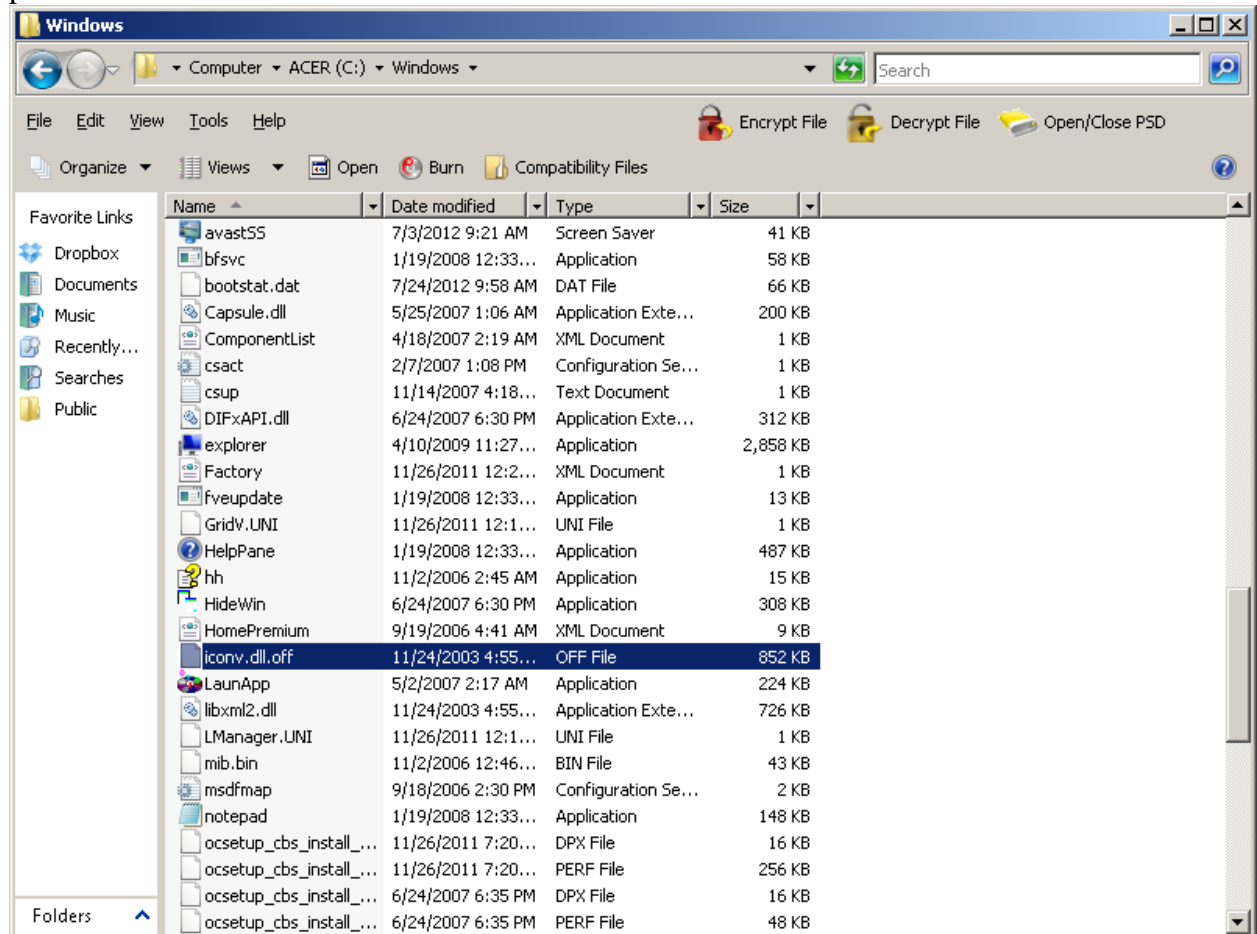


Watershed Modeling for QGIS-GRASS GIS

Purpose: To find the water and sediment discharge of a small watershed catchment (1-10 square kilometers).

