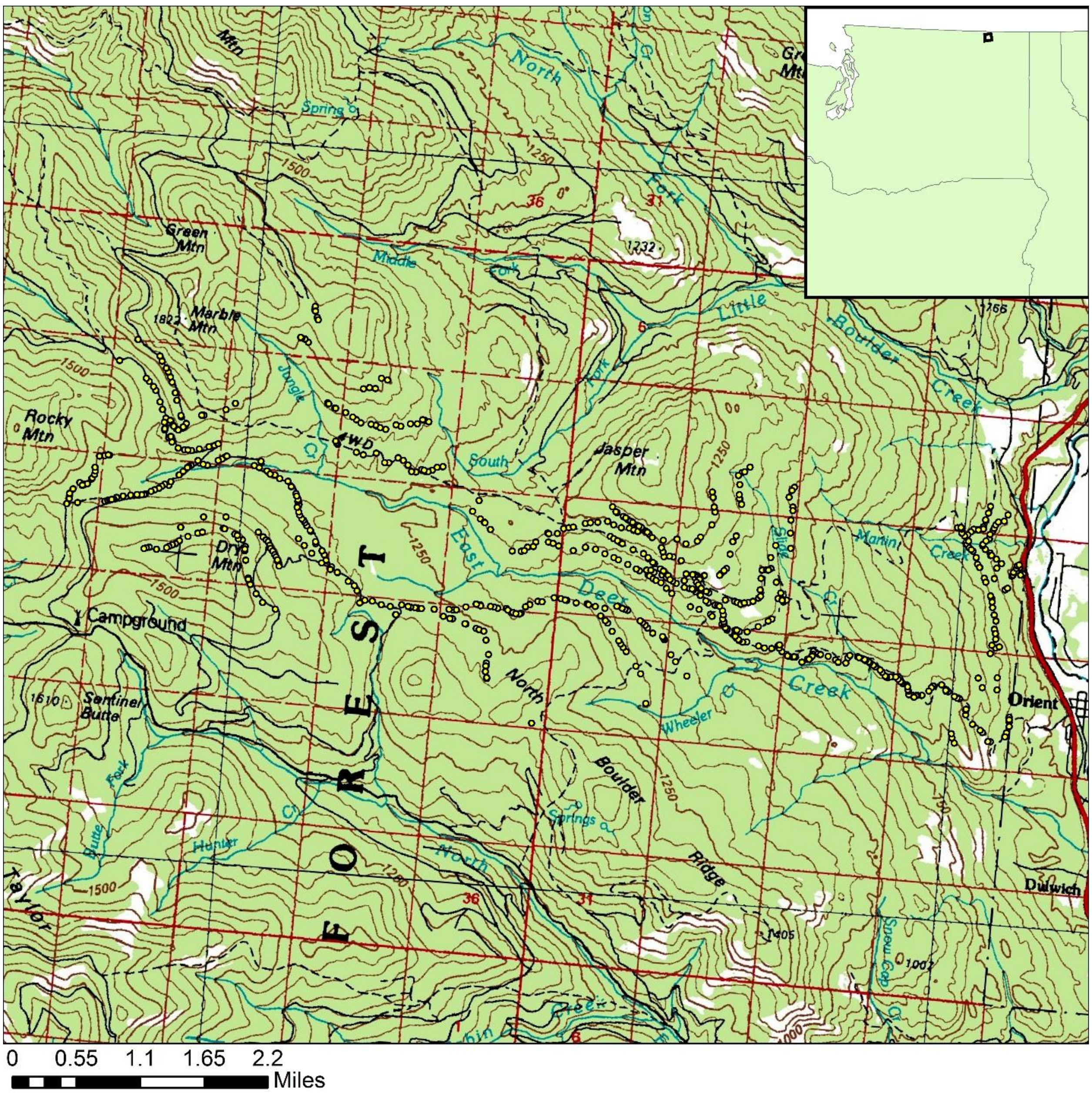


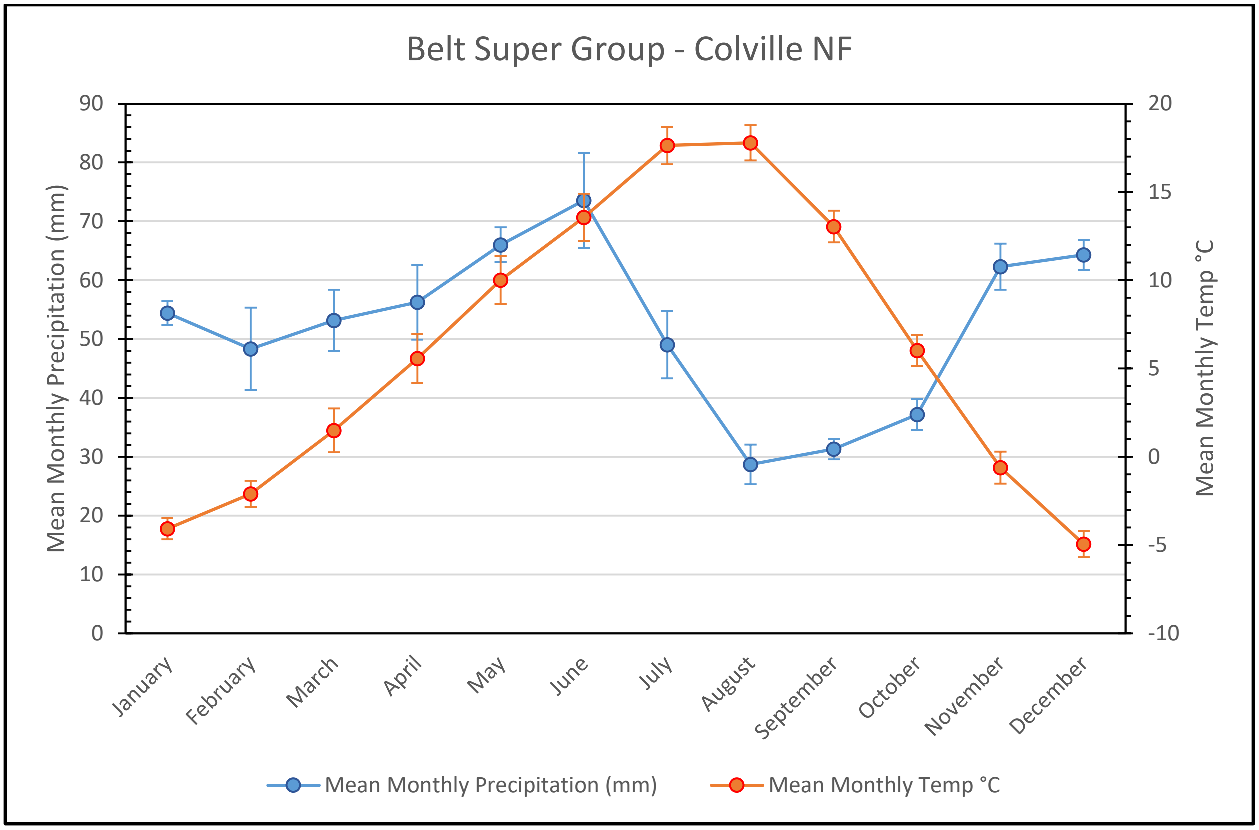
Basalt/Sandstone - Siuslaw NF
GAP Vegetation Distribution
51%
12%
11%
10%
5%
4%
7%
North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest
North Pacific Lowland Mixed Hardwood-Conifer Forest and Woodland
North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest
Harvested Forest - Northwestern Conifer Regeneration
North Pacific Lowland Riparian Forest and Shrubland
Developed, Open Space
Other


Large, n= 670 ,nConn= 58
Medium, n= 3536 ,nConn= 142
Short, n= 1067 ,nConn= 1
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

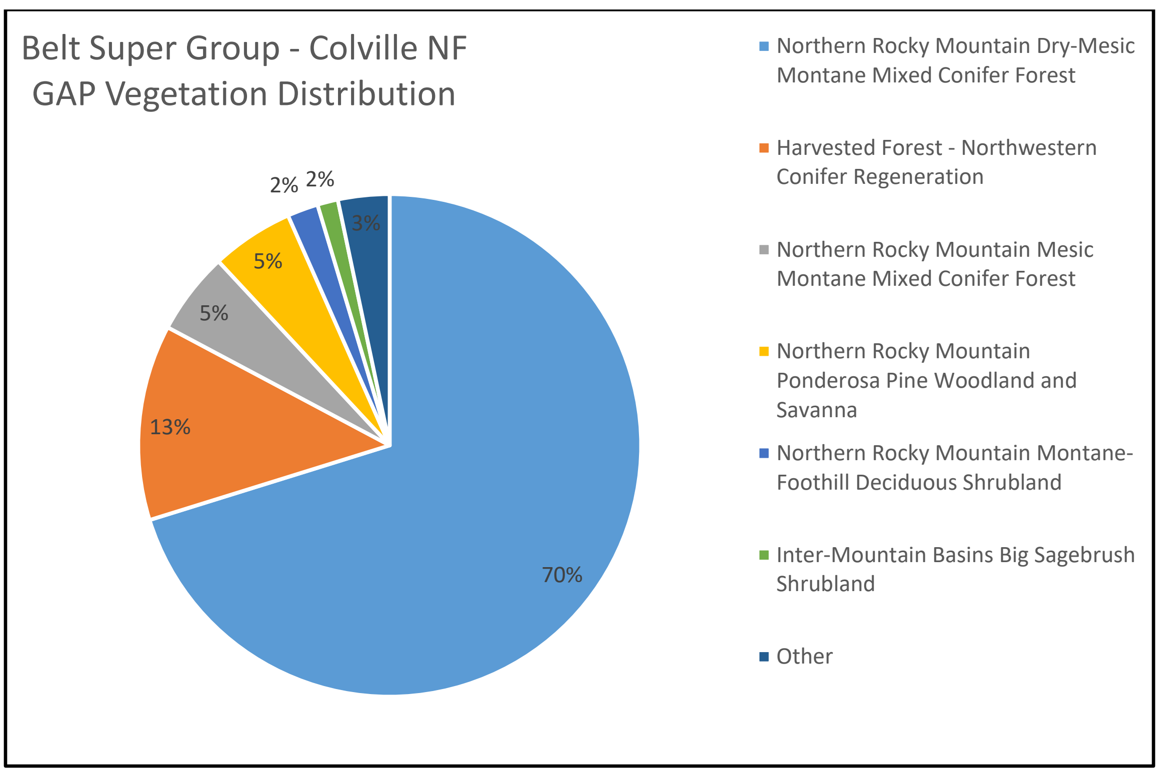
Belt Super Group – Coleville NF: This calibration set consists of a small GRAIP inventory collected as a baseline for planned fuels remediation treatments in the Deer Creek watershed on the Colville National Forest. Because this watershed functions as a municipal water supply for the town of Orient, WA, all roads in the watershed are closed to motorized vehicles. It consists of 768 calibration points collected from 70 km of road. The observed stream connection rate was 8 percent. The mean stream distance was 324 m with a standard deviation of 330 m. Elevations range from 464 m to 1,625 m, with a mean of 1,151 m and standard deviation of 276 m. Mean annual precipitation in 625 mm with a standard deviation across the calibration set of 39 mm.

This calibration uses a baserate of 14 kg/yr/m derived from the plots on the Lolo National Forest for the Belt Super Group – Lolo Helena Flathead NFs calibration set.

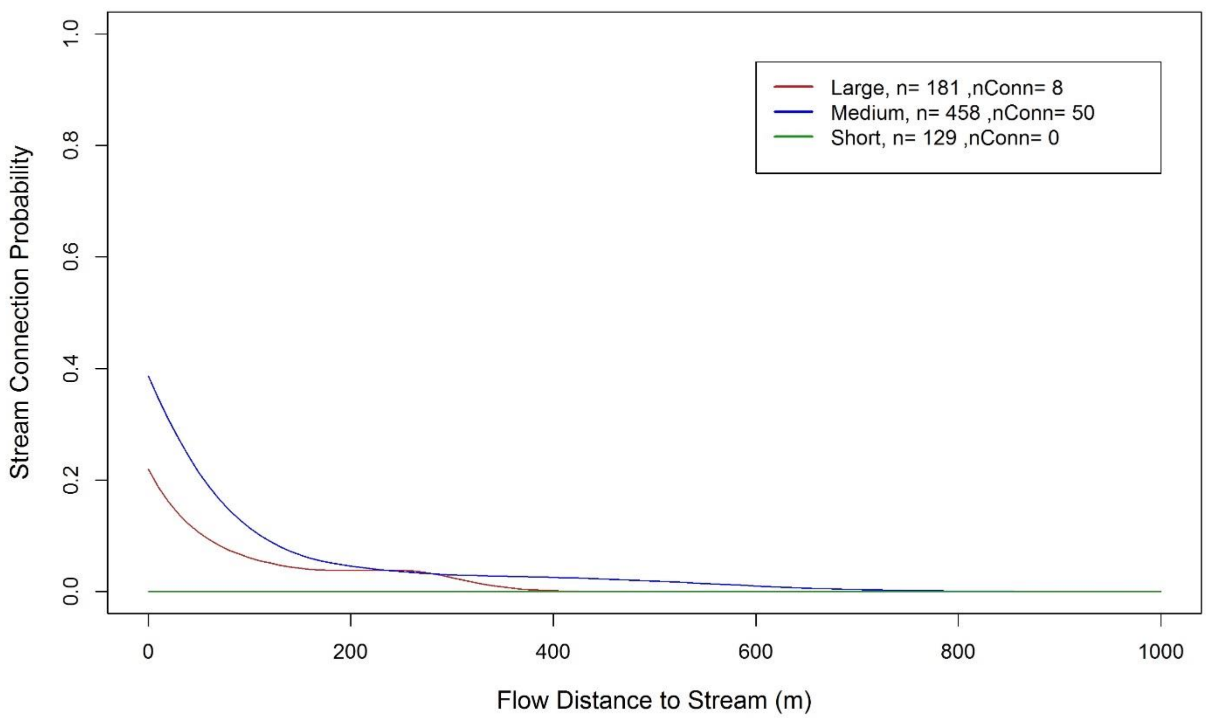




Belt Super Group - Colville NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
90
80
70
60
50
40
30
20
10
0
20
15
10
5
0
-5
-10
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C

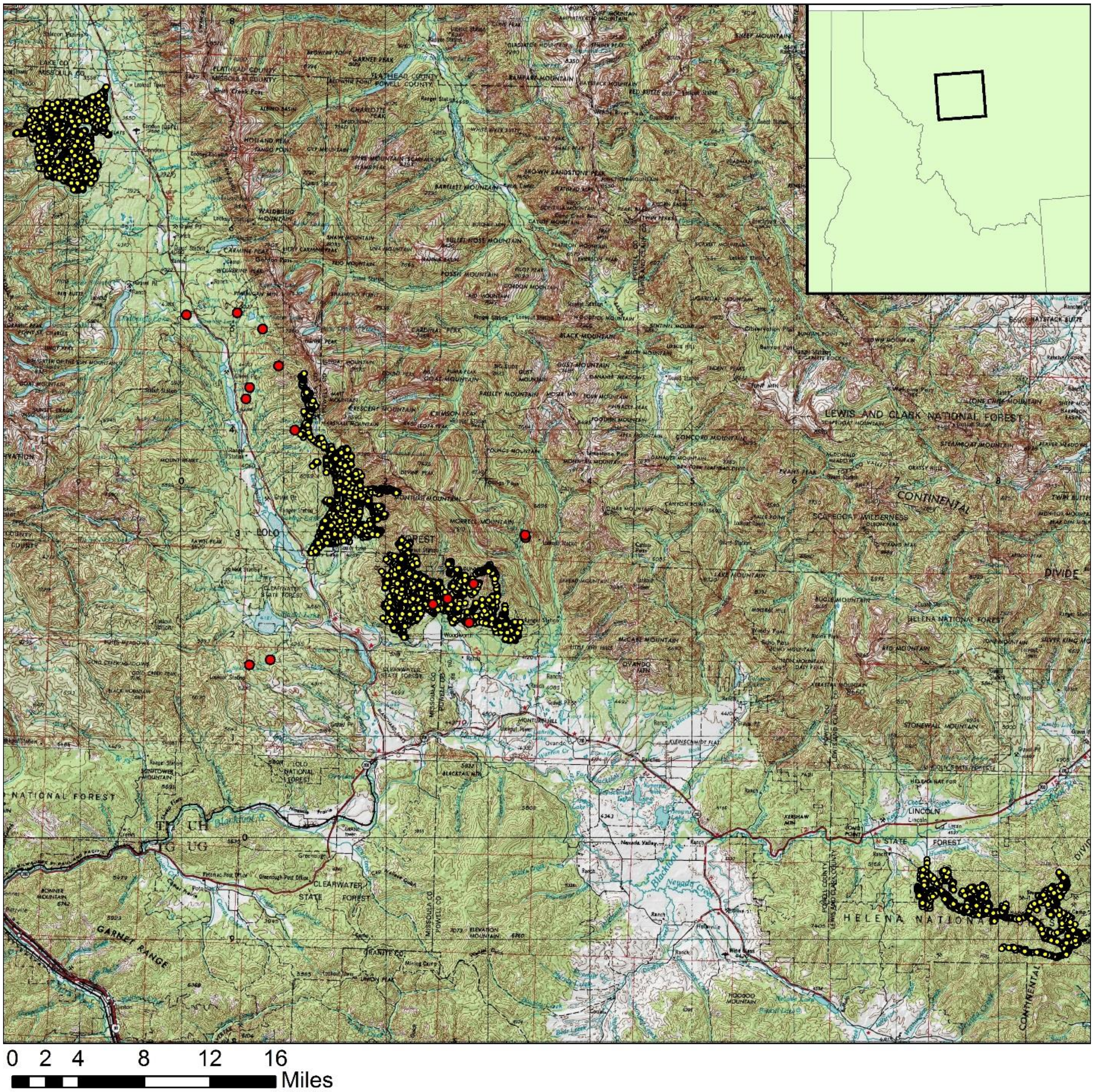


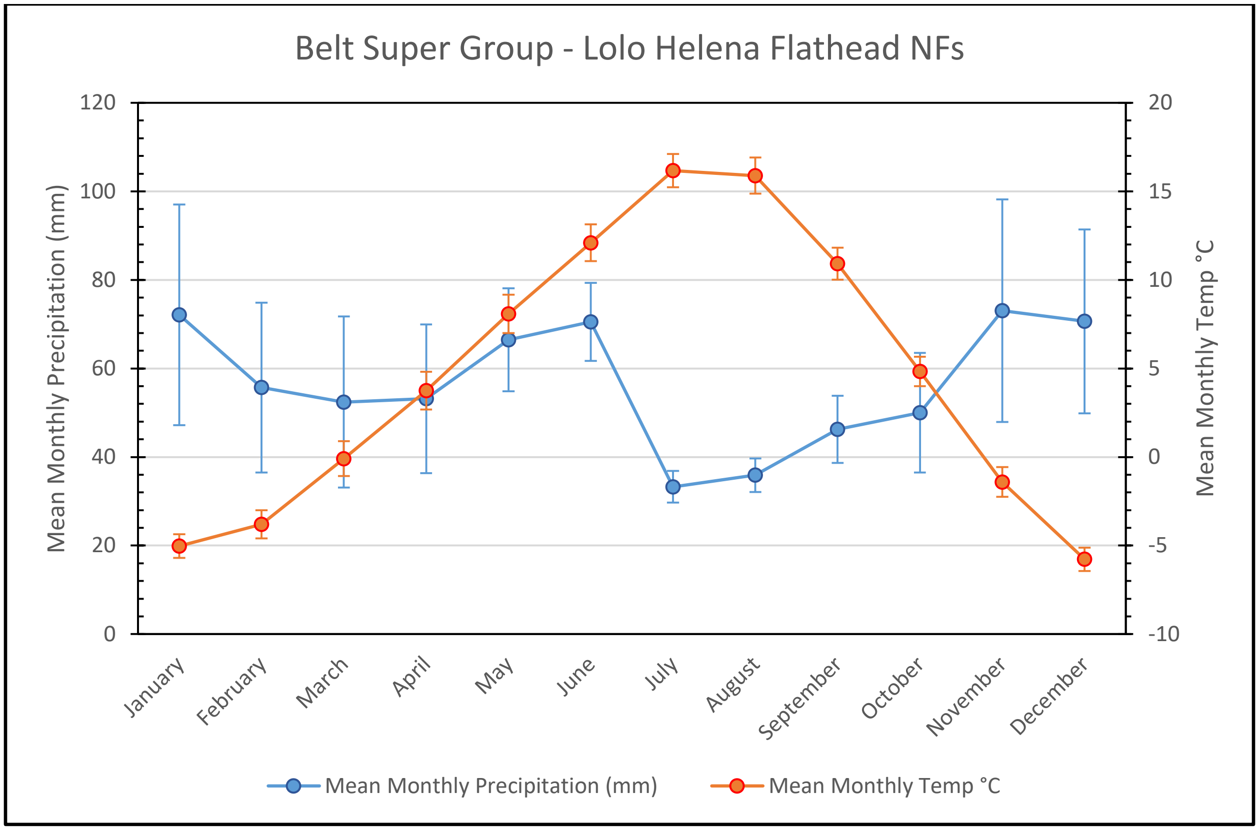
Belt Super Group - Colville NF
GAP Vegetation Distribution
2%
2%
3%
5%
5%
13%
70%
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
Harvested Forest - Northwestern Conifer Regeneration
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
Northern Rocky Mountain Montane-Foothill Deciduous Shrubland
Inter-Mountain Basins Big Sagebrush Shrubland
Other


Large, n= 181 ,nConn= 8
Medium, n= 458 ,nConn= 50
Short, n= 129 ,nConn= 0
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

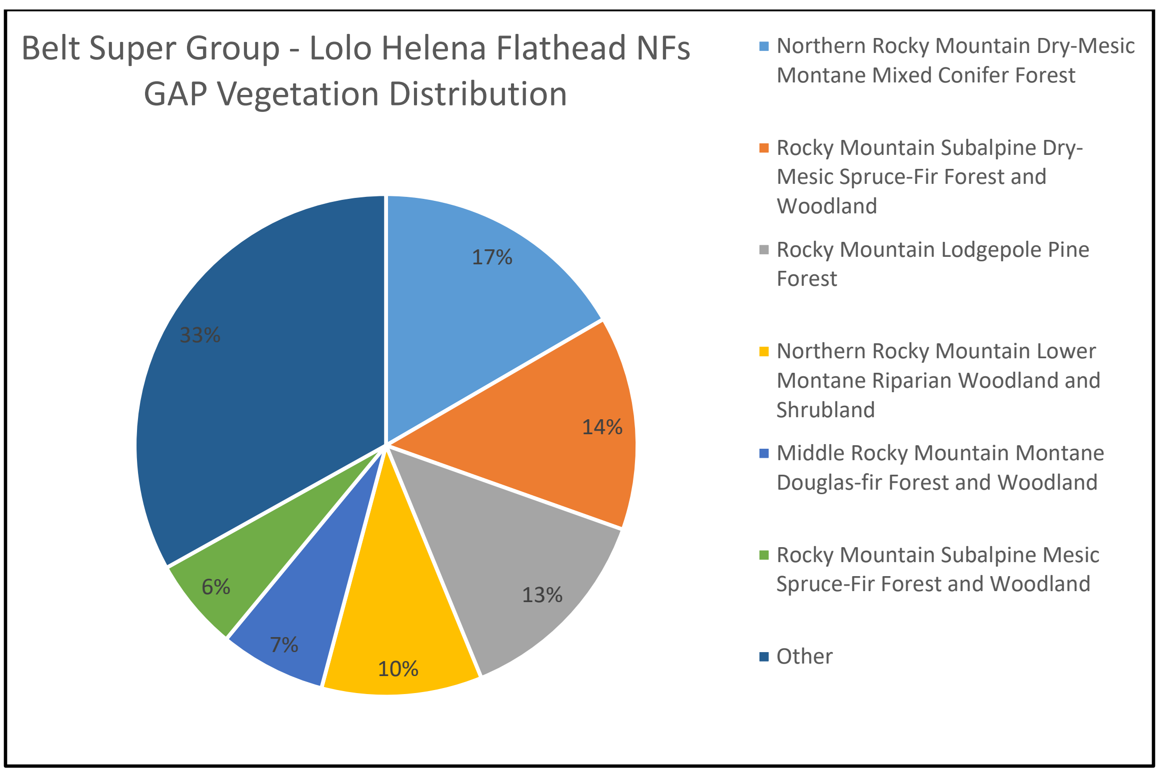
Belt Super Group – Lolo Helena Flathead NFs: This calibration set consists of several GRAIP watershed inventories collected from 2012 through 2013 on the Lolo, Helena, and Flathead National Forests as part of work being done by the South West Crown of the Continent Collaborative Forest Landscape Restoration Program. It consists of 10,826 calibration points collected from 616 km of road. The observed stream connection rate was 6 percent. The mean stream distance was 189 m with a standard deviation of 187 m. Elevations range from 1,081 m to 2,260 m, with a mean of 1,523 m and standard deviation of 246 m. Mean annual precipitation is 680 mm with a standard deviation across the calibration set of 165 mm.

This calibration uses a baserate of 14 kg/yr/m derived from 15 separate sediment monitoring plots. Eight of these plots use a large settling tank combined with a flow splitter and sediment blanket supported by a basket for fines collection; the other seven plots use a main settling tank, tipping bucket flow gage, and a flow splitter leading to a fines collection tank. The original eight plots, with filter fabric, were installed in 2011. Four plots were then installed in 2015, and the last three plots were installed in 2016.

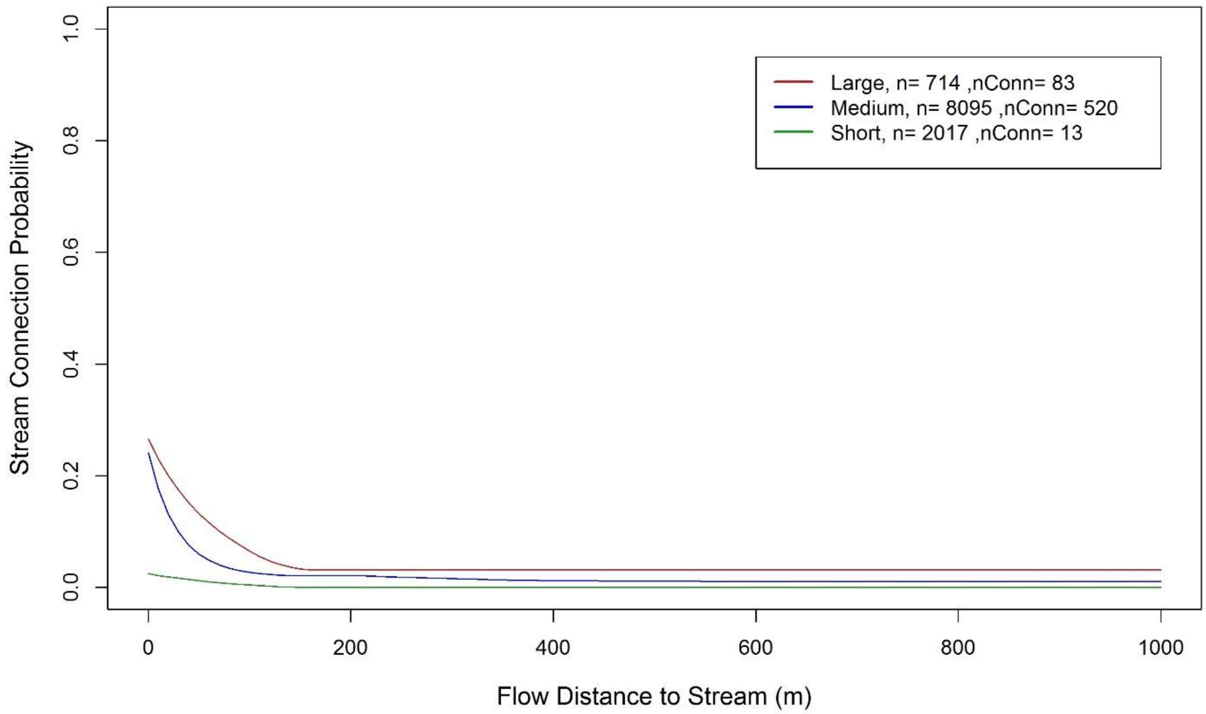




Belt Super Group - Lolo Helena Flathead NFs
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
120
100
80
60
40
20
0
20
15
10
5
0
-5
-10
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C

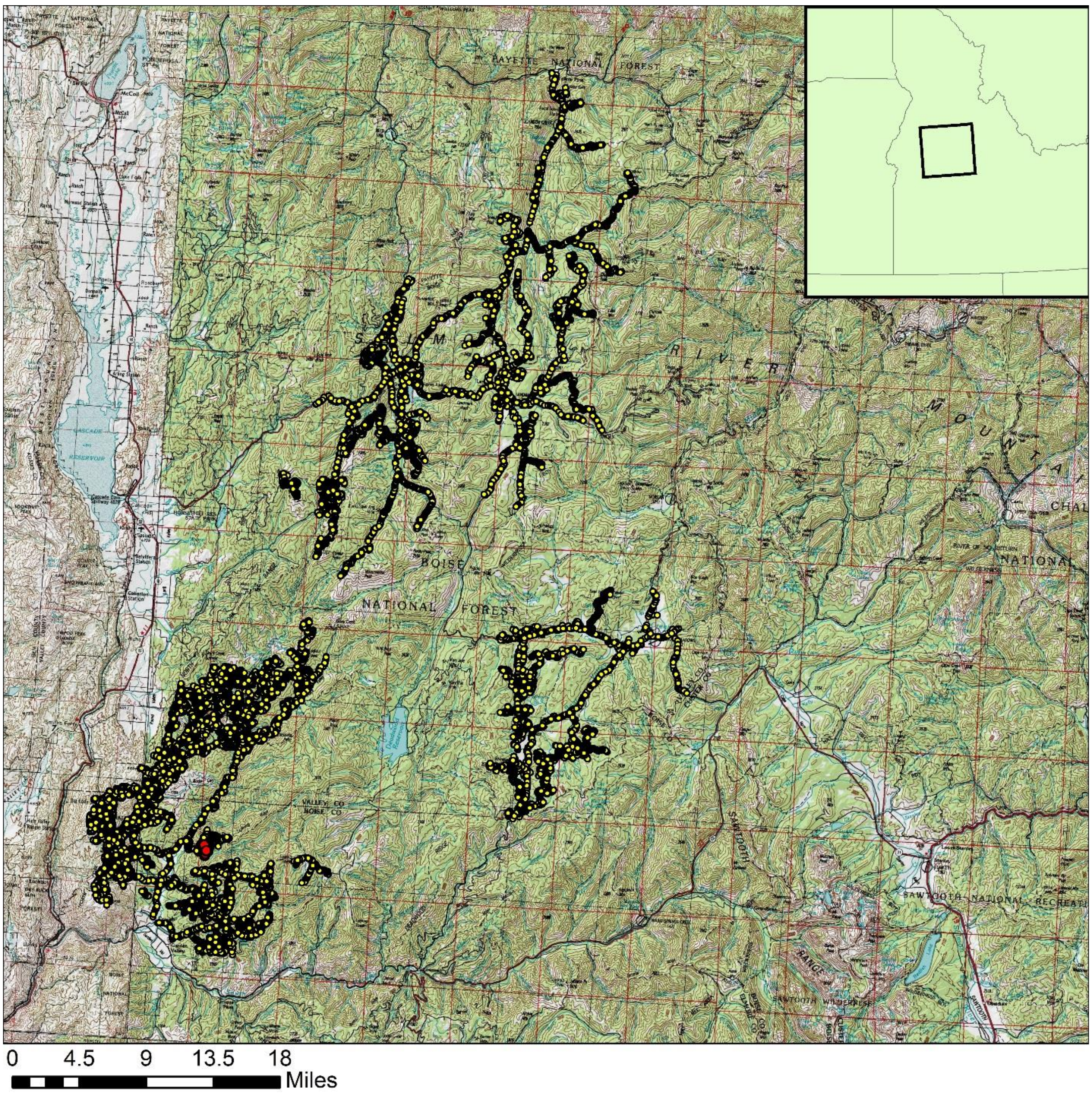


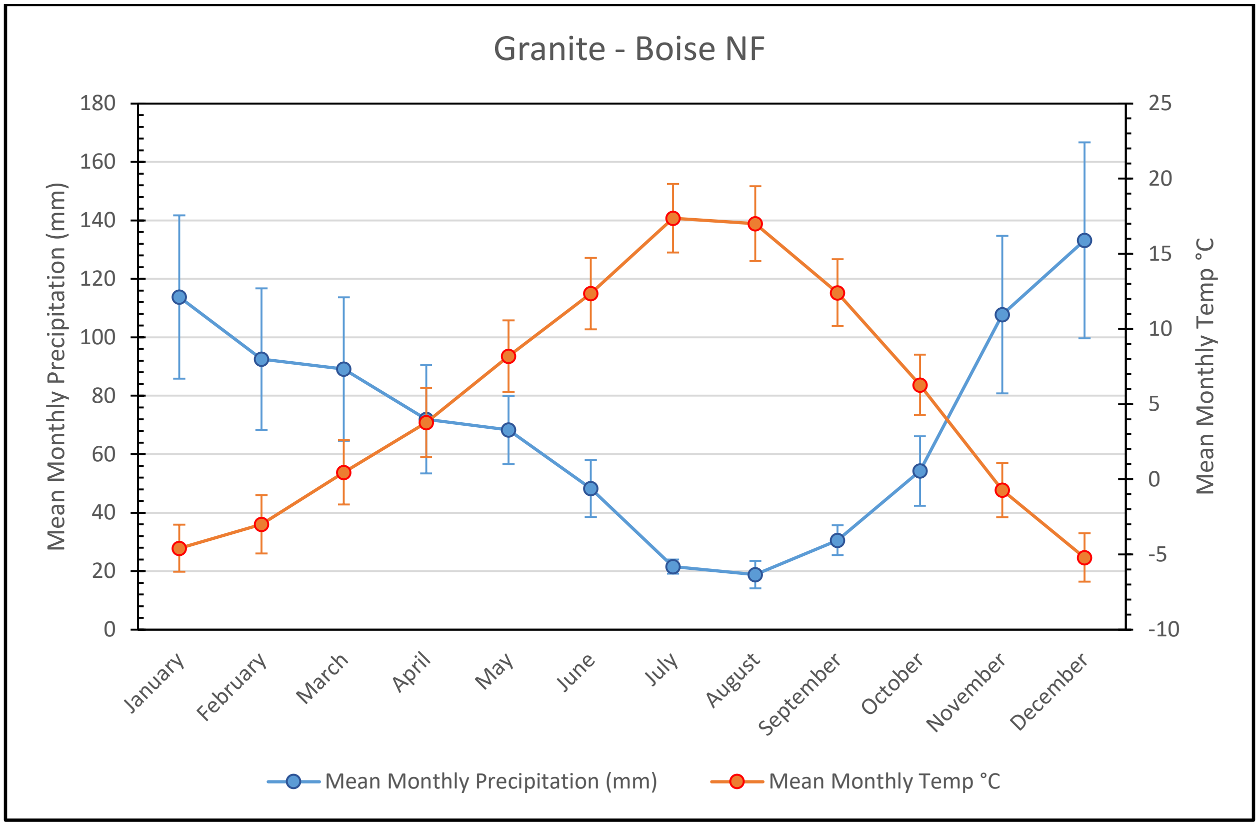
Belt Super Group - Lolo Helena Flathead NFs
GAP Vegetation Distribution
17%
14%
13%
10%
7%
6%
33%
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
Rocky Mountain Lodgepole Pine Forest
Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland
Middle Rocky Mountain Montane Douglas-fir Forest and Woodland
Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
Other


Large, n= 714 ,nConn= 83
Medium, n= 8095 ,nConn= 520
Short, n= 2017 ,nConn= 13
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

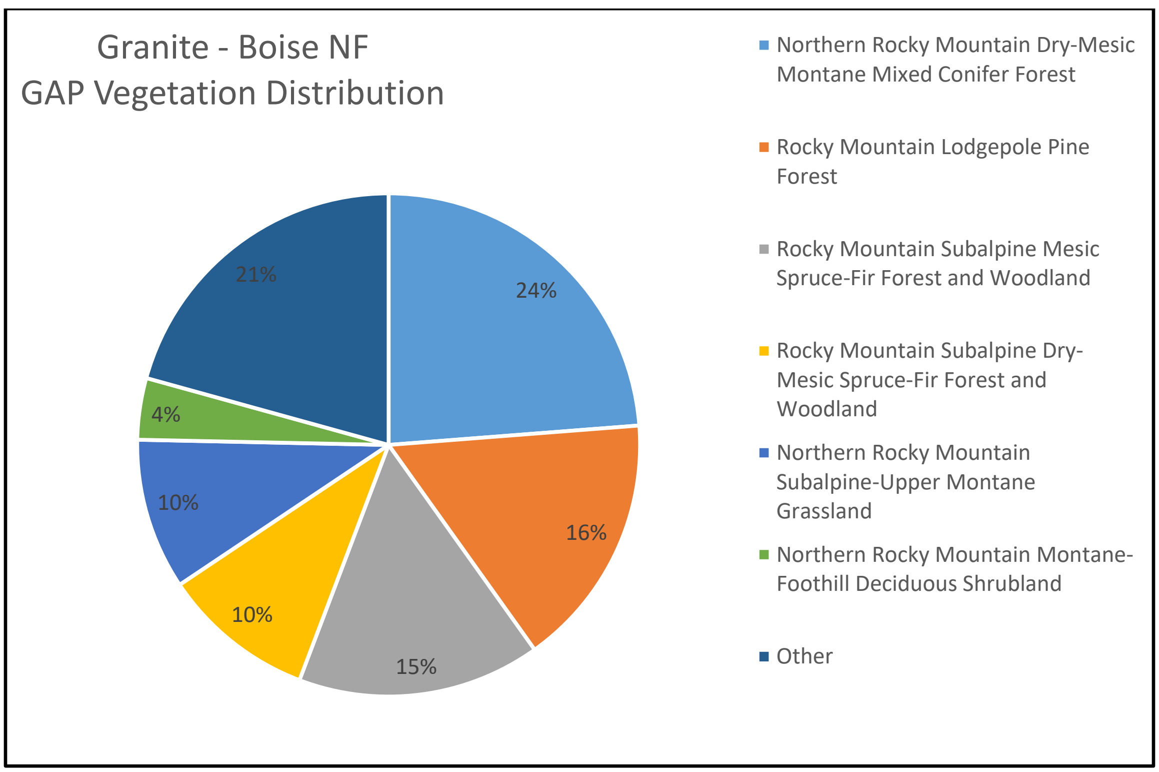
Granite – Boise NF: This calibration set consists of several GRAIP watershed inventories collected on the Boise National Forest between 2009 and 2011 in support of TMDL, 4b, and other restoration projects. It consists of 27,430 calibration points collected from 1,655 km of road. The observed stream connection rate was 17 percent. The mean stream distance was 149 m with a standard deviation of 146 m. Elevations range from 932 m to 2,581 m, with a mean of 1,707 m and standard deviation of 336 m. Mean annual precipitation is 850 mm with a standard deviation across the calibration set of 195 mm.

This calibration uses a baserate of 21.3 kg/yr/m derived from 6 separate sediment monitoring plots installed on the Lightning Creek road. Five of these plots were installed in 2009 and the sixth plot was installed in 2010 using a prototype tipping bucket. Later, a second tipping bucket was added on one additional plot. Currently, four plots consist of just a main sediment tank and two plots have a main sediment tank, tipping bucket with splitter, and fines collection tank.