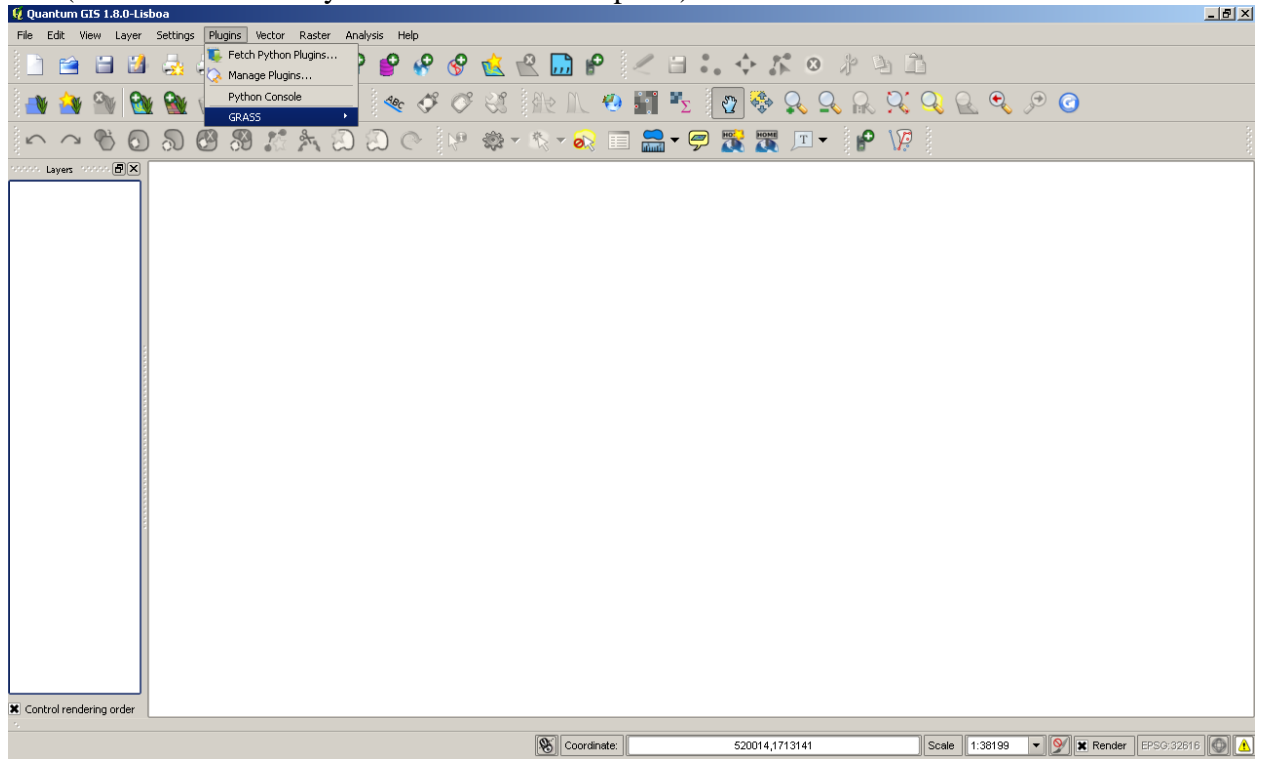
Help and Support: Please see <http://www.qgis.org/en/community.html> for sources of assistance. The mailing list and IRC chat are probably the most useful of assistance.

1. Download QGIS from here: <http://hub.qgis.org/projects/quantum-gis/wiki/Download#11-Standalone-Installer-recommended-for-new-users>
 - a. Download the Standalone Installer. This should download and install both QGIS and the GRASS GIS Plugin.
 - b. It has been found that you may not be able to run QGIS due to a duplicate file (called iconv.dll) in the C:/Windows folder. Simply rename the file to iconv.dll.off to fix the problem.

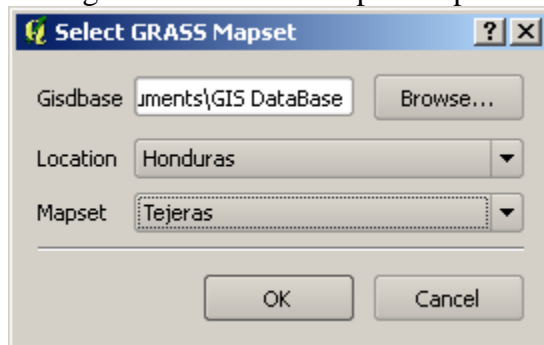


2. Run QGIS under administration settings (right click on desktop icon and select 'Run as Administrator'). Go to Plugins → GRASS → New Mapset. Make sure you database is located in the GIS Database folder in your documents folder where QGIS was supposed to install it into. Create a new location and mapset. Mapset is a subfolder within the Locations folder where all your data regarding the project will be stored. My preference for location is the region (nation or state) and the mapset is a nearby town or name of the area. It will also

ask you for the Geographic Coordinate System. Use the WGS84 system and look for your UTM zone (<http://www.dmap.co.uk/utmworld.htm>). Is your project north or south of the equator (hint: its relevant to your UTM zone description)?