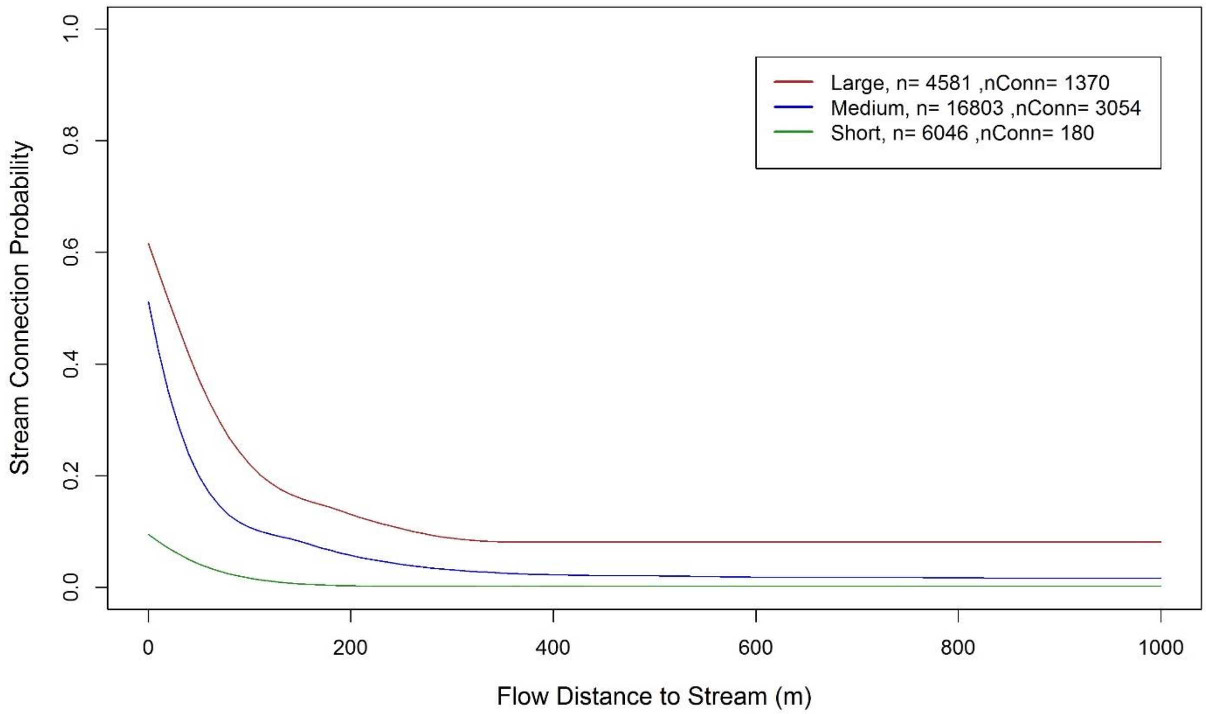




Granite - Boise NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
180
160
140
120
100
80
60
40
20
0
25
20
15
10
5
0
-5
-10
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C



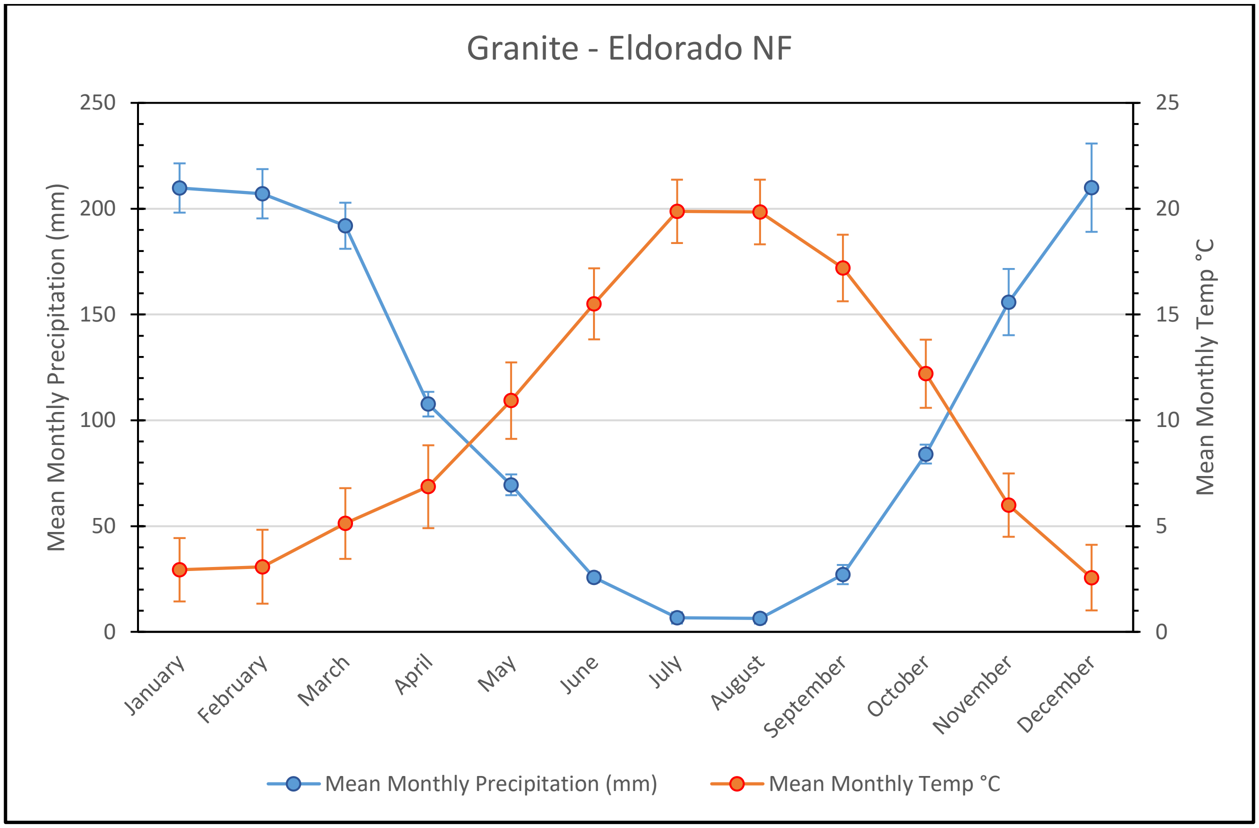
Granite - Boise NF
GAP Vegetation Distribution
24%
16%
15%
10%
10%
4%
21%
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
Rocky Mountain Lodgepole Pine Forest
Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
Northern Rocky Mountain Subalpine-Upper Montane Grassland
Northern Rocky Mountain Montane-Foothill Deciduous Shrubland
Other

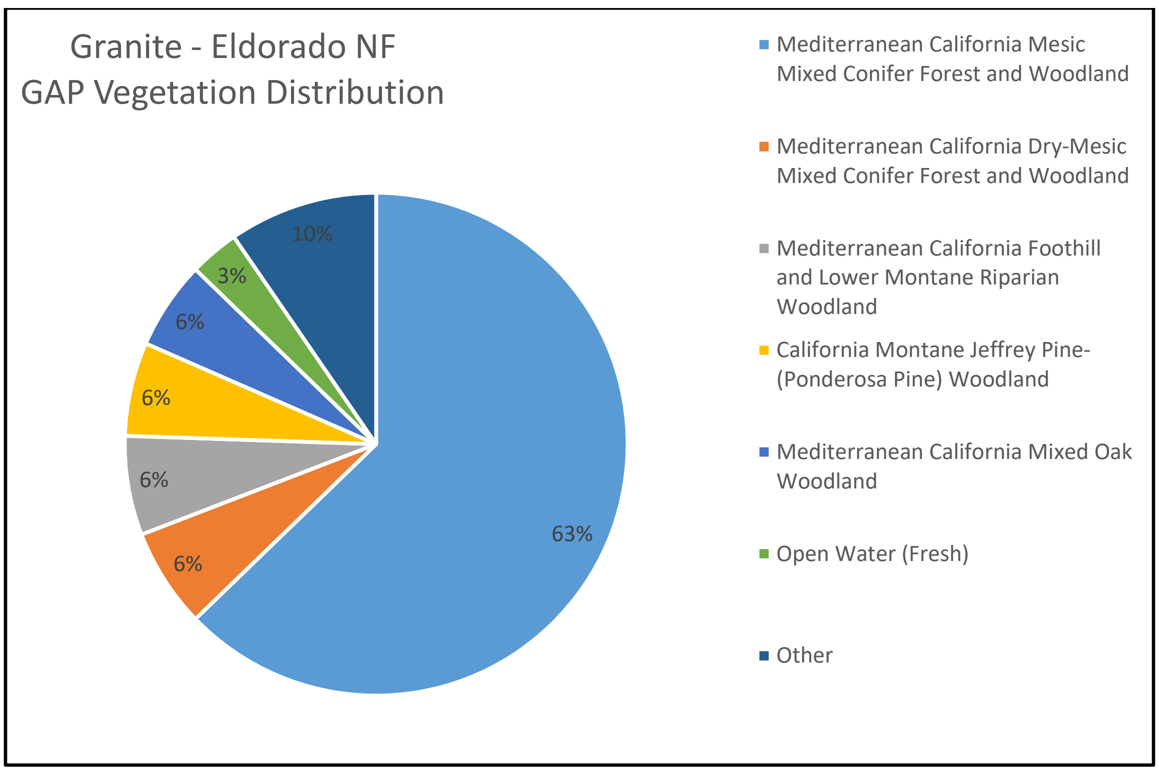


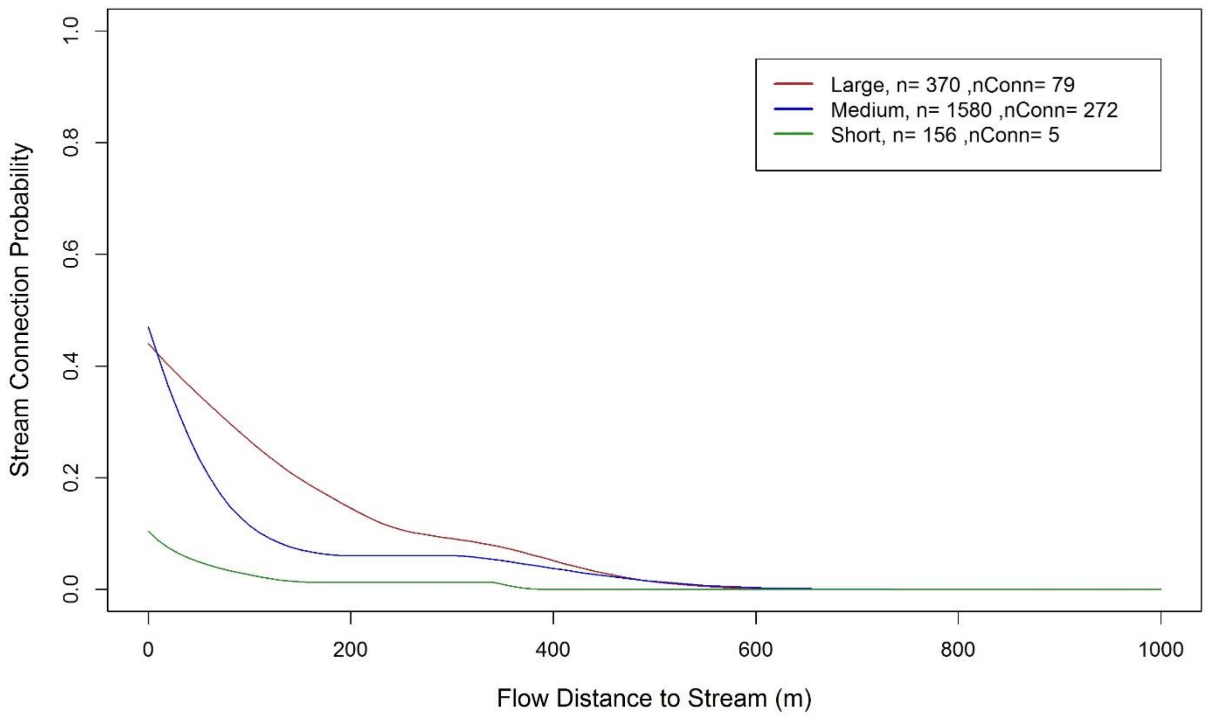
Large, n= 4581 ,nConn= 1370
Medium, n= 16803 ,nConn= 3054
Short, n= 6046 ,nConn= 180
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

Granite – Eldorado NF: This calibration set was collected as part of a GRAIP inventory conducted as part of restoration work associated with the Power Fire on the Eldorado National Forest. It consists of 2,106 calibration points collected from 145 km of road. The observed stream connection rate was 17 percent. The mean stream distance was 192 m with a standard deviation of 199 m. Elevations range from 1,070 m to 2,394 m, with a mean of 1,766 m and standard deviation of 311 m. Mean annual precipitation is 1,302 mm with a standard deviation across the calibration set of 86 mm.

The baserate used with this calibration set is 49.5 kg/yr/m vertical drop along the road, and comes from three sediment monitoring plots utilizing a main settling tank, tipping bucket flow gage, and a flow splitter leading to a fines collection tank. These plots were installed in 2015.

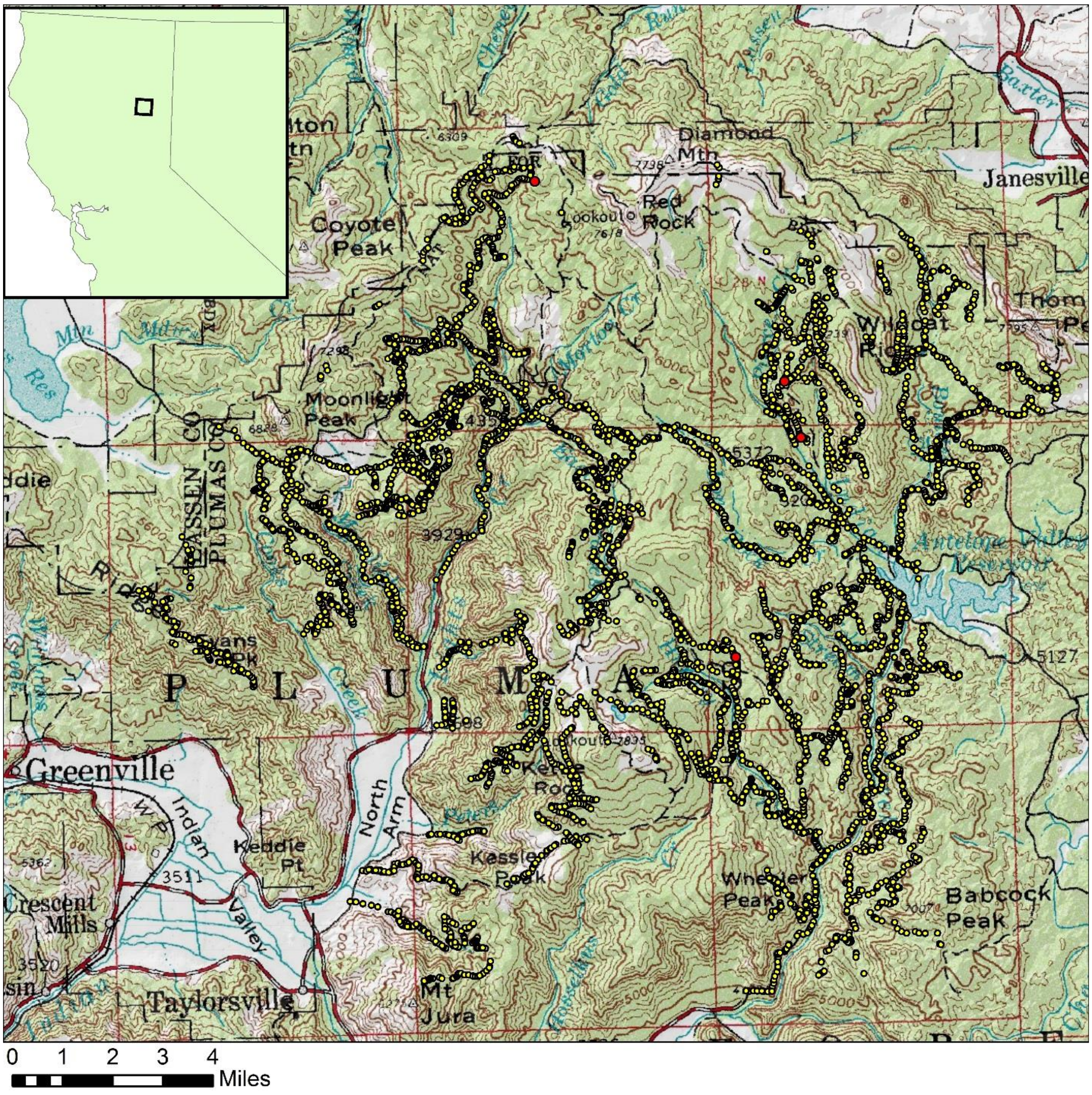

Granite - Eldorado NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
250
200
150
100
50
0
25
20
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C

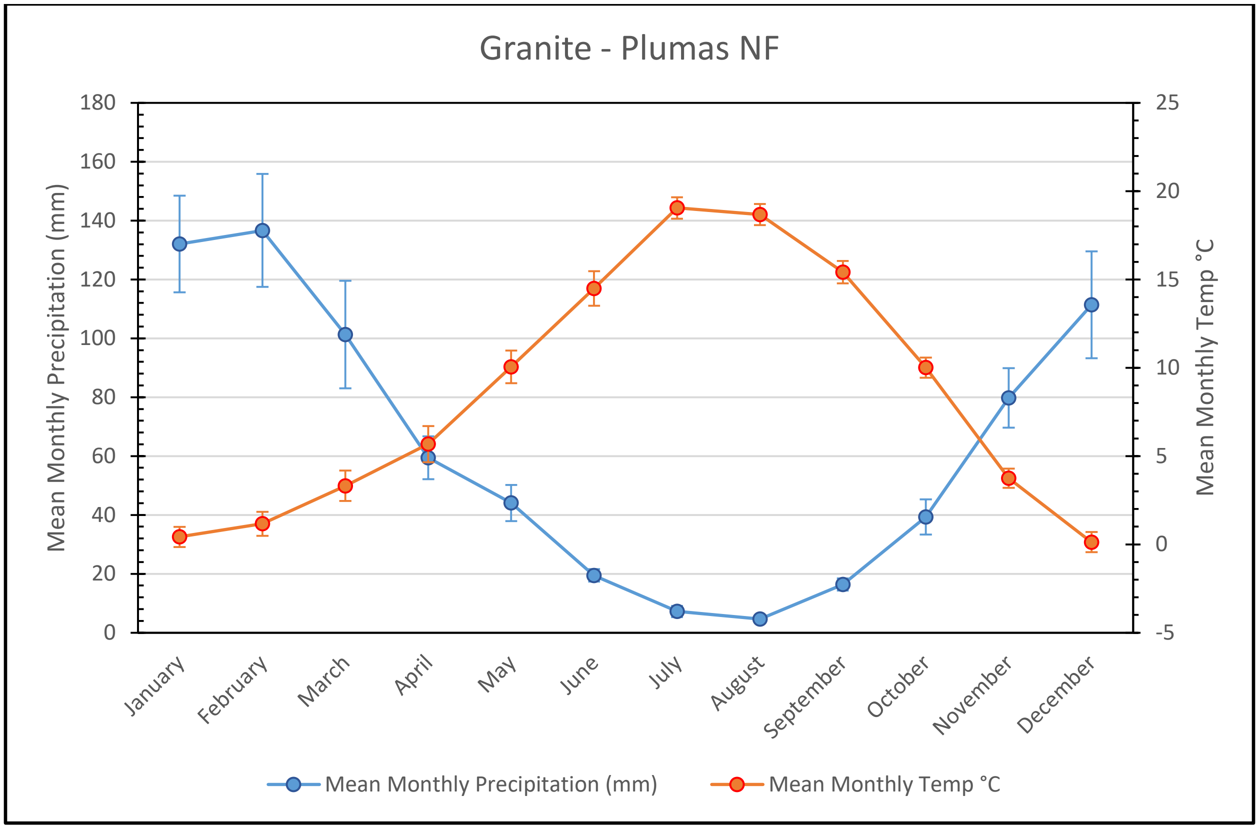

Granite - Eldorado NF
GAP Vegetation Distribution
10%
3%
6%
6%
6%
6%
63%
Mediterranean California Mesic Mixed Conifer Forest and Woodland
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
Mediterranean California Foothill and Lower Montane Riparian Woodland
California Montane Jeffrey Pine-(Ponderosa Pine) Woodland
Mediterranean California Mixed Oak Woodland
Open Water (Fresh)
Other

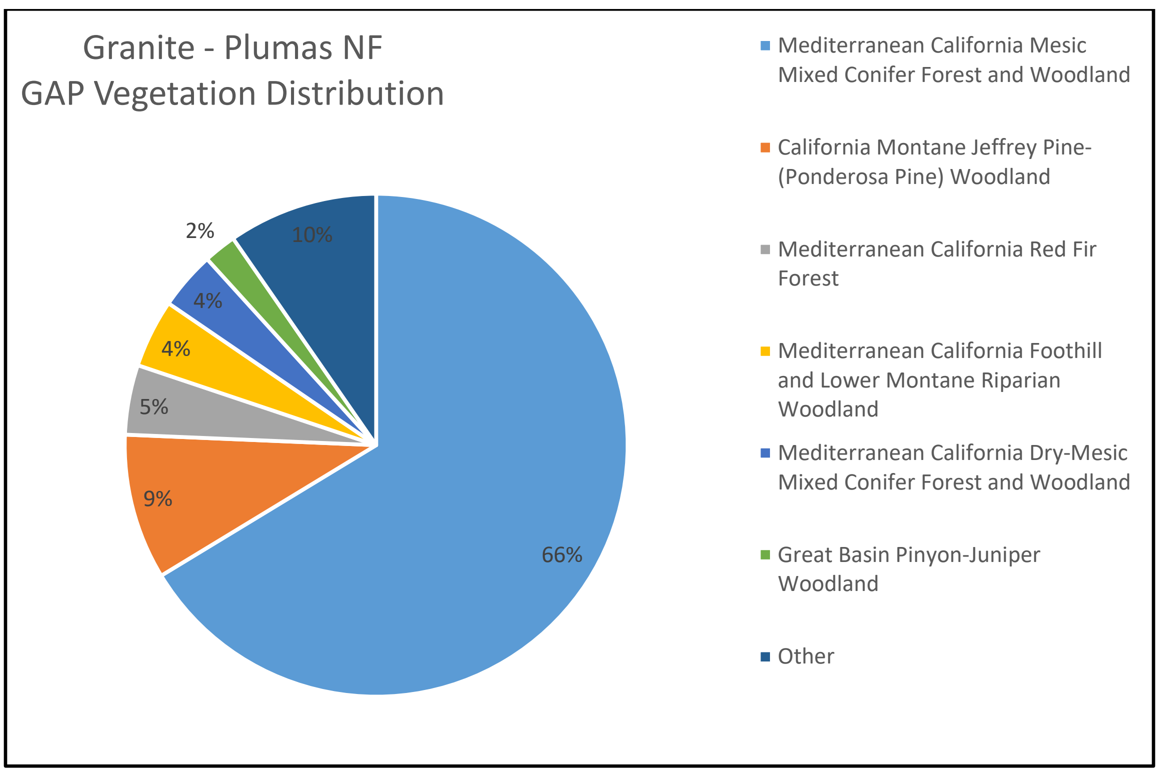

Large, n= 370 ,nConn= 79
Medium, n= 1580 ,nConn= 272
Short, n= 156 ,nConn= 5
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

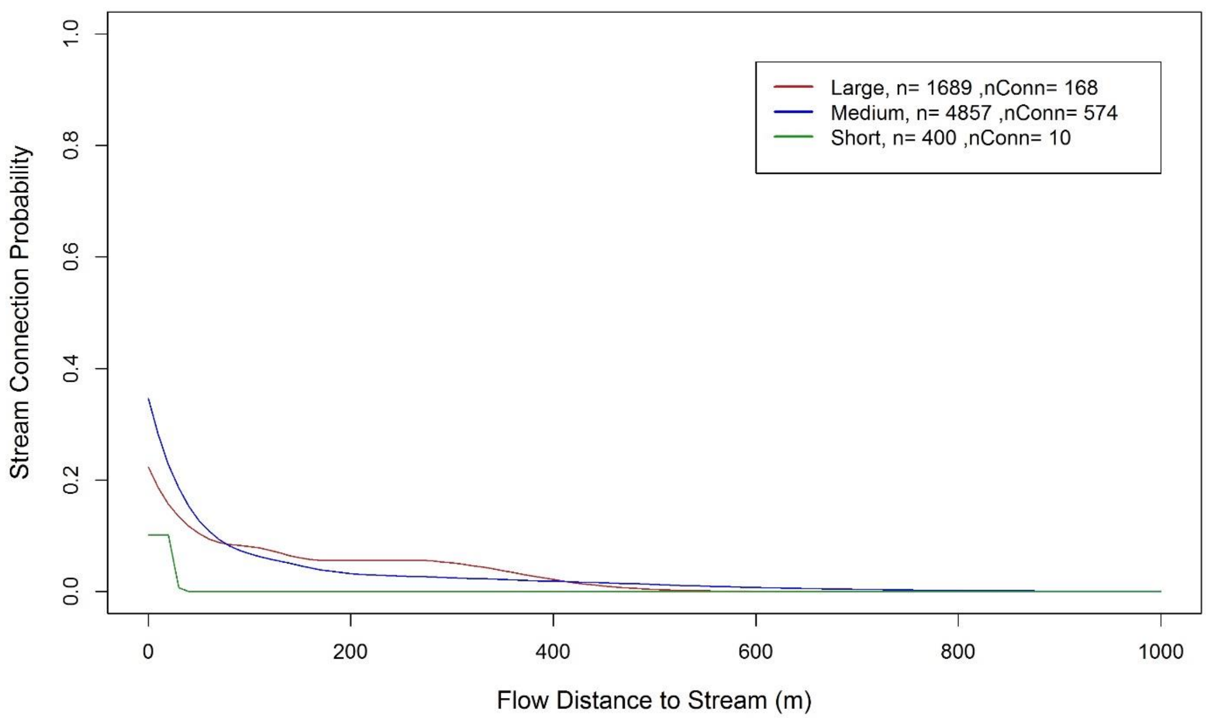
Granite – Plumas NF: This calibration set was collected as part of a GRAIP inventory conducted as part of restoration work associated with the Moonlight Fire on the Plumas National Forest. It consists of 6,946 calibration points collected from 495 km of road. The observed stream connection rate was 11 percent. The mean stream distance was 149 m with a standard deviation of 149 m. Elevations range from 1,089 m to 2,260 m, with a mean of 1,701 m and standard deviation of 189 m. Mean annual precipitation is 751 mm with a standard deviation across the calibration set of 92 mm.

The baserate used with this calibration set is 30.2 kg/yr/m vertical drop along the road, and comes from four sediment monitoring plots utilizing a main settling tank, a flow splitter, and a second tank to collect fines. These plots were installed in 2014.



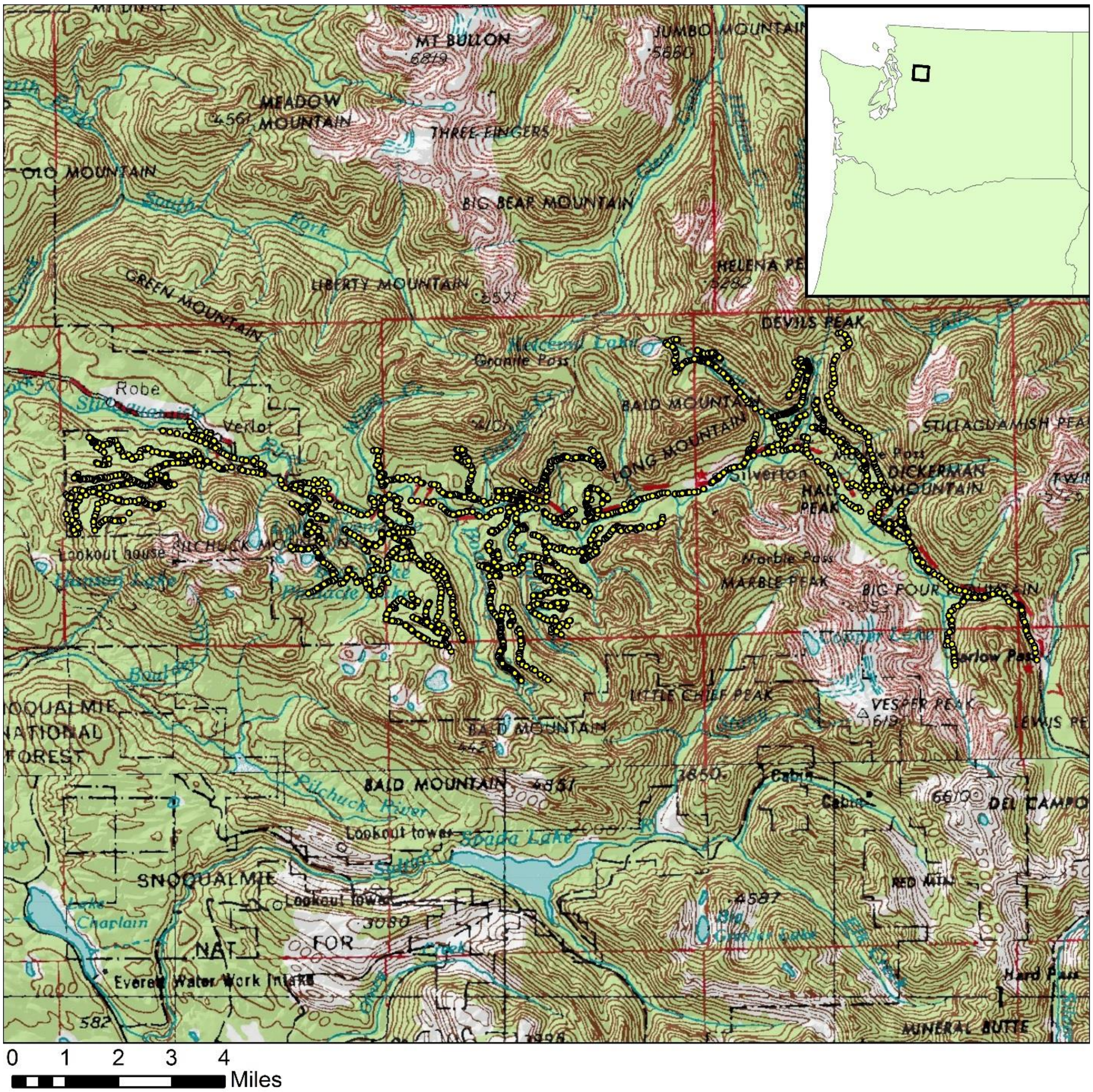

Granite - Plumas NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
180
160
140
120
100
80
60
40
20
0
25
20
15
10
5
0
-5
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C

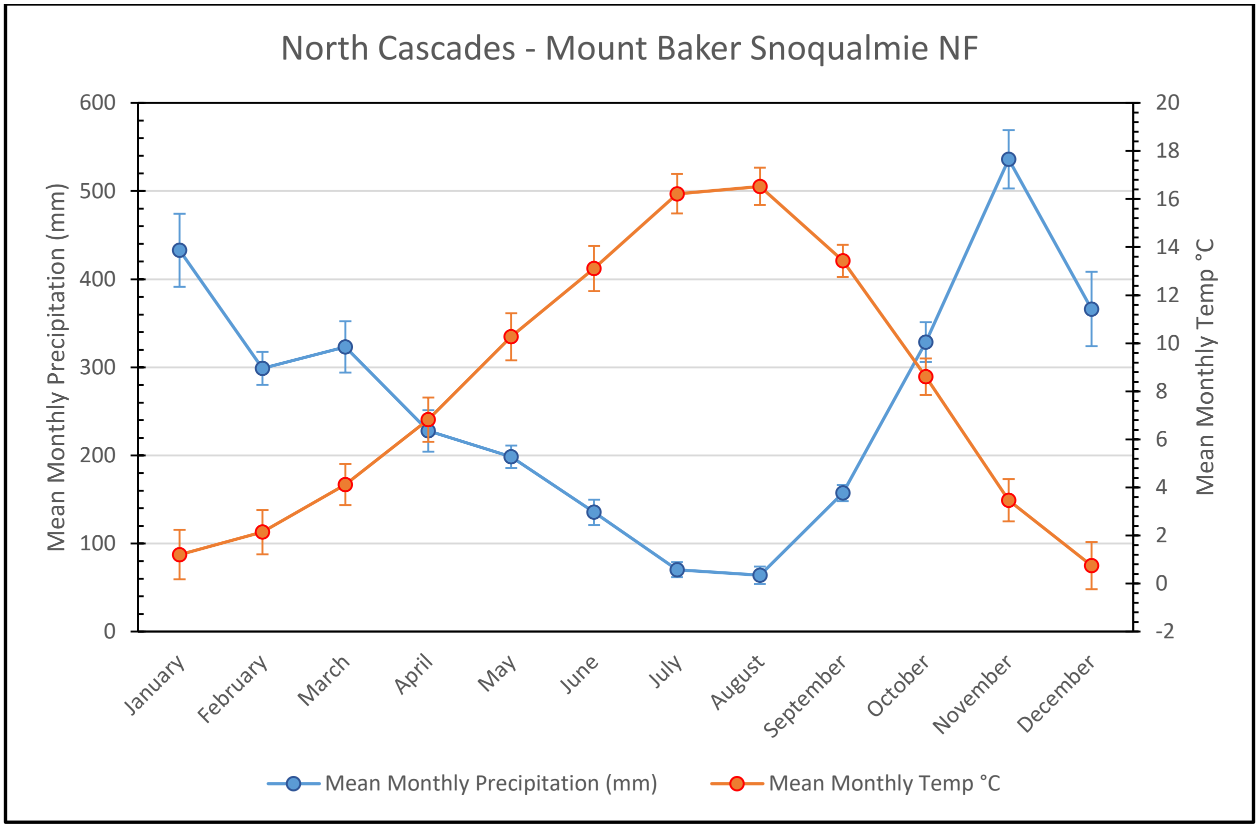

Granite - Plumas NF
GAP Vegetation Distribution
66%
9%
5%
4%
4%
2%
10%
Mediterranean California Mesic Mixed Conifer Forest and Woodland
California Montane Jeffrey Pine-(Ponderosa Pine) Woodland
Mediterranean California Red Fir Forest
Mediterranean California Foothill and Lower Montane Riparian Woodland
Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland
Great Basin Pinyon-Juniper Woodland
Other

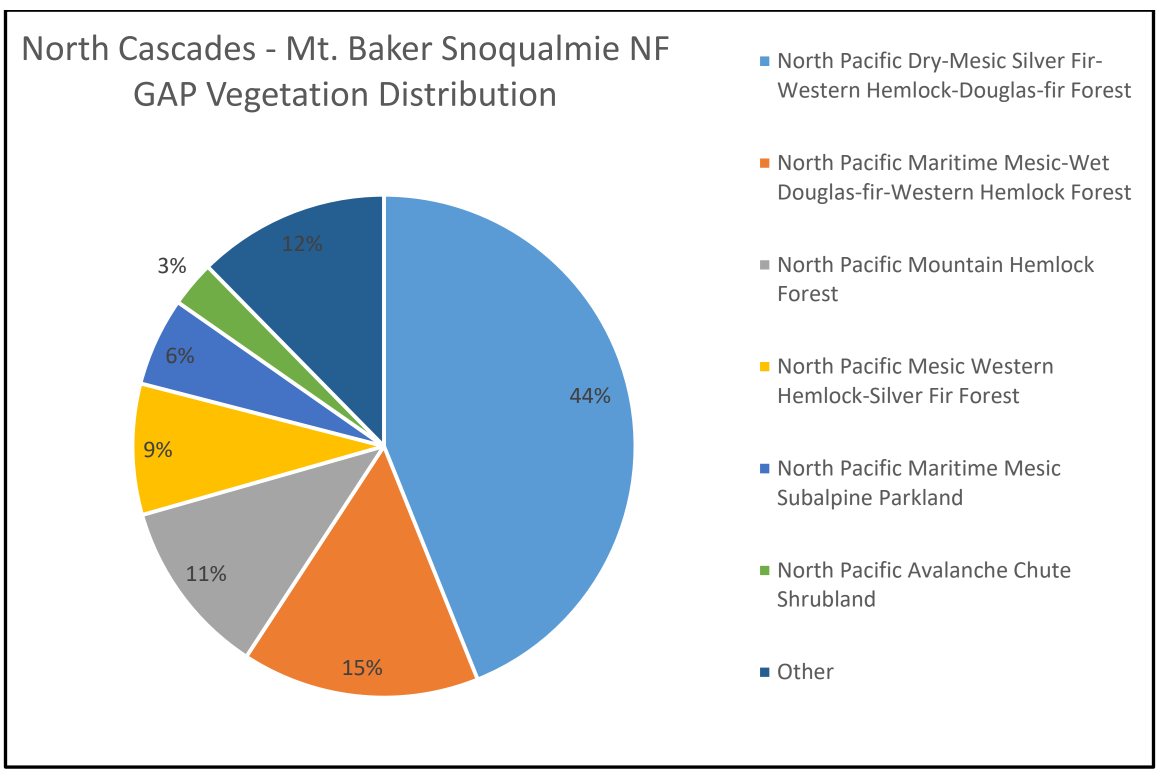

Large, n= 1689 ,nConn= 168
Medium, n= 4857 ,nConn= 574
Short, n= 400 ,nConn= 10
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

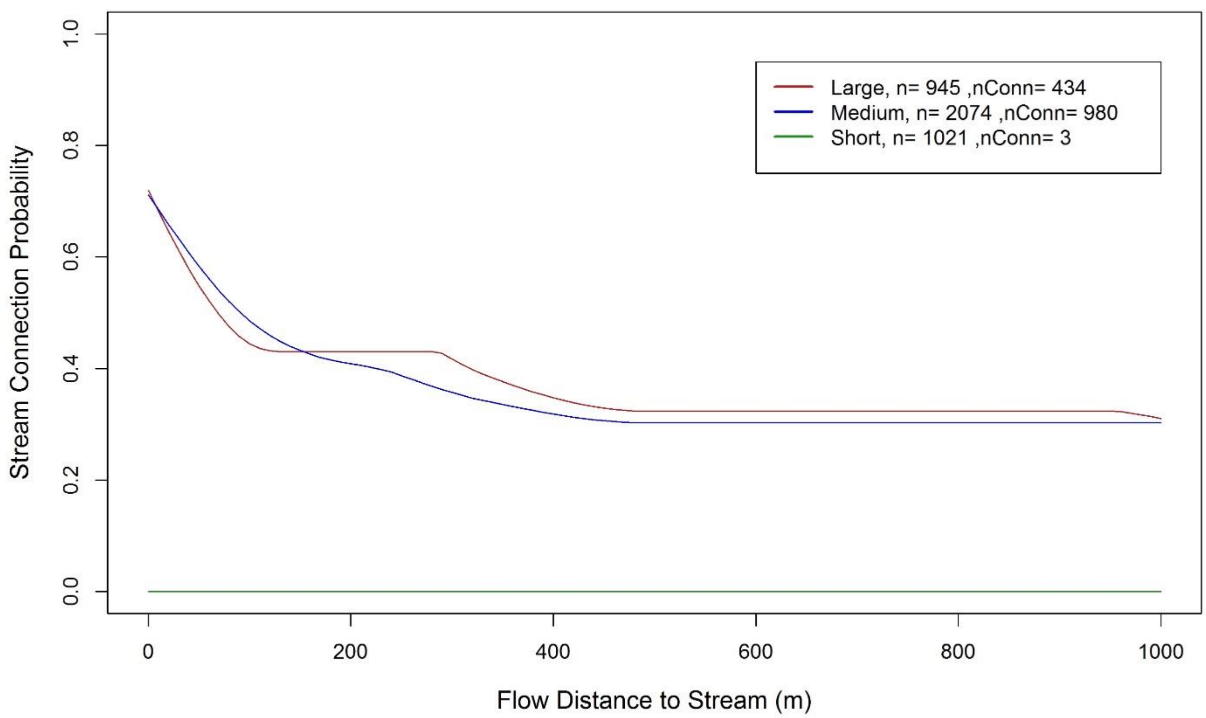
North Cascades – Mount Baker Snoqualmie NF: This calibration set consists of a GRAIP inventory collected during 2013 and 2014 in the Stilliguamish River watershed on the Mount Baker – Snoqualmie National Forest. It consists of 4,040 calibration points collected from 203 km of road. The observed stream connection rate was 35 percent. The mean stream distance was 227 m with a standard deviation of 211 m. Elevations range from 308 m to 1,132 m, with a mean of 631 m and standard deviation of 165 m. Mean annual precipitation is 3,147 mm with a standard deviation across the calibration set of 232 mm.

This calibration set uses the default baserate.




North Cascades - Mount Baker Snoqualmie NF
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C
600
500
400
300
200
100
0
20
18
16
14
12
10
8
6
4
2
0
-2
January
February
March
April
May
June
July
August
September
October
November
December
Mean Monthly Precipitation (mm)
Mean Monthly Temp °C


North Cascades - Mt. Baker Snoqualmie NF
GAP Vegetation Distribution
44%
15%
11%
9%
6%
3%
12%
North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest
North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest
North Pacific Mountain Hemlock Forest
North Pacific Mesic Western Hemlock-Silver Fir Forest
North Pacific Maritime Mesic Subalpine Parkland
North Pacific Avalanche Chute Shrubland
Other


Large, n= 945 ,nConn= 434
Medium, n= 2074 ,nConn= 980
Short, n= 1021 ,nConn= 3
Stream Connection Probability
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Flow Distance to Stream (m)

Appendix B: Description of Treatments

New Road – Temporary: This treatment is used when a road will be added for use during the project and then fully recontoured at the end of the project. For the initial condition, it assumes the road does not exist. For the disturbed condition, it assumes a bare, native surfaced, ML2 or equivalent road with high traffic and drainage at 100m distances. For the recovered condition, it assumes the road has been recontoured yielding a native surfaced ML1 with no traffic covered in vegetation and having drainage every 25m.

New Road – Permanent: This treatment is used when a road will be added for long-term access. For the initial condition, it assumes the road does not exist. For the disturbed condition, it assumes a bare, crushed rock surfaced, ML3 or equivalent road with high traffic and drainage at 100m distances. For the recovered condition, it assumes the road has come to vegetative equilibrium similar to other like roads and that traffic is low.

New Road – Reroute: This treatment is used when a road will be added to make a connection during a reroute project. For the initial condition, it assumes the road does not exist. For the disturbed condition, it assumes a bare, crushed rock surfaced, ML3 or equivalent road with high traffic and drainage at 100m distances. For the recovered condition, it assumes the road has come to vegetative equilibrium similar to other like roads and that traffic is low. The maintenance level and drainage distance should be set to match the road being replaced.

Re-Open – Temporary: This treatment is used when a closed road will be temporarily opened for use during a project and then recontoured. For the initial condition, it assumes the road is closed (ML1) with normal vegetation, drainage every 50m, and a native surface. For the disturbed condition, it assumes a bare, native surfaced, ML2 or equivalent road with high traffic and drainage at 100m distances. For the recovered condition, it assumes the road has been recontoured yielding a native surfaced ML1 with no traffic covered in vegetation and having drainage every 25m.

Re-Open – Permanent: This treatment is used when a closed road will be reopened, often as part of a reroute project. For the initial condition, it assumes the road is closed (ML1) with normal vegetation, drainage every 50m, and a native surface. For the disturbed condition, it assumes a bare, crushed rock surfaced, ML2 or equivalent road with high traffic and drainage at 50m distances. For the recovered condition, it assumes the road has come to vegetative equilibrium similar to other like roads and that traffic is low. If this is part of a reroute, the maintenance level and drainage distance should be set to match the road being replaced.