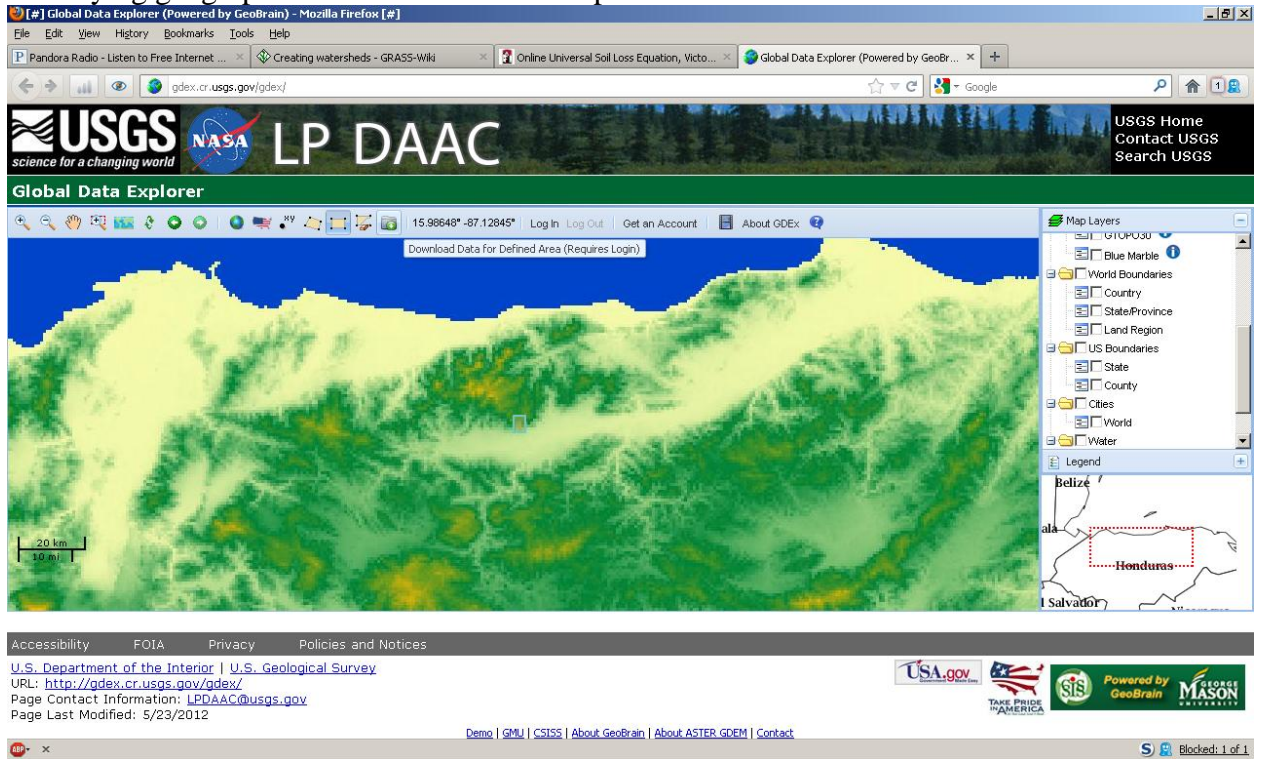


- a. Now every time you open up QGIS, you can use Open Mapset to get your project files: Plugins → GRASS → Open Mapset.

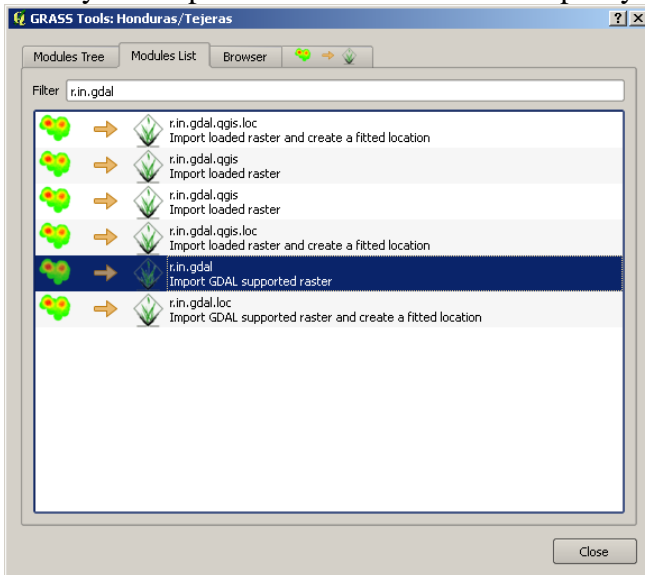


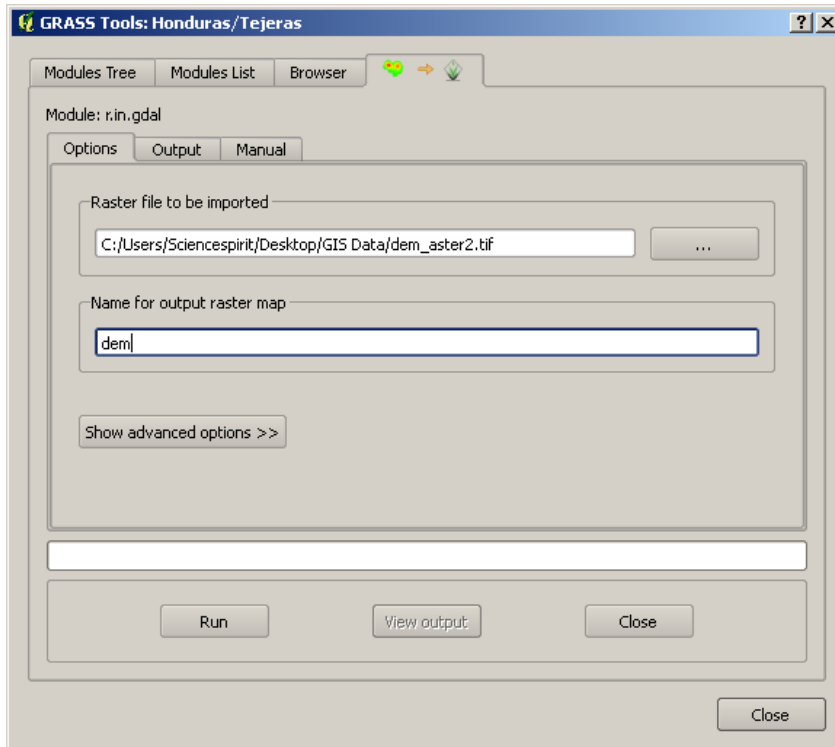
3. Next, you need to get a DEM file (Digital Elevation Model) for your catchment. You may do so by downloading it via this website: <http://gdex.cr.usgs.gov/gdex/>
 - a. You need to create an account first by clicking “Get an Account” on the Menu Bar and putting in a username, password, and email address.
 - b. Next, click on “Define Rectangular Area” or the rectangle icon to give the dimensions of your DEM. Click on the folder icon to download the DEM data.
 - c. Make sure you select ASTER Global DEM V2 or the STRM 90m option since they give different resolutions. The ASTER Global DEM V2 has a resolution of 30 meters whereas the STRM 90m option has a resolution of 90 meters. Resolution is the cell size and will be important to remember. Ideally, the smaller the cell size the greater the accuracy.