Traffic Increase – ML2 with gravel: This treatment is used when gravel will be applied to a ML2 road to support temporary increased traffic loads such as during haul operations. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare, crushed rock surface with high traffic and a drainage distance of 100m. For the recovered condition, it assumes that the surface has degraded back to a native surface, the vegetation has recovered to an average state, the traffic level has dropped to low, and the drainage distance has returned to 50m.

Traffic Increase – ML3 with gravel: This treatment is used when gravel will be applied to a ML3 road to support temporary increased traffic loads such as during haul operations. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare, crushed rock surface with high traffic and a drainage distance of 100m. For the recovered condition, it assumes that the surface is crushed rock, the vegetation has recovered to an average state, the traffic level has dropped to medium, and the drainage distance is 100m.

Traffic Increase – ML4 with gravel: This treatment is used when gravel will be applied to a ML4 road to support temporary increased traffic loads such as during haul operations. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare, crushed rock surface with high traffic and a drainage distance of 100m. For the recovered condition, it assumes that the surface is crushed rock, the vegetation has recovered to an average state, the traffic level has dropped to medium, and the drainage distance is 100m.

Traffic Increase – ML5 Paved: This treatment is used when gravel will be applied to a ML5 road to support temporary increased traffic loads such as during haul operations. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare ditch, paved surface with high traffic and a drainage distance of 200m. For the recovered condition, it assumes that the vegetation in the ditch has returned to the average condition.

SDRR Improvement – Nat-Gravel ML2: This treatment is used to simulate the effect of converting a native surfaced ML2 road to a crushed rock surface. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare crushed rock surface with high traffic and a 50m drainage spacing. For the recovered condition, it assumes that the traffic has decreased to low and that the vegetation has returned to average conditions.

SDRR Improvement – Nat-Gravel ML3: This treatment is used to simulate the effect of converting a native surfaced ML3 road to a crushed rock surface. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare crushed rock surface with high traffic and a 100m drainage spacing. For the recovered condition, it assumes that the traffic has decreased to medium and that the vegetation has returned to average conditions.

SDRR Improvement – Drainage ML3: This treatment is used to simulate the effect of increasing the drainage density of a ML3 road with a gravel surface. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare crushed rock surface with high traffic and a 50m drainage spacing. For the recovered condition, it assumes that the traffic has decreased to medium and that the vegetation has returned to average conditions.

Reconstruct – ML2: This treatment is used to simulate the effect of reconstructing a native surfaced ML2 road to a using a crushed rock surface. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare crushed rock surface with high traffic and a 100m drainage spacing. For the recovered condition, it assumes that the traffic has decreased to low and that the vegetation has returned to average conditions.

Reconstruct – ML3: This treatment is used to simulate the effect of reconstructing an ML3 road using a crushed rock surface. It is functionally the same as Traffic Increase – ML3 with gravel.

Upgrade – Pave: This treatment is used to model paving a road and establishing a 200m drainage spacing. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a paved road surface with a bare ditch, high traffic, and a 200m drainage spacing. For the recovered condition, vegetation in the ditch is returned to an average condition and traffic remains high.

Storage – Close ML2: This treatment is used to model long-term closure (storage) of an ML2 road. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a native surface with no traffic and a 50m drainage spacing; vegetation is modeled as the average condition for the ML2 road. For the recovered condition, vegetation is modeled as the average condition on ML1 roads.

Storage – Drainage Removal ML2: This treatment is used to model long-term closure (storage) of an ML2 road and specifies the removal of existing drainage culverts; it is modeled the same as the Storage – Close ML2 treatment. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a native surface with no traffic and a 50m drainage spacing; vegetation is modeled as the average condition for the ML2 road. For the recovered condition, vegetation is modeled as the average condition on ML1 roads.

Decommission – Rip/Till: This treatment is used to model decommissioning a road by ripping or tilling, rather than recontouring, and then seeding or planting vegetation. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare native surface with no traffic and a 50m drainage spacing. For the recovered condition, vegetation is modeled as covered. If treatment will not involve seeding or planting, V2 should be set to Default rather than Covered.

Decommission – Partial Recontour: This treatment is used to model decommissioning a road by partially recontouring the road surface, and then seeding or planting vegetation. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare native surface with no traffic and a 50m drainage spacing. For the recovered condition, vegetation is modeled as covered. If treatment will not involve seeding or planting, V2 should be set to Default rather than Covered.

Decommission – Full Recontour: This treatment is used to model decommissioning a road by fully recontouring the road surface, and then seeding or planting vegetation. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare native surface with no traffic and a 25m drainage spacing. For the recovered condition, vegetation is modeled as covered. If treatment will not involve seeding or planting, V2 should be set to Default rather than Covered.

Use and Decommission – ML2 Recontour: This treatment is used to model using a road for a project and then recontouring that road after project completion. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare native surface with high traffic and a 100m drainage spacing. For the recovered condition, it assumes a covered native surface with no traffic and a 25m drainage spacing. If treatment will not involve seeding or planting, V2 should be set to Default rather than Covered.

Use and Decommission – ML3 Recontour: This treatment is used to model using a road for a project and then recontouring that road after project completion. For the initial condition, it uses the road attributes from the initial GRAIP_Lite run based on the INFRA road layer. For the disturbed condition, it assumes a bare crushed rock surface with high traffic and a 100m drainage spacing. For the recovered condition, it assumes a covered native surface with no traffic and a 25m drainage spacing. If treatment will not involve seeding or planting, V2 should be set to Default rather than Covered.

Appendix C: Data Structure and Requirements

Name in Structure	Explanation
Project Folder	**Main folder containing project**
Alternative1	**Folder containing rasters for Alternative 1**
gl_acclength0	Accumulated connected road length, Initial condition
gl_acclength1	Accumulated connected road length, Disturbed condition
gl_acclength2	Accumulated connected road length, Recovered condition
gl_connlen0	Drainpoints, connected road length, Initial condition
gl_connlen1	Drainpoints, connected road length, Disturbed condition
gl_connlen2	Drainpoints, connected road length, Recovered condition
gl_dp0	Drainpoints, delivered sediment, Initial condition
gl_dp1	Drainpoints, delivered sediment, Disturbed condition
gl_dp2	Drainpoints, delivered sediment, Recovered condition
gl_seddel0	Accumulated sediment, Initial condition
gl_seddel1	Accumulated sediment, Disturbed condition
gl_seddel2	Accumulated sediment, Recovered condition
gl_sedstr0	
gl_sedstr1	
gl_sedstr2	
gl_specsedstr0	Specific sediment, Initial condition
gl_specsedstr1	Specific sediment, Disturbed condition
gl_specsedstr2	Specific sediment, Recovered condition

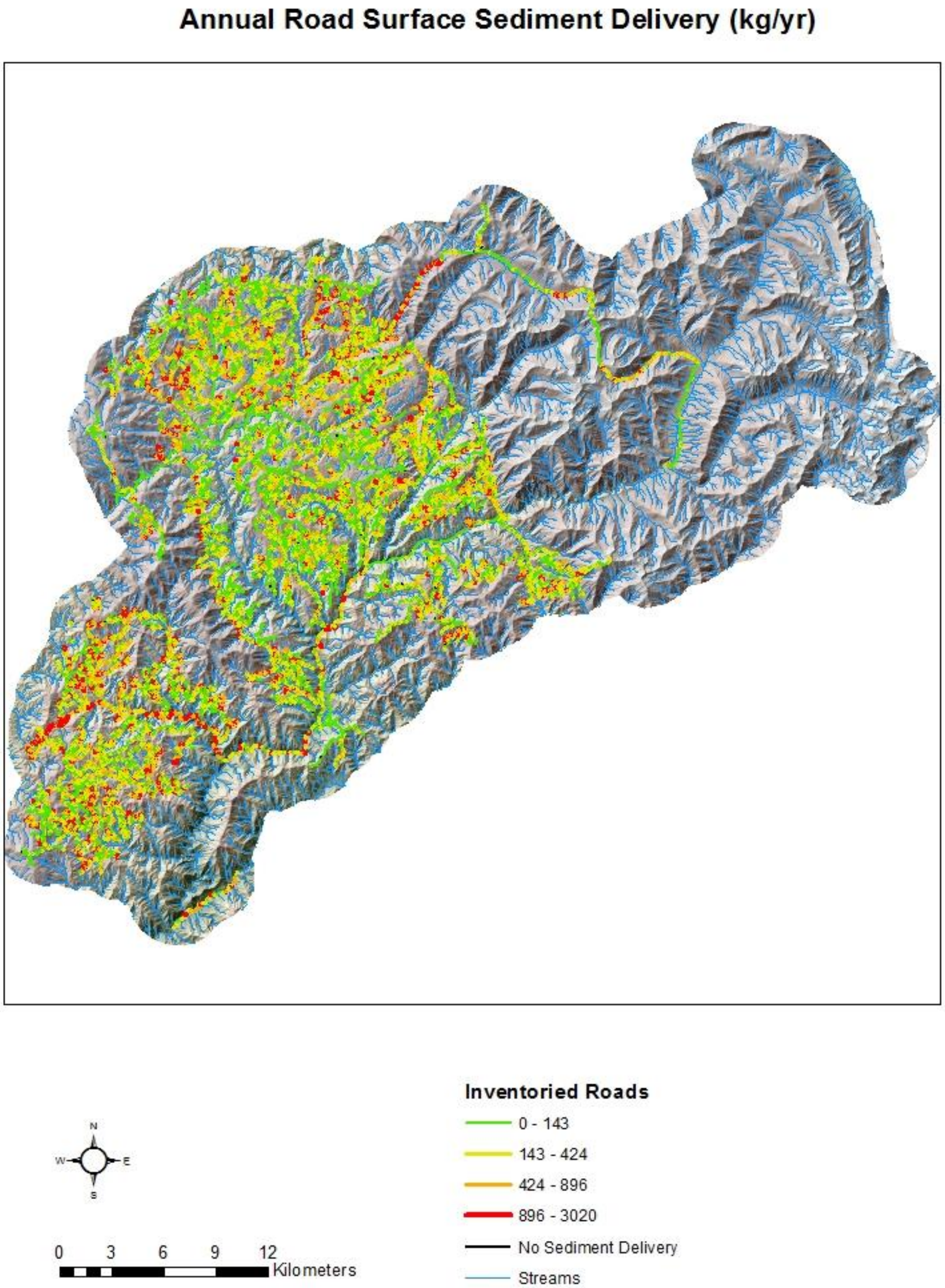
gl_strrdden0	Connected road density, Initial condition
gl_strrdden1	Connected road density, Disturbed condition
gl_strrdden2	Connected road density, recovered condition
gl_strrdlen0	
gl_strrdlen1	
gl_strrdlen2	
Layers	**Folders for rasters created by initial model**
cat	Catchments
dem	DEM, copy if Input DEM
disttostrm	Flow distance to stream
fac	Flow accumulation
fdr	Flow direction
fil	Pit-filled DEM
gl_acclength	Accumulated road length
gl_connlength	Drainpoints connected road length
gl_dp	Drainpoints sediment delivery
gl_seddel	Accumulated sediment
gl_sedstr	
gl_specsedstr	Specific sediment
gl_strroadden	Road density
gl_strroadlen	
Input DEM	The DEM used as model input
hillshade	Hillshade of the DEM
str	Stream network raster
strlnk	
project.gdb	**Project geodatabase**
Alternative1	**Geodatabase folder for feature classes related to Alternative 1**
Alternative1_DrainageLine	Stream network feature class for Alternative 1
Alternative1_Road	Initial road layer for Alternative 1
Alternative1_RoadDrainPoint0	Drainpoints for Initial condition

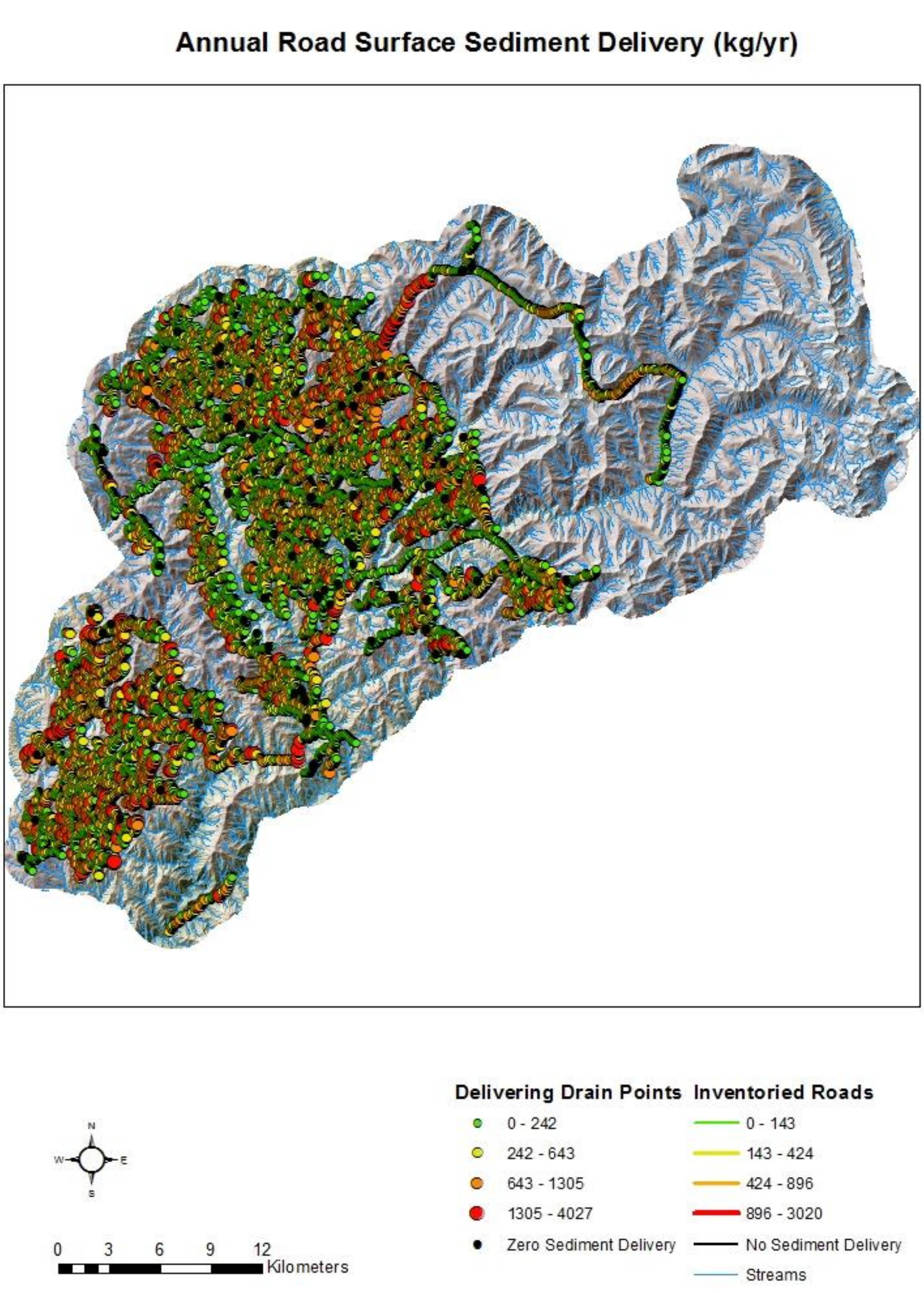
Alternative1_RoadDrainPoint0Diss	Dissolved drainpoints for Initial condition
Alternative1_RoadDrainPoint1	Drainpoints for Disturbed condition
Alternative1_RoadDrainPoint1Diss	Dissolved drainpoints for Disturbed condition
Alternative1_RoadDrainPoint2	Drainpoints for Recovered condition
Alternative1_RoadDrainPoint2Diss	Dissolved drainpoints for Recovered condition
Alternative1_RoadSegment0	Road segments for Initial condition
Alternative1_RoadSegment1	Road segments for Disturbed condition
Alternative1_RoadSegment2	Road segments for Recovered condition
Alternative1_RoadSplitPoint0	Road split points for Initial condition
Alternative1_RoadSplitPoint1	Road split points for Disturbed condition
Alternative1_RoadSplitPoint2	Road split points for Recovered condition
Layers	**Geodatabase folder for feature classes related to initial model**
CalibrationZone	Calibration zone feature class
Catchment	Catchments feature class
DrainageLine	Drainage lines (streams) feature class
DrainagePoint	Stream network intersection points
DrainPointObserved	Observed drainpoints; copy of Input Known Drains
Road	Road feature class with GRAIP_Lite attributes, including QC
Road_overlap	Overlapping road segments, part of QC
RoadDrainPoint	Drainpoints
RoadDrainPointDiss	Dissolved drainpoints
RoadInit	Road feature class with GRAIP_Lite attributes
RoadSegment	GRAIP_Lite road segments
RoadSplitPoint	GRAIP_Lite road split points

APUNIQUEID	
Baserate	Table with baserates by calibration
DeliveryProbability	Table with delivery probability curves by calibration
DrainageLine_FS	
GLAlternatives	Descriptions of alternatives analyzed
GLDefaultVTLSbyML	Default vegetation, traffic, split lengths, and surfacing by maintenance level
GLRoadTreatment	VTLS by treatment type
MaintenanceLevelLookup	Lookup table to fill in missing maintenance levels base on ROUTE_STAT field
RoadSegmentSizeCategory	Maximum road segment length definitions for delivery curves
SplitDistancebyMaintenanceLevel	Maximum road segment lengths by maintenance level
SurfaceFactor	Surface factors by surface type and traffic level
SurfaceTypeLookup	Lookup table to condense INFRA surface type values
TrafficbyMaintenanceLevel	Default traffic levels based on maintenance level
VegFactor	Vegetation factors by calibration, surface type, and maintenance level
VegFactorbyVegCover	Vegetation factors for Bare and Covered values for treatment options
project.mxd	Map document in which GRAIP_Lite is done.
Input Roads	Input road layer, line shapefile or feature class, must have route status, maintenance level, and surface type fields with appropriate values
Input Calibration Zones	Input calibration zones, polygon shapefile or feature class, must have name field with appropriate values

Input Known Drains	Input known drains, point shapefile or feature class

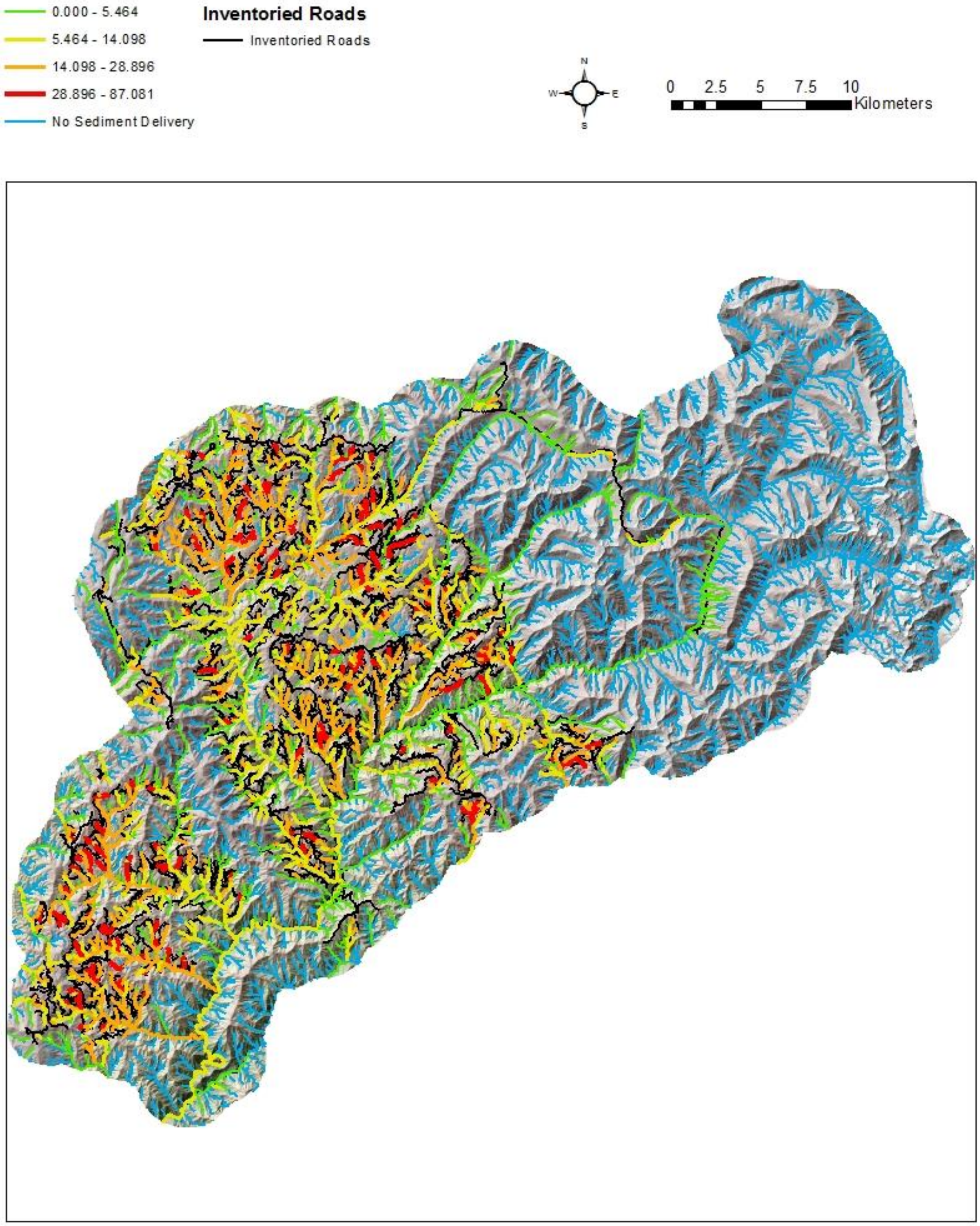
Appendix D: Basic Report Example




Annual Road Surface Sediment Delivery (kg/yr)
N
W
E
S
0 3 6 9 12
Kilometers
Delivering Drain Points
0 - 242
242 - 643
643 - 1305
1305 - 4027
Zero Sediment Delivery
Inventoried Roads
0 - 143
143 - 424
424 - 896
896 - 3020
No Sediment Delivery
Streams

Road Surface Sediment Accumulation in Streams (ton/yr)
0 - 241
241 - 1137
1137 - 2677
2677 - 6490
No Sediment Delivery
Inventoried Roads
Inventoried Roads
N
W
E
S
0 2.5 5 7.5 10
Kilometers

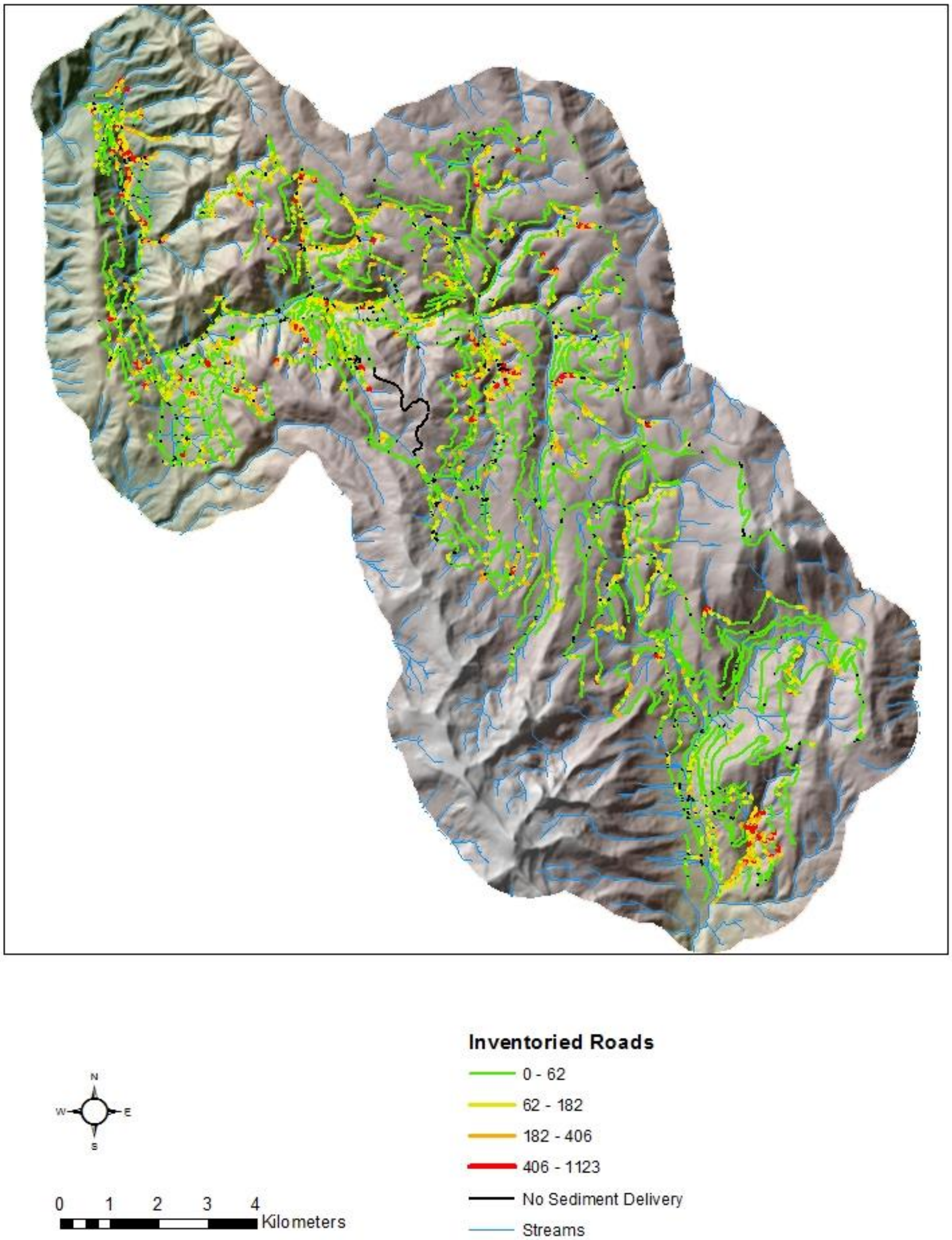
Road Surface Specific Sediment Accumulation in Streams (ton/yr/sqkm)



Appendix E: Alternative Report Example

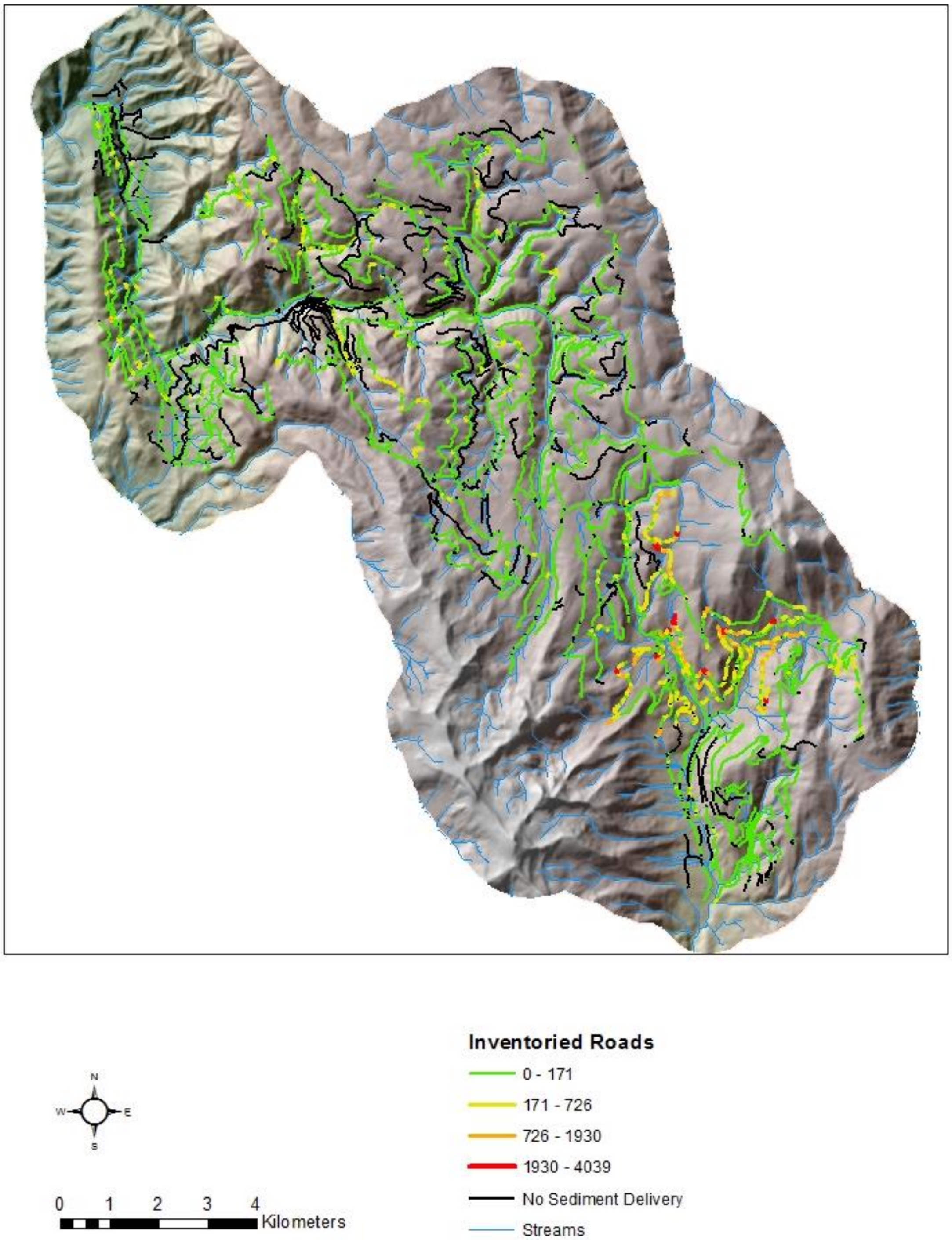
Annual Road Surface Sediment Delivery (kg/yr)

Alternative1 - Current



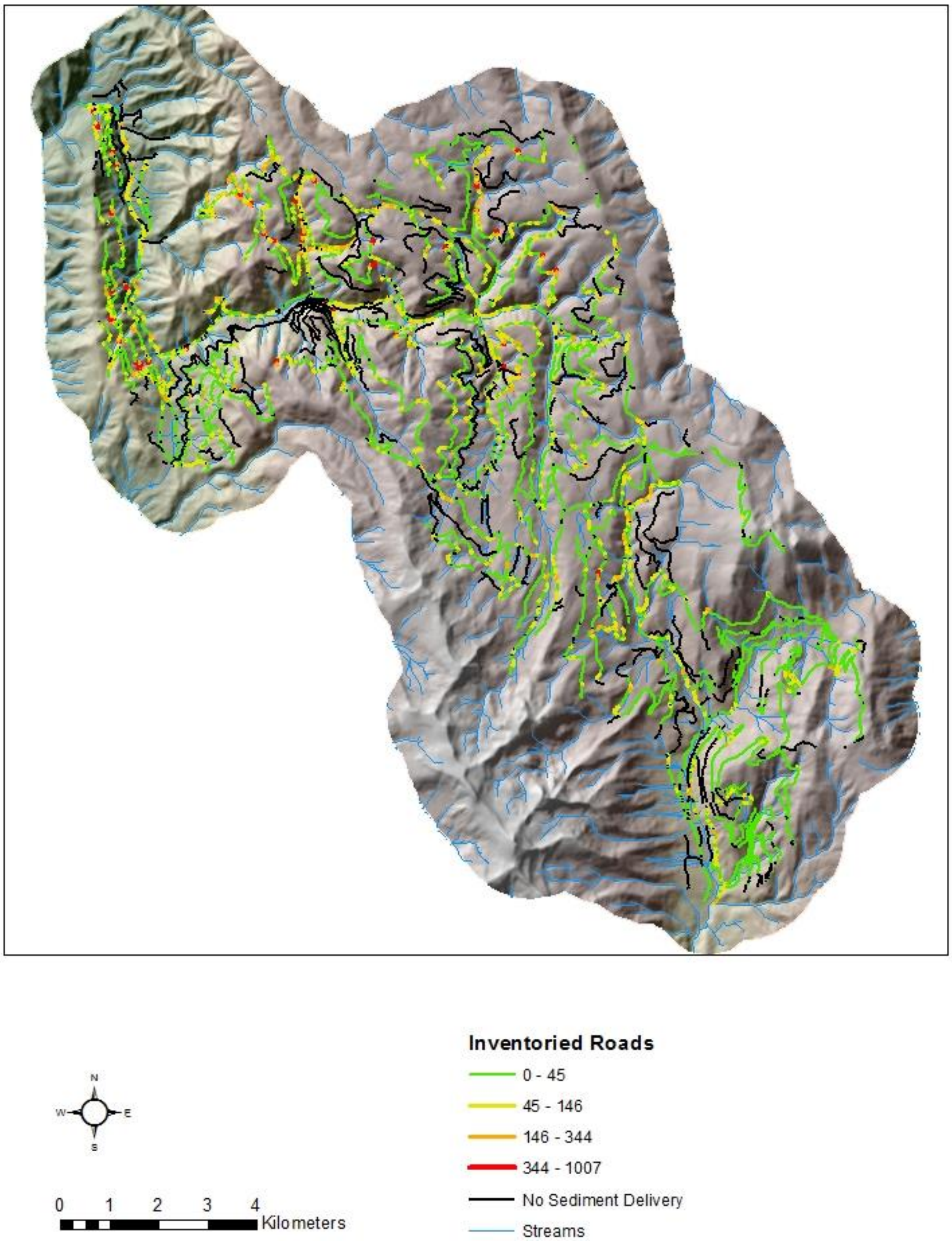
Annual Road Surface Sediment Delivery (kg/yr)

Alternative1 - Disturbed



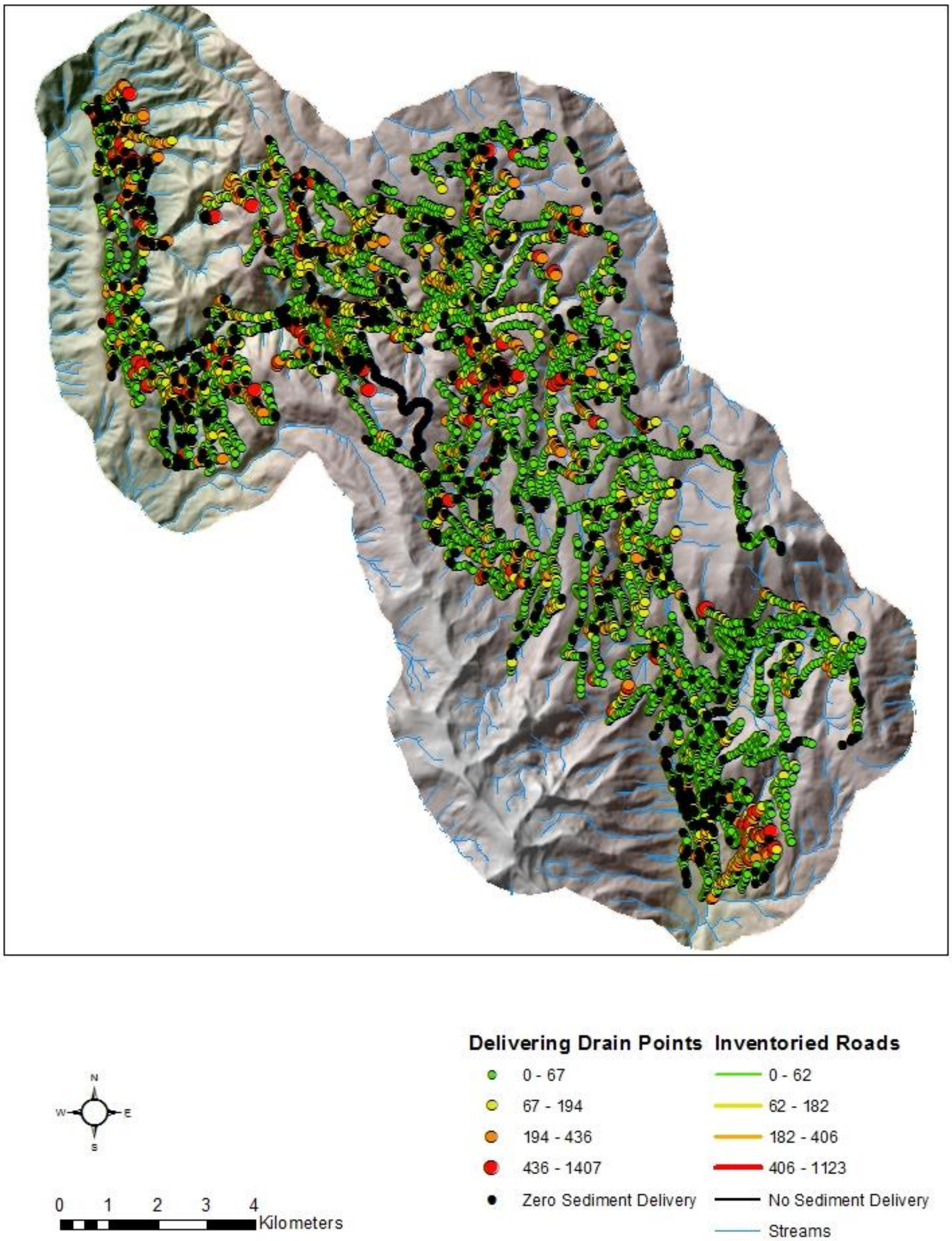
Annual Road Surface Sediment Delivery (kg/yr)

Alternative1 - Long Term



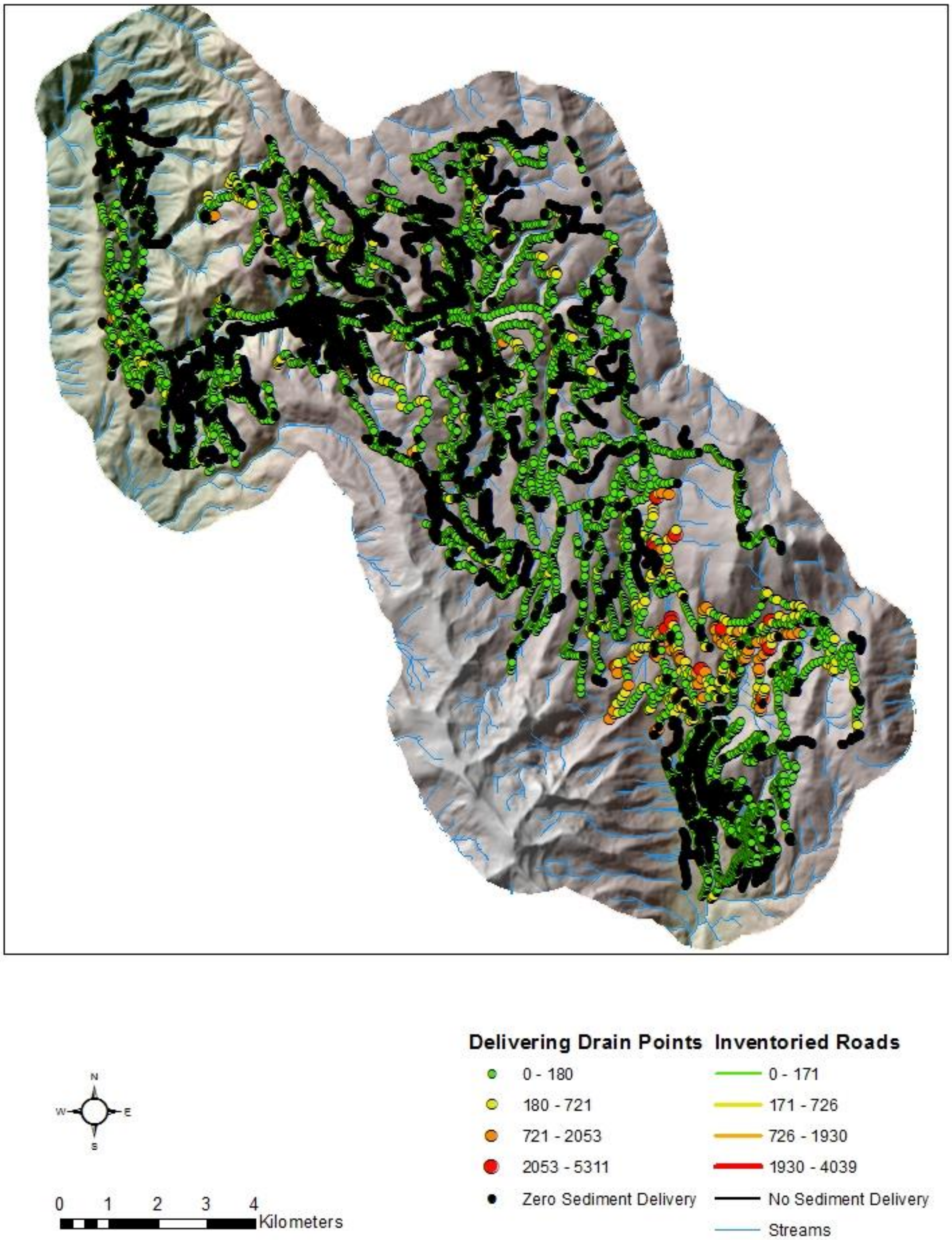
Annual Road Surface Sediment Delivery (kg/yr)