- d. Finding the dimensions of your catchment may be trial and error for you so keep clicking on the folder icon and see the preview to know if you got what you need. I have it big enough to encompass my catchment but not big enough to encompass multiple catchments that don't relate to my own catchment. You may use Google Earth (<http://earth.google.com>) to figure out where your catchment is located by identifying geographic features and elevation patterns.

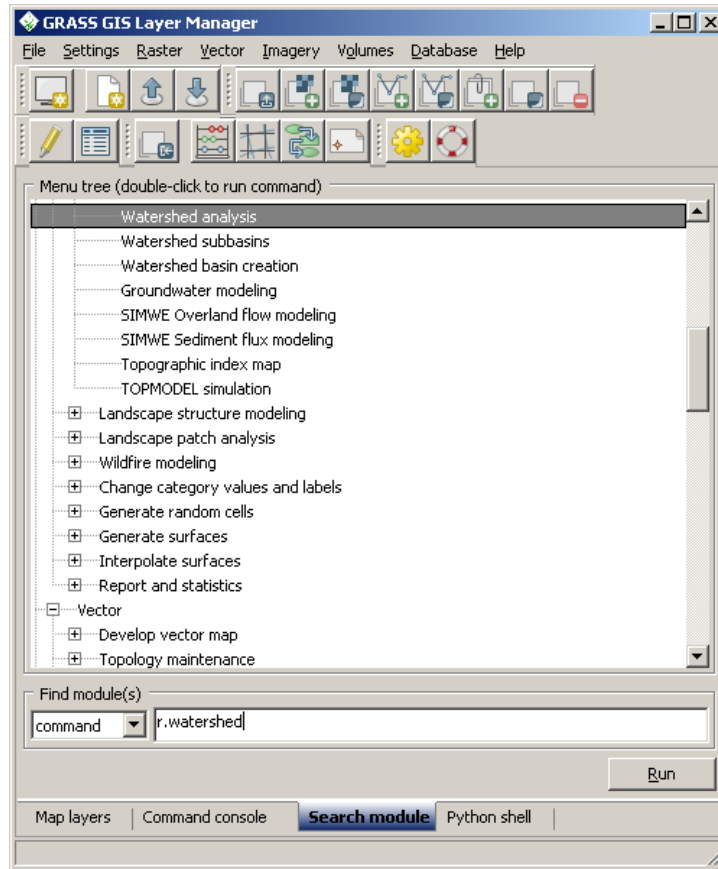


4. Import the DEM file into GRASS GIS by the following process. Look for GRASS GIS Tools by Plugins → GRASS → Open GRASS Tools. In the Modules List, search for “r.in.gdal” and select that option. Select your DEM in your computer to be imported and name your output raster file. Hit Run to import your DEM file into GRASS GIS.