Alternative1 - Current



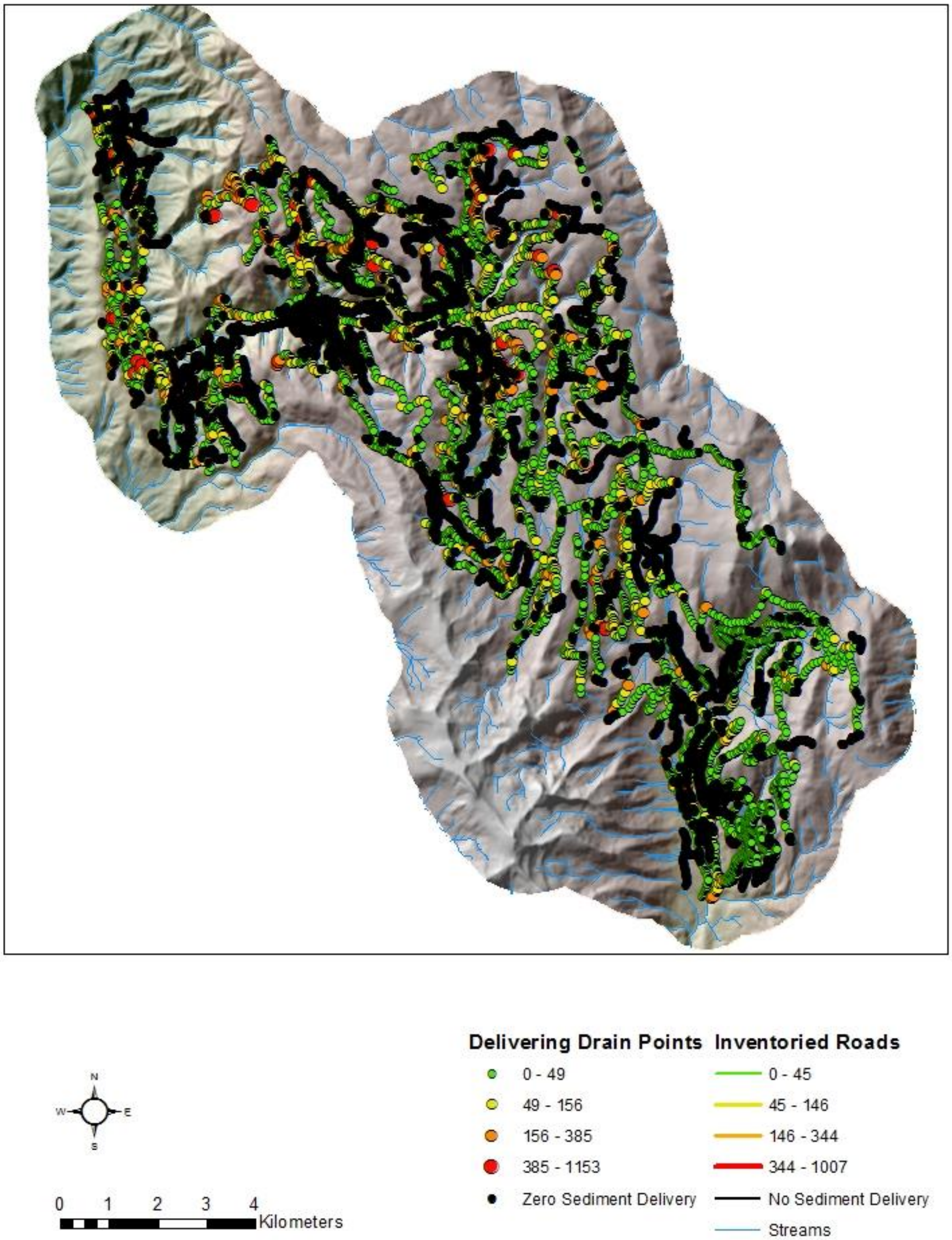
Annual Road Surface Sediment Delivery (kg/yr)

Alternative1 - Disturbed



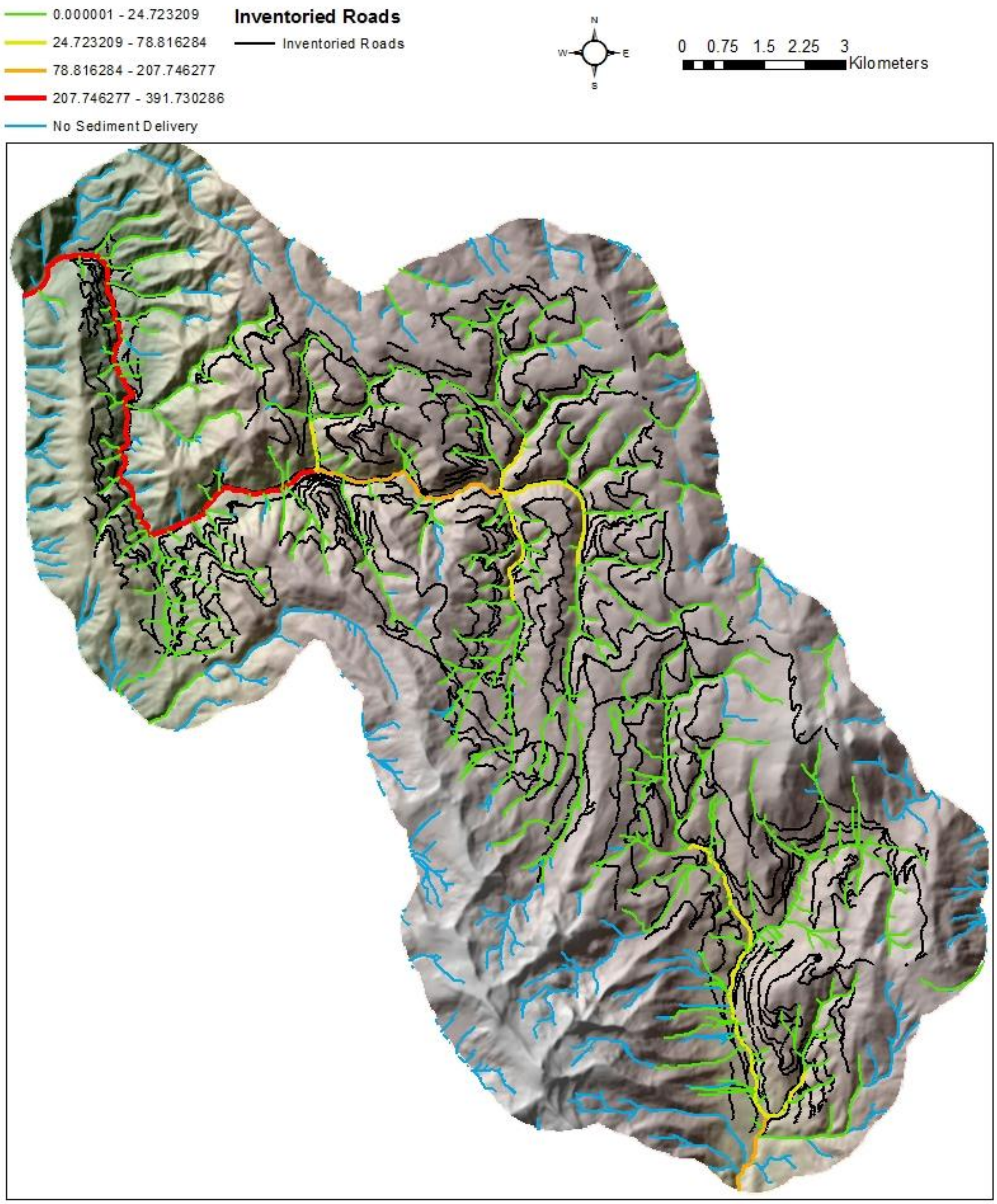
Annual Road Surface Sediment Delivery (kg/yr)

Alternative1 - Long Term



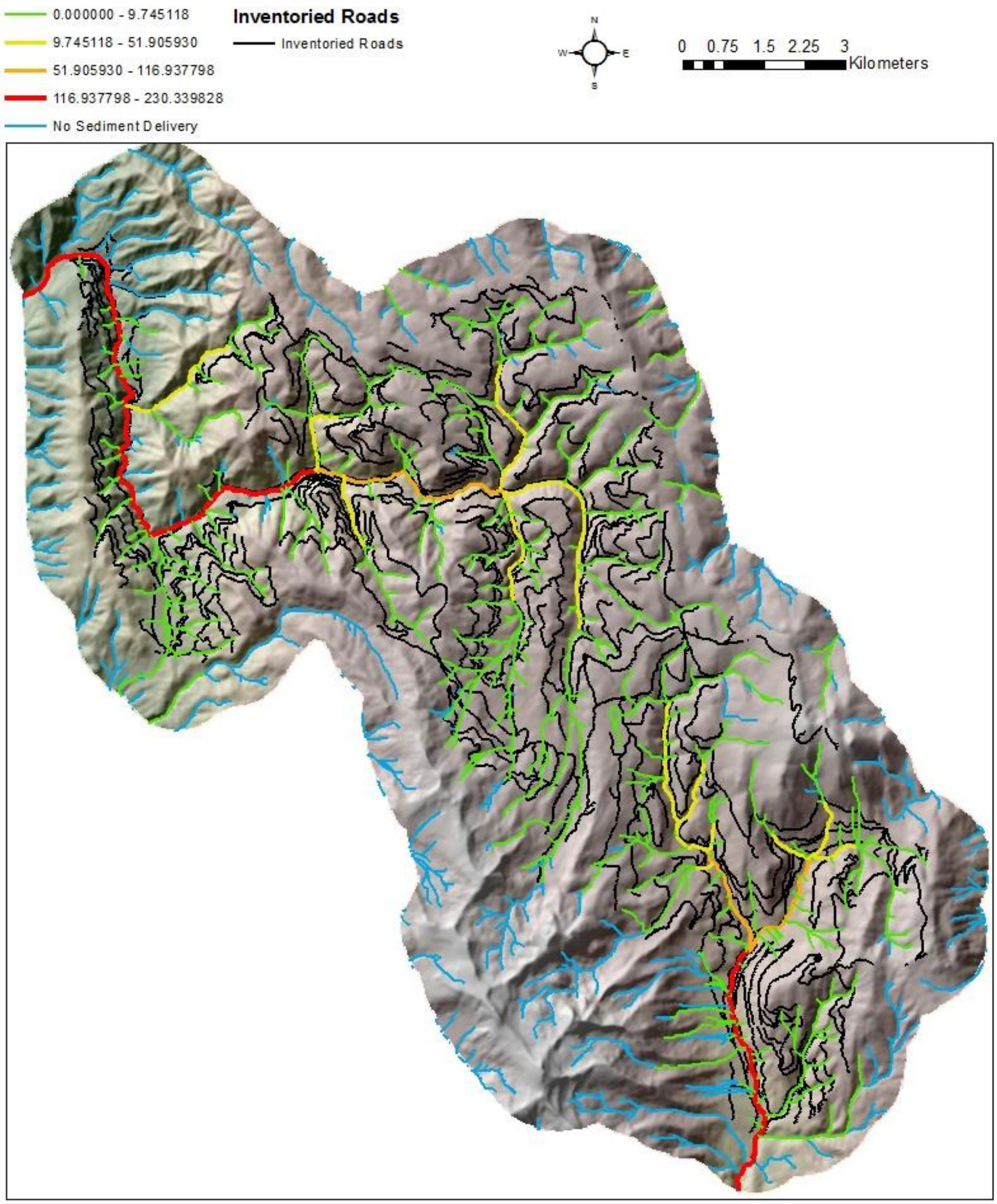
Road Surface Sediment Accumulation in Streams (ton/yr)

Alternative1 - Current



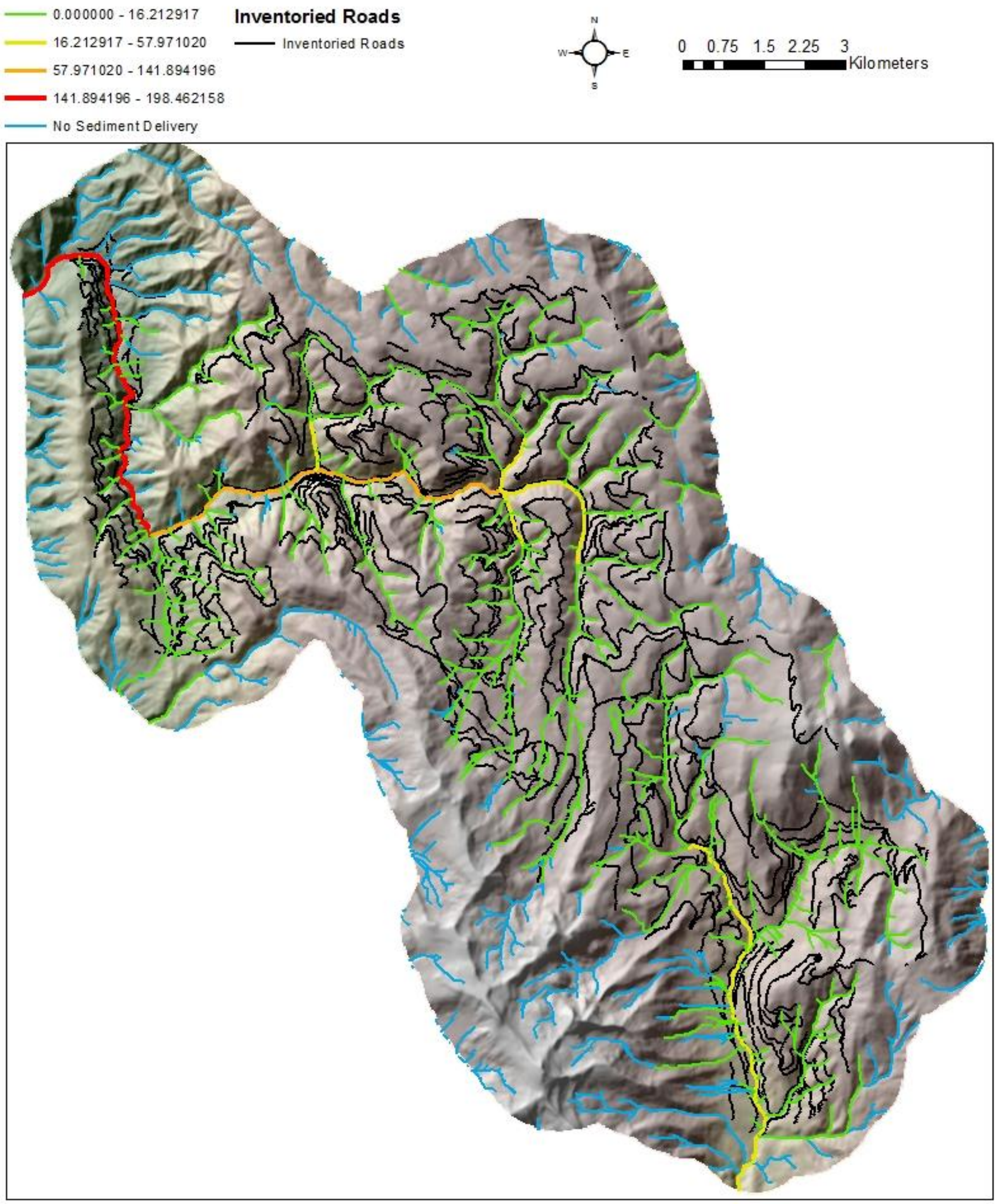
Road Surface Sediment Accumulation in Streams (ton/yr)

Alternative1 - Disturbed



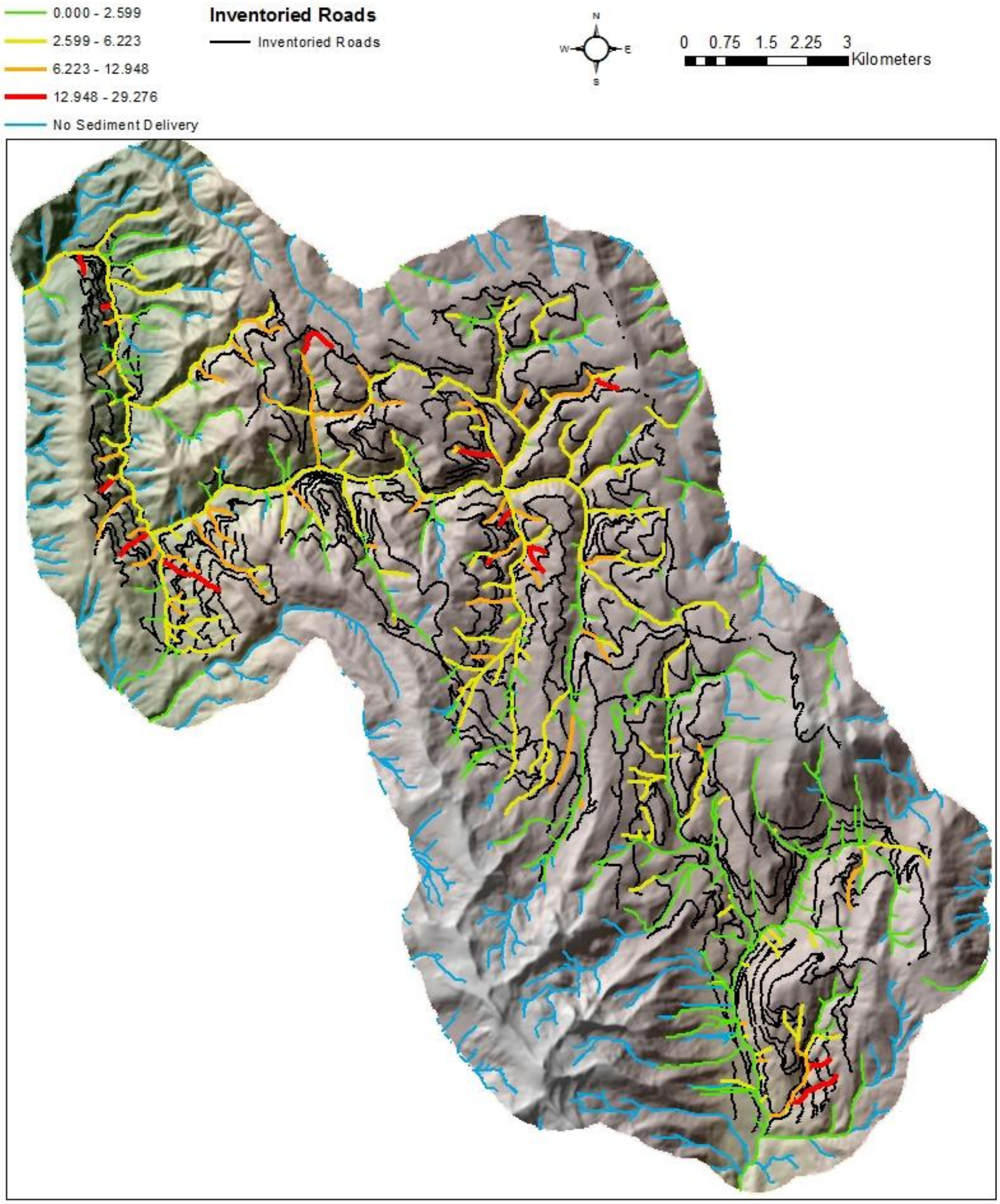
Road Surface Sediment Accumulation in Streams (ton/yr)

Alternative1 - Long Term



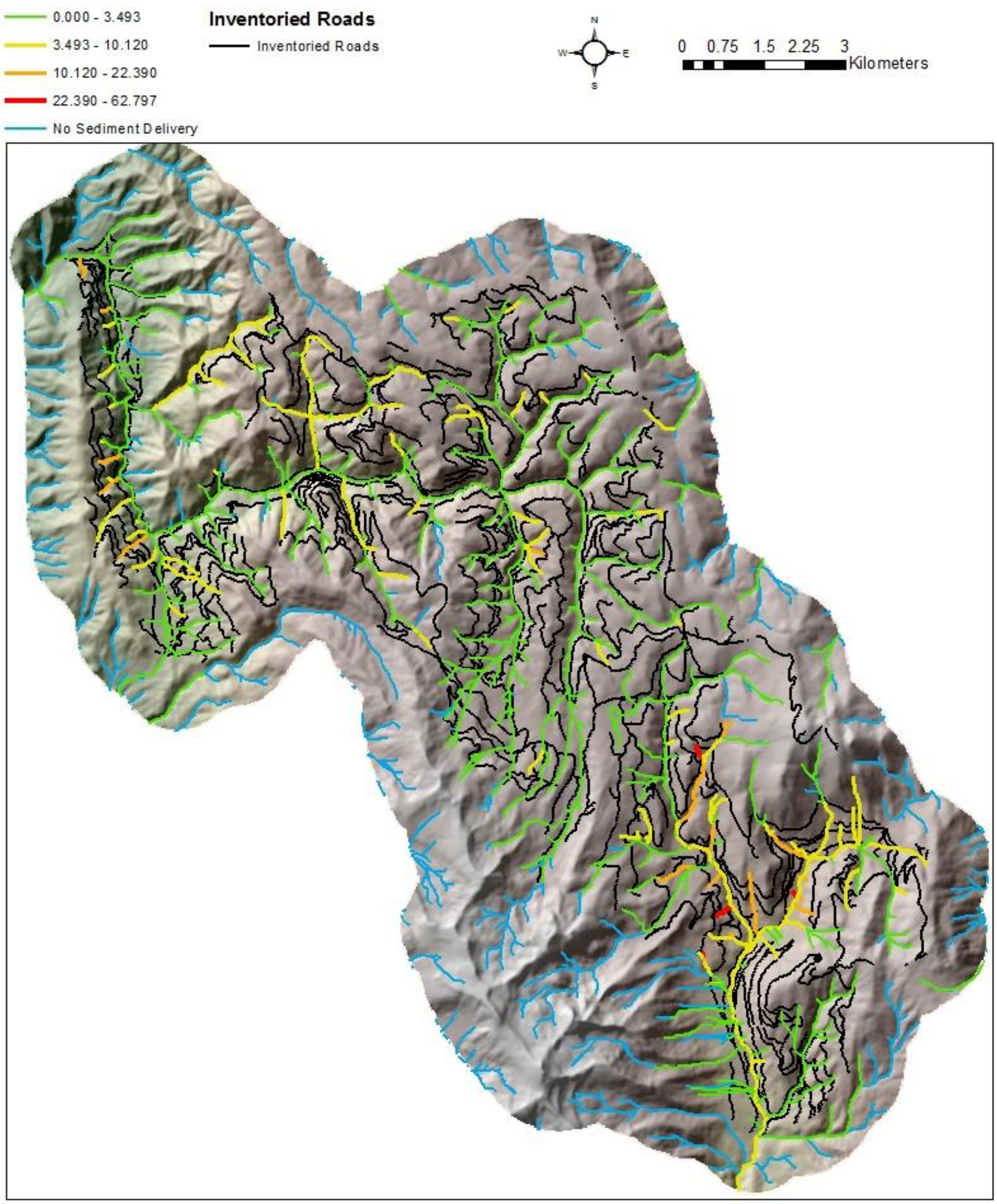
Road Surface Specific Sediment Accumulation in Streams (ton/yr/sqkm)