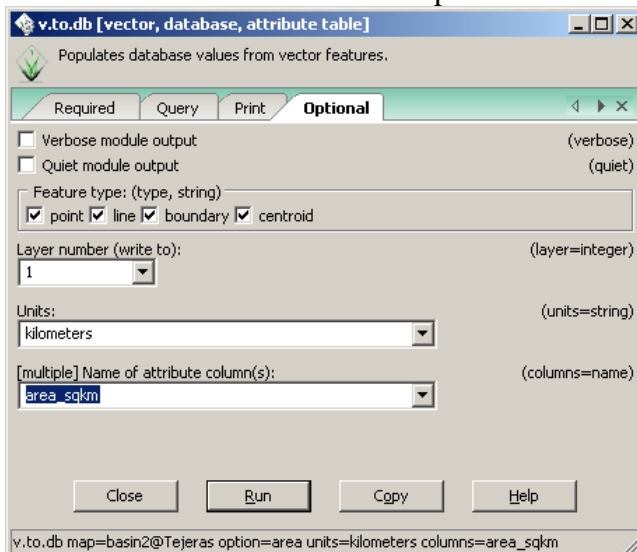




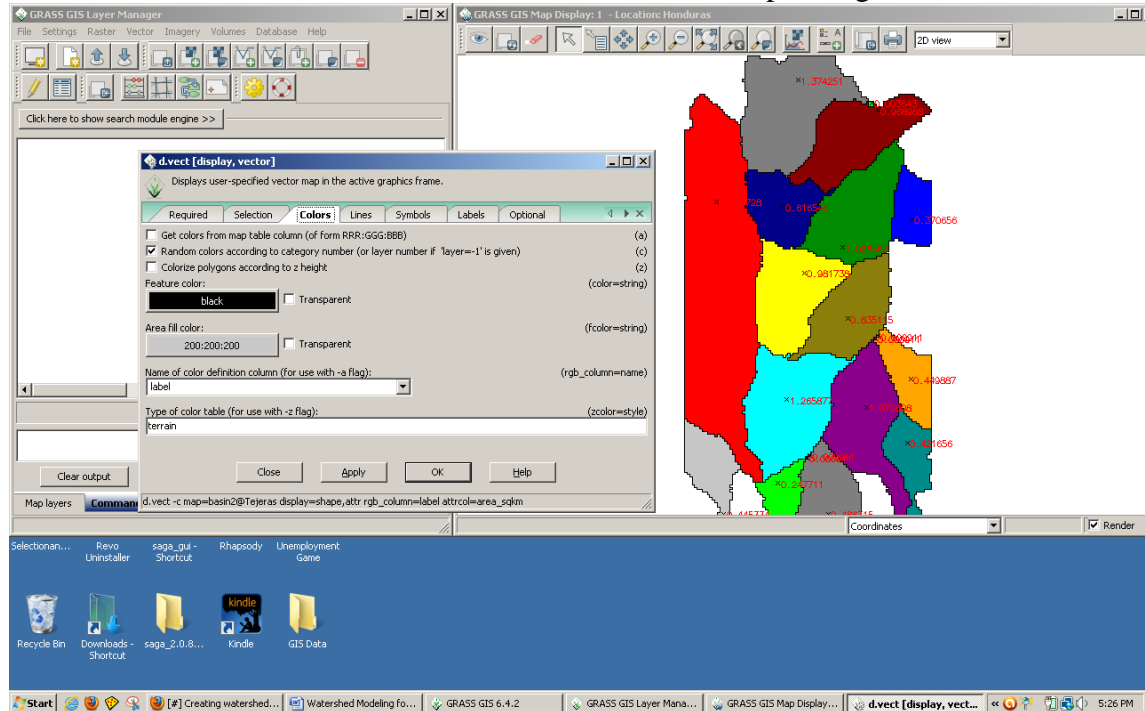
5. Now you can run a watershed analysis with GRASS by following these instructions:
 - http://grass.osgeo.org/wiki/Creating_watersheds
 - a. First, you need to set the region of the DEM. In the GRASS Tools Module, search for `g.region.multiple.raster` and input your DEM file. Now your project is set with the coordinate system as your raster file.
 - b. Search for `r.watershed` in the GRASS Tools Module. Your input map is your DEM file. Your threshold is the size of your smallest subbasin. You may use Google Earth (<http://earth.google.com>) and find the area of the smallest subbasin in your watershed or put in a value of 270,000 square meters. The formula is $\text{Cell Size} * \text{Threshold} = \text{Area of Smallest Subbasin}$. So if your resolution is 30 meters, your cell size should be $30 \text{ meters} * 30 \text{ meters} = 900 \text{ square meters}$. If so, the threshold should be 300 ($270,000 / 900 = 300$). Your outputs in order from top to bottom are accumulation, drainage direction, stream, and watershed basins. Provide a short name for those aspects and hit run. You should get three raster files and one vector file in the Layers window.
 - a. If for any reason the QGIS interface isn't working as it should, go to the desktop and double click on the GRASS GIS icon to open GRASS GIS. Make sure you run the program with Administrator Rights (Right click on the desktop icon and select "Run as Administrator"). Then run those GRASS Tools on GRASS GIS directly instead of through QGIS. You may need to search for the tools you'll be using in that interface (see picture below) to use those tools. Remember to click Enter to move to the next option and to start the search query.



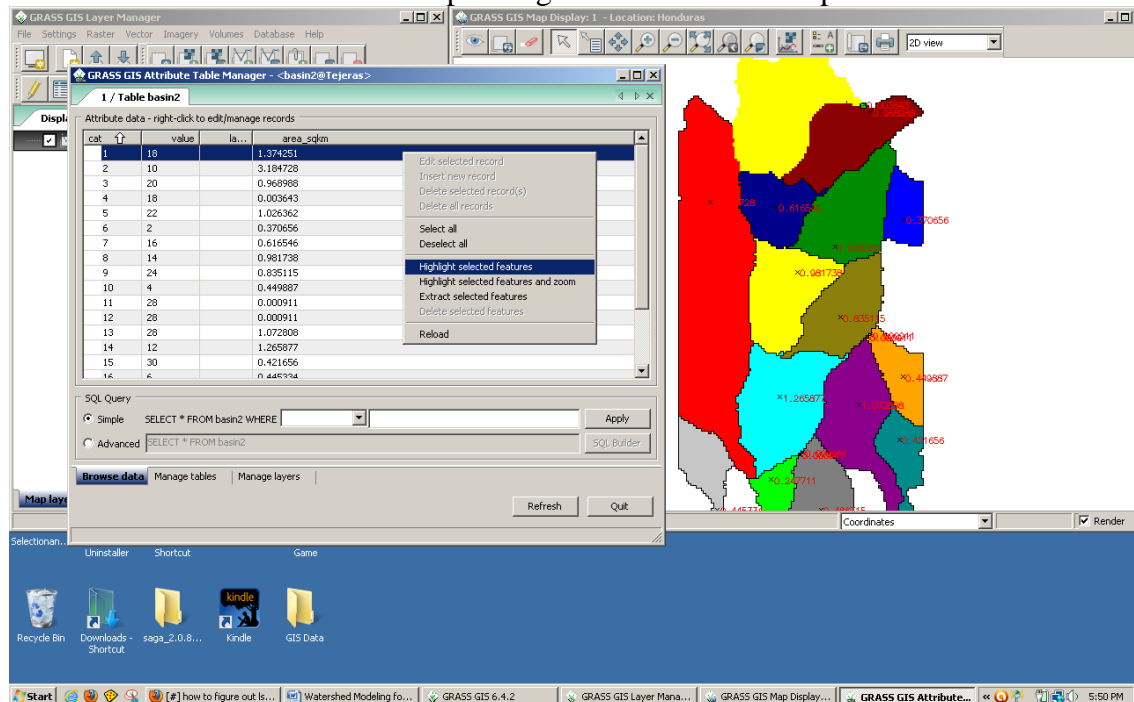
6. Find the Area of your subbasins is the next step.
 - a. Convert your watershed basin raster map (processed from r.watershed) into a vector basin map using r.to.vect.area GRASS Tool function.
 - b. Add a column by using the v.db.addcol GRASS Tool function with inputs of the vector basin map and new column name (call it “area_sqkm double”).
 - c. Then use the v.to.db GRASS Tool function to select kilometers as the unit and select the name of attribute table as “area_sqkm” (see picture below). Your input values should be the vector basin map and value to upload is area (in the required tab).



- d. Use d.vect GRASS Tool function to display vector basin map. On required tab, select display geometry of features and display selected attribute based on 'attrcol'. On labels tab, select name of column to be displayed as "area_sqkm". In colors tab, select random colors associated to category number and name of color definition column as label. Write out the watersheds areas and corresponding colors in a table.



- e. As an option if step d doesn't work. You can right click on the vector basin map and select attribute data. Then right click on the rows in the table and select highlight selected features to find the corresponding subbasin with its respected area.



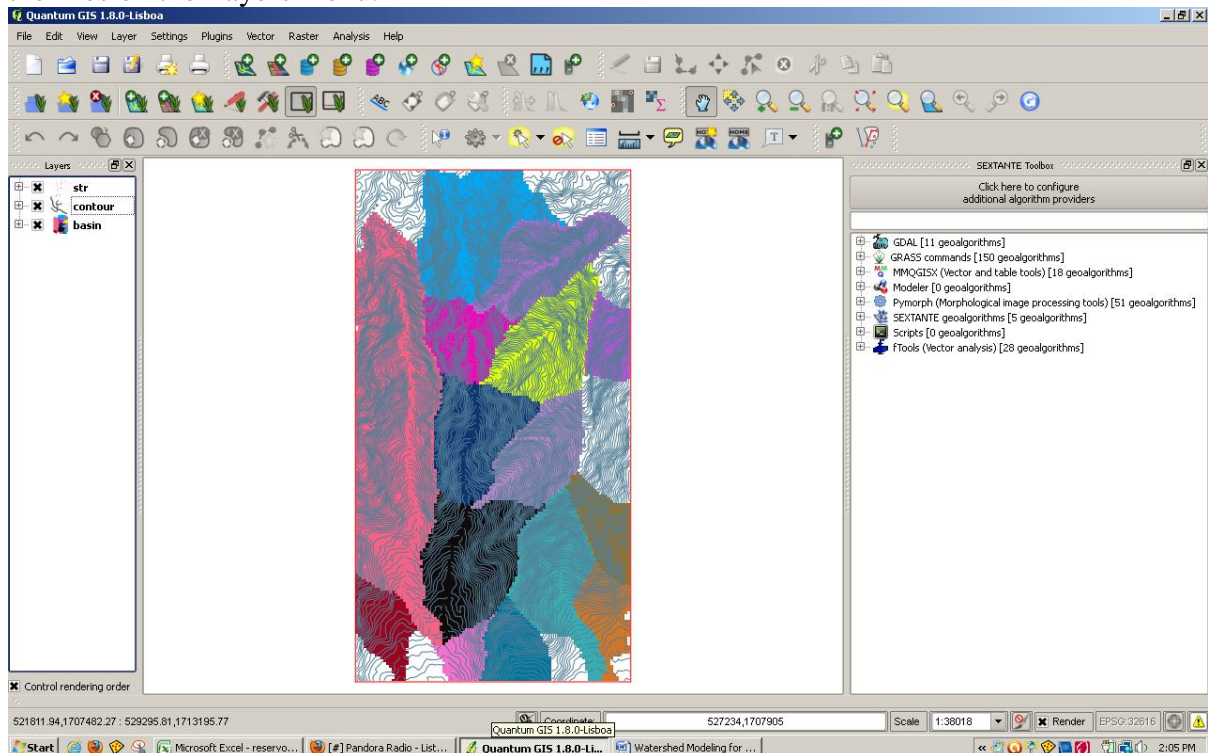
7. Find the LS factor of your subbasins.