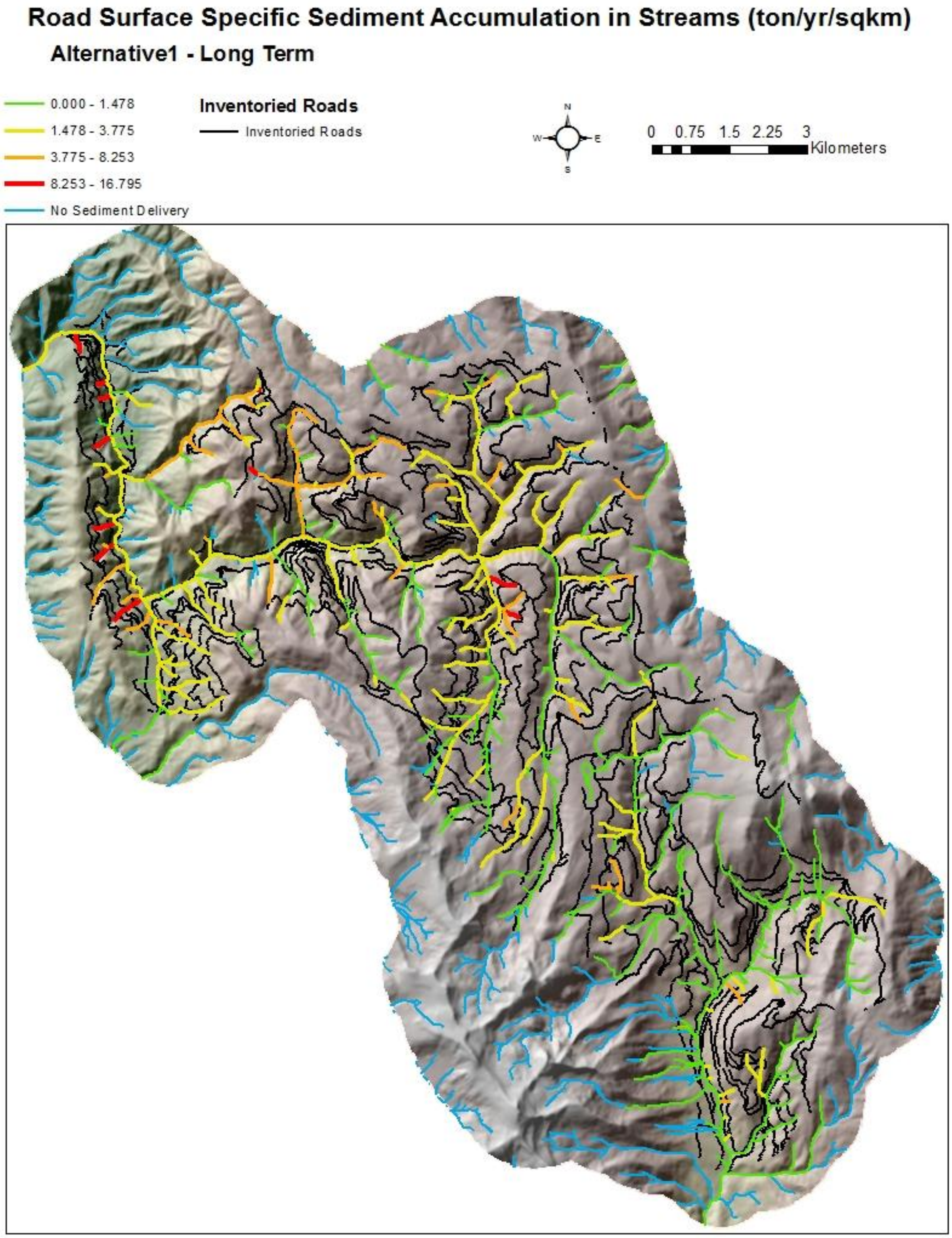
Alternative1 - Current



Road Surface Specific Sediment Accumulation in Streams (ton/yr/sqkm)

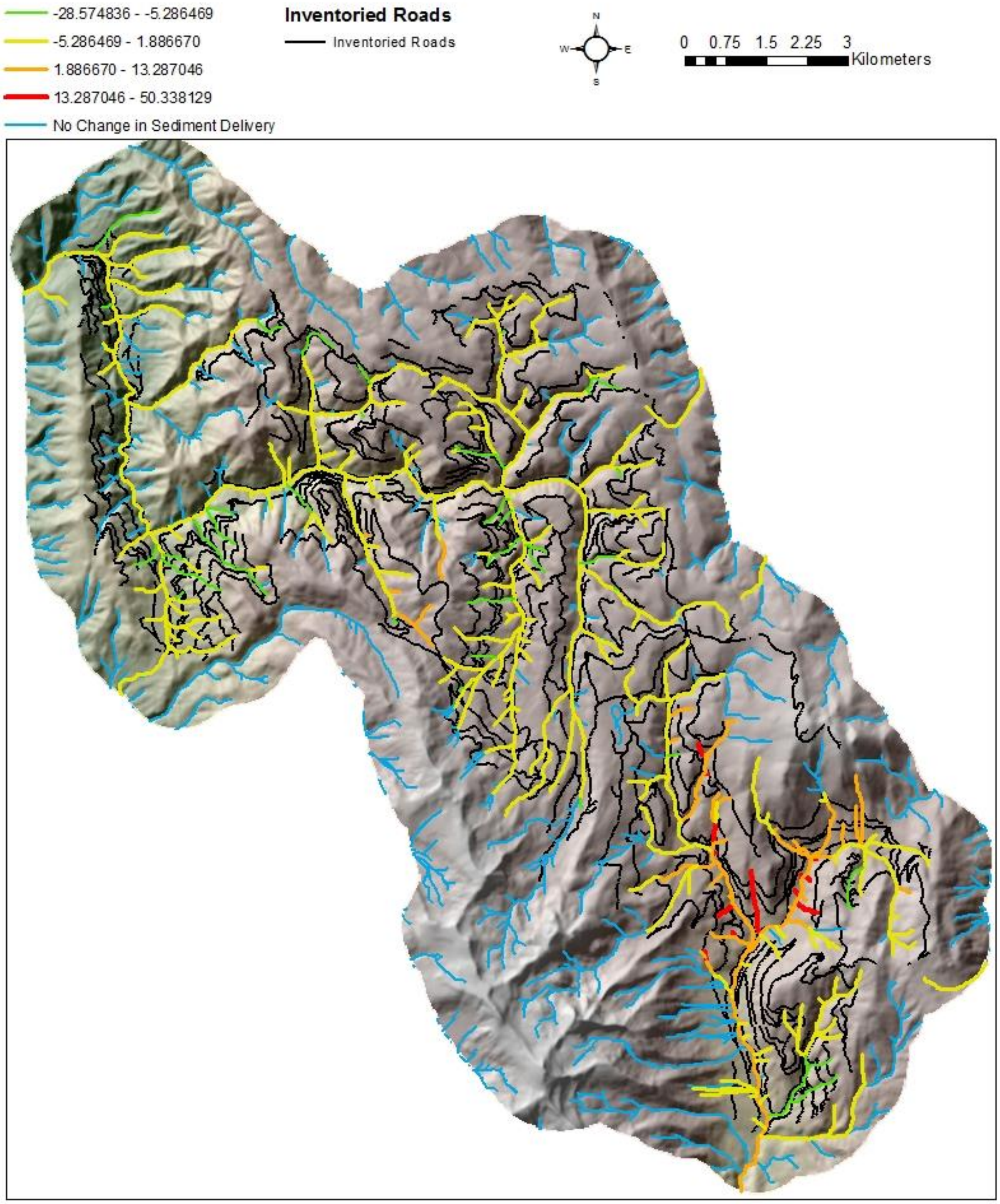
Alternative1 - Disturbed




Road Surface Specific Sediment Accumulation in Streams (ton/yr/sqkm)
Alternative1 - Long Term
0.000 - 1.478
1.478 - 3.775
3.775 - 8.253
8.253 - 16.795
No Sediment Delivery
Inventoried Roads
Inventoried Roads
N
W
E
S
0 0.75 1.5 2.25 3
Kilometers

Change in Road Surface Specific Sediment Load in Streams (ton/yr/sqkm)

Alternative1 - Disturbed




Change in Road Surface Specific Sediment Load in Streams (ton/yr/sqkm)
Alternative1 - Long Term
-29.034059 - -11.696178
-11.696178 - -5.097678
-5.097678 - -1.558374
-1.558374 - 1.150805
No Change in Sediment Delivery
Inventoried Roads
Inventoried Roads
N
W
E
S
0 0.75 1.5 2.25 3
Kilometers

Appendix F: Tips and Tricks

How to change traffic levels, surface types, maintenance levels, and split distances when using the Processing tools in GRAIP_Lite.

Run the Initialize GRAIP Lite Database tool. This imports the roads and creates the GL_Traffic field in the Road feature class. The process to change the traffic could also be used to update surface type or maintenance level fields as well to correct inaccuracies in the INFRA layer used as input.

1. Start an editing session and select the Road feature class as your editing target.
2. Select the roads on which you need to make the changes.
3. Open the attribute table for the Road feature class and scroll to the right until you find GL_Traffic.
4. For your selected roads, click in the GL_Traffic field, which should open a drop-down menu of the available options.
5. Select the option you want, which won't be <null> unless you are trying to crash GRAIP_Lite.
6. Save edits and exit the editing session.
7. Continue with the GRAIP_Lite run.

For numeric fields like GL_MaintenanceLevel or GL_SplitDistance, you don't get a drop-down menu so you need to be a little more careful about what numbers you put in there, especially for maintenance level.

How to reset the calibration zone from Default.

Run the Initialize GRAIP Lite Database tool. One of the things this does is create a CalibrationZone feature class in the geodatabase if you haven't provided one. The CalibrationZone will be the same extent as the DEM you supplied, and stores the name of the calibration data set to be used in the GL_CalibrationZone field. If you change this name to match a different existing calibration data set, it will make the model use the corresponding calibration data for baserate, vegetation factors, and delivery curves. If you change it to something that does not match the names used for existing calibration data sets, you need to provide the data for the calibration or the model will crash.

Glossary

Calibration zone: A polygon that defines which calibration, with its attendant baserate, vegetation factors, and delivery curves, is used for modelling roads within that polygon.

Connected road density: The density of stream-connected road within the contributing watershed area for a given stream reach, reported as GL_RoadDen in the DrainageLine feature class. Connected road length is determined for each road segment as the road length multiplied by the delivery probability; this is then accumulated through the stream network and normalized by contributing area. The units are km/km^2.

Connected road length: The length of stream-connected road within the contributing watershed area for a given stream reach, reported as GL_RoadLen in the DrainageLine feature class. Connected road length is determined for each road segment as the road length multiplied by the delivery probability; this is then accumulated through the stream network. The units are km.

Drainpoint: A point on the road network where water and sediment leave the road. In GRAIP_Lite, these are arbitrarily defined based on topography and other factors except where known drainpoints are present in the known drainpoints layer.

Sediment accumulation: The sum of all delivered sediment that is routed to a given stream reach, reported as GL_SedAccum in the DrainageLine feature class. The units are Mg/yr.

Sediment delivery: That portion of sediment produced on the road surface that makes it into the stream network, reported as GL_SedDel in the RoadSegment, RoadDrainPoint, and RoadDrainPointDiss feature classes. The units are kg/yr.

Sediment production: Surface erosion generated on the road tread and ditch, reported as GL_SedProd in the RoadSegment and RoadDrainPoint feature classes. The units are kg/yr.

Specific sediment delivery: Sediment accumulation normalized by contributing area, reported as GL_SpecSedDel in the DrainageLine feature class. The units are $Mg/yr/km^2$.

References

Apadoca, M., Tippie, M., Verde, A. M., and Barandino, V. Jr. 2012. Guidelines for road maintenance levels. San Dimas CA. U.S. Department of Agriculture, Forest Service, San Dimas Technology Development Center. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3793545.pdf.

Bilby, R. E., Sullivan, K., and Duncan, S.H. 1989. The generation and fate of road-surface sediment in forested watersheds in southwestern Washington. Forest Science. Vol. 35, No. 2, pp: 453-468.

Black, T.A., Cissel, R., Nelson, N. and C. Luce. Sediment plot data from open and closed roads in the Southwest Crown of the Continent. Lolo, National Forest. Unpublished data.

Black, T. A., Luce, C. H. 2013. Measuring water and sediment discharge from a road plot. Gen. Tech. Rep. RMRS-GTR-287, Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Clarkin, K., Connor, A., Furniss, M. J., Gubernick, B., Love, M., Moynan, K., and WilsonMusser, S. 2005. National inventory and assessment procedure for identifying barriers to aquatic organism passage at road-stream crossings. San Dimas, CA. U.S. Department of Agriculture, Forest Service, National Technology and Development Program.

Cline, R., Cole, G., Megahan, W., Patten, R., and Potyondy J. 1984. Guide for predicting sediment yield from forested watersheds. Missoula, MT and Ogden, UT. U.S. Department of Agriculture, Forest Service, Northern Region and Intermountain Region.

Fahey, B.D., and Coker, R.J. 1989. Forest Road Erosion in the Granite Terrain of Southwest Nelson, New Zealand. New Zealand Journal of Hydrology 28(2).

Flanagan, S. A., Furniss, M. J., Ledwith, T. S., Thiesen, S., Love, M., Moore, K., and Ory. J. 1998. Methods for inventory and environmental risk assessment of road drainage crossings. Water Road Interaction Technology Series. San Dimas CA. U.S. Department of Agriculture, Forest Service, San Dimas Technology Development Center, July 15, 1999.

Fly, C. M., Grover-Weir, K., Thornton, J., Black, T. A., and Luce, C. M. 2010. Bear Valley road inventory (GRAIP) report; Bear Valley Category 4b assessment, Boise National Forest. Boise, ID. U.S. Department of Agriculture, Forest Service, Boise National Forest.

Foltz, R. B., Traffic and no-traffic on an aggregate surfaced road: Sediment production-differences Seminar on environmentally sound forest roads and wood transport. Food and Agric. Organ. Rome, Italy, 1999.

Goode, J. R., Luce, C. H., & Buffington, J. M. (2012). Enhanced sediment delivery in a changing climate in semi-arid mountain basins: Implications for water resource management and aquatic habitat in the northern Rocky Mountains. *Geomorphology, 139-140*, 1-15. doi: doi: 10.1016/j.geomorph.2011.06.02

Kochenderfer, J. N., and J.D. Helvey (1987) Using gravel to reduce soil losses from minimum-standard forest roads. Journal of Soil and Water Conservation 42(1).

Istanbulluoglu, E., Tarboton, D. G., Pack, R. T., Luce, C. H. 2003. A sediment transport model for incision of gullies on steep topography. *Water Resources Research*. Vol. 39, No. 4, pp: 1103-1117.

Luce, C. H., and Black, T. A. 1999. Sediment production from forest roads in western Oregon. Water Resources Research, Vol. 35, No. 8, pp: 2561-2570.

Luce, C. H. and Black, T. A. 2001. Effects of traffic and ditch maintenance on forest road sediment production. In Proceedings of the Seventh Federal Interagency Sedimentation Conference, March 25-29, 2001, Reno, NV. pp: V67-V74.

Luce, C. H. and Black, T. A. 2001. Spatial and temporal patterns in erosion from forest roads. In Influence of Urban and Forest Land Uses on the Hydrologic-Geomorphic Responses of Watersheds, M.S. Wigmosta and S.J. Burges, Editors, American Geophysical Union, Washington, D.C. pp: 165-178.

Luce, C. H. and Wemple, B. C. 2001. Introduction to special issue on hydrologic and geomorphic effects of forest roads. Earth Surface Processes and Landforms. Vol. 26. No. 2, pp: 111-113.

Maturana, O., Tonina, D., McKean, J. A., Buffington, J. M., Luce, C. H., & Caamaño, D. (2014). Modeling the effects of pulsed versus chronic sand inputs on salmonid spawning habitat in a low-gradient gravel-bed river. *Earth Surface Processes and Landforms, 39*(7), 877-889.

MacDonald, L. H., Anderson, D. M. and Dietrich, W. E. 1997. Paradise threatened: land use and erosion on St. John, US Virgin Islands. Environmental Management, Vol. 21, No. 6, pp: 581-863.

McCammon, B. P., Rector, J. R., and Gebhardt, K. 1998. A framework for analyzing the hydrologic condition of watersheds. Denver, CO. U.S. Department of Agriculture, Forest Service and U.S. Department of the Interior, Bureau of Land Management. 40 p.

Megahan, W. F. and Kidd, W. J. 1972. Effect of logging roads on sediment production rates in the Idaho batholith. Research Paper INT-123. Ogden, UT. U.S. Department of Agriculture, Forest Service. Intermountain Forest and Range Experiment Station.

Megahan, W. F. 1974. Erosion over time: a model. Research Paper INT-156. Ogden, UT. U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Megahan, W. F., and Ketcheson, G. L. 1996. Predicting downslope travel of granitic sediments from forest roads in Idaho. Water Resources Bulletin Vol. 32, No. 2, pp: 371-182.

Moll, J. 1997. Glossary of Water/Road Interaction Terminology. Water Road Interaction Technology Series. San Dimas CA. U.S. Department of Agriculture, Forest Service, San Dimas Technology Development Center.

Montgomery, D. R. 1994. Road surface drainage, channel initiation, and slope instability. Water Resources Research. Vol. 30, pp: 1925-1932.

Pack, R. T., Tarbotan, D. G., Goodwin, C. N., and Prasad, A. 2005. SINMAP 2. a stability index approach to terrain stability hazard mapping, technical description and users guide for version 2.0. Utah State University.

Prasad, A. 2007. A tool to analyze environmental impacts of roads on forest watersheds. MS Thesis, Civil and Environmental Engineering, Utah State University. http://www.neng.usu.edu/cee/faculty/dtarb/graip/AjayThesis.pdf

Reid, L. M., and Dunne. T. 1984. Sediment production from forest road surfaces. Water Resources Research. Vol. 20, No.11, pp: 1753-1761.

Sheridan, G.J., Noske, P.J., Whipp, R.K. and Wijesinghe, N., 2006. The effect of truck traffic and road water content on sediment delivery from unpaved forest roads. *Hydrological Processes*, *20*(8), pp.1683-1699.

Six Rivers Watershed Interactions Team. 1999. FishXing Version 2.1. USDA Forest Service Stream Technology Center and San Dimas Technology and Development Center. November 1999. www.stream.fs.fed.us/fishxing.

Swift, L. W. 1984. Gravel and grass surfacing reduces soil loss from mountain roads. Forest Science. Vol. 30, No. 3, pp: 657-670.

Tysdal, L., Elliot, W., Luce, C., & Black, T. (1999). Modeling erosion from insloping low-volume roads with WEPP watershed model. *Transportation Research Record: Journal of the Transportation Research Board, 1652*, 250-255.

USDA Forest Service. 1999. Roads analysis: informing decisions about managing the national forest transportation system. Misc. Rep. FS-643. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 222 p.

Washington Forest Practices Board. 1995. Standard methodology for conducting watershed analysis. Version 3.0, November 1995. Washington State Department of Natural Resources, Olympia, WA. pp. B1-B52.

Wemple, B. C., Jones, J. A., and Grant, G. E. 1996. Channel network extension by logging roads in two basins, western Cascades, Oregon. Water Resources Bulletin. Vol. 32, pp: 1195-1207.

Ziegler, A. D., Sutherland, R. A. and Giambelluca, T. W. 2001. Interstorm surface preparation and sediment detachment by vehicle traffic on unpaved mountain roads. Earth Surface Processes and Landforms. Vol. 26, pp: 235-250.