a. There are two approaches to finding the LS factor of your subbasins: the manual way and the automatic way.

b. Here is the manual way of finding the LS factor.

a. Create a contour vector map from your DEM raster file using the r.contour GRASS Tool function. Name your output file and select the increment between contour lines to 10 meters (found in options tab). Use higher or lower increment values depending that the change of elevation could be readily recognized.

b. Load your stream raster file, the contour vector file, and basin raster file in that order. If you need to rearrange the files, please do so by click and drag the files on the Layers menu.



c. Determine the ‘floodplain’ of your subbasins by seeing flat or relatively low sloped areas close to your stream. Large gaps between contour lines indicate flat or low sloped areas. Use the Measure Area QGIS function to measure the area of your ‘floodplain.’ The difference between the subbasin area and the ‘floodplain’ area is the area of your slopes.

d. Open Excel or other spreadsheet program. Follow the table below to input and identify the average slope and length of your sloped area within the subbasin through identifying flowpaths. When identifying flowpaths, see the general pattern of the slopes (similar length and slopes) and estimate the percentage of the sloped area that the general pattern occupies. In this example, I identified 10 flowpaths in one subbasin and assigned each flowpath to influence 10% of the sloped area. Each flowpath has an elevation range and length. Length can be determined via Measure Distance QGIS function from the highest elevation to the lowest elevation of your flowpath up until the

boundary of the ‘floodplain.’ Elevation Range is the difference between the highest and lowest elevation of your flowpath. Input the elevation range and lengths of your flowpaths into your spreadsheet. Slope is the elevation range divided by the length. The weighted average is the sum of either the slope or lengths multiplied by the percentage of the area. To find the average slopes and lengths of the entire subbasin instead of the sloped area, find the Percentage of Total Area = (1-(Floodplain Area/Total Subbasin Area))*Percentage of Sloped Area (represented as %Area Slope in example below). Next, the weighted averages of the total subbasin area by finding the sum of Percentage of Total Area multiplied by either slope or length. You can also find the length and slope of the stream (or floodplain) using the same method as the slopes. Just remember the boundaries you designated as the floodplain to dictate the elevation range and the length of the stream.

ID	Path Location	Elevation Range (m)	Length (m)	Slope	% Area Slope	Sloped Wgt Avg Slope	Sloped Wgt Avg Length	% Area Total	Total Wgt Avg Slope	Total Wgt Avg Length	Tc (min)
1	N Slope	90	500	0.18	0.1	0.018	50	0.08857	0.0159426	44.285	1.217382
1	NW Slope	310	475	0.653	0.1	0.06526316	47.5	0.08857	0.0578036	42.07075	0.607369
1	NW Slope	200	300	0.667	0.1	0.06666667	30	0.08857	0.0590467	26.571	0.379542
1	SW Slope	310	400	0.775	0.1	0.0775	40	0.08857	0.0686418	35.428	0.469356
1	SW Slope	230	350	0.657	0.1	0.06571429	35	0.08857	0.0582031	30.9995	0.445996
1	NE Slope	175	530	0.33	0.1	0.03301887	53	0.08857	0.0292448	46.9421	0.95277
1	NE Slope	190	350	0.543	0.1	0.05428571	35	0.08857	0.0480809	30.9995	0.490703
1	SE Slope	340	500	0.68	0.1	0.068	50	0.08857	0.0602276	44.285	0.626338
1	SE Slope	290	420	0.69	0.1	0.06904762	42	0.08857	0.0611555	37.1994	0.522117
1	SE Slope	250	450	0.556	0.1	0.05555556	45	0.08857	0.0492056	39.8565	0.623652
						Total:	0.57305187	427.5	0.5285181	503.185513	

ID (for streams)	Range (m)	Length (m)	Slope	Floodplane Area (ha)	% Area Total
1	200	1090	0.18348624	15.7	0.11426492
3	310	1215	0.25514403	13.3	0.1372549

- e. Use the following formulas to finding the LS factor of your subbasins (L is length in meter and S is slope in percent):

$$LS = \sqrt{\frac{L}{22} [(0.065 + 0.045S) + (0.0065 \cdot S^2)]}$$

- c. Here is the automatic way of finding the LS factor. [?]
- a. I do not know how to use this method but these are the procedures from what I heard. Use r.watershed GRASS Tool function to create LS factor raster map. Use r.calc GRASS Tool function with the LS factor raster map and the basins map (raster or vector?) to find the average LS factor of those basins. End product must be vector file.
8. Find the R factor for your watershed catchment.
- a. Download and install the New_LocClim program from this website: http://www.fao.org/nr/climpag/pub/en3_051002_en.asp
 - b. Determine the GPS coordinates of your by looking it up on google maps: <http://maps.google.com>
 - a. Look for your catchment in google maps through visual searching and zooming in. Once you found it, locate the center of your catchment and right click. Select the option ‘whats here?’ It should bring up the GPS coordinate

in the search bar above the map. Round the GPS coordinates to the nearest thousandths (three decimal places to the right).

- c. Open the New_LocClim program and select “Single Point Mode.” You can either Select Location from either the World Map or By Coordinates. Select Location by Coordinates since you have GPS coordinates. Then enter the GPS coordinates that you got from google maps. You will be taken to another window with a graph. Select ‘Precipitation/Potential Evapotraspiration’ tab above the graph and ‘Table of Results’ tab below the graph. Sum up all the Best Estimate Column data in the Precipitation graph (top graph) to get the Average Yearly Precipitation that you will use to calculate your R value.

The screenshot shows the 'New LocClim' software interface. The 'Table of Results' tab is active, displaying a table with the following data:

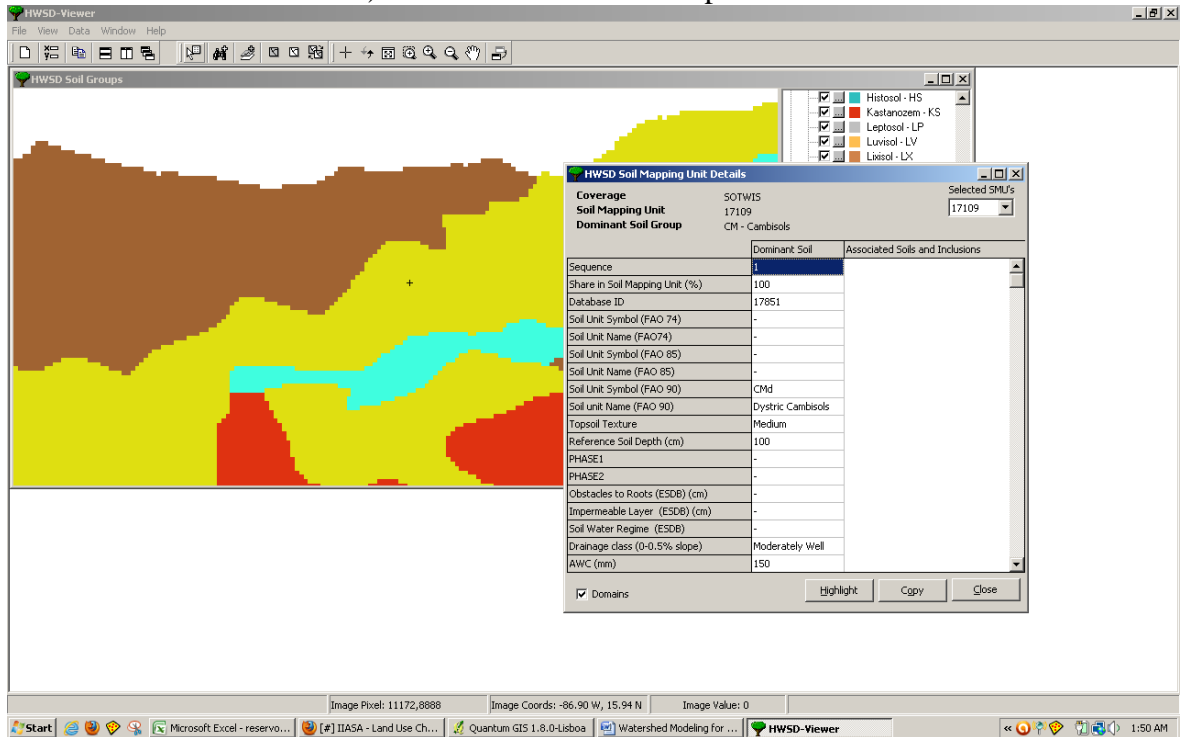
	Best Estimate	Low Estimate	High Estimate	Standard Error	Bias	Vertical Gradient	Longitudinal Gradient	Latitudinal Gradient	Gradient Direction	Gradient Direction	Absolute Gradient	Expl. Var of
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm/100m]	[mm/100km]	[mm/100km]	Degrees		[mm/100km]	%
Prec												
January	51.00	0.00	137.92	86.92	6.00							
February	31.00	0.00	105.27	74.27	-9.22							
March	22.00	0.00	204.72	182.72	31.89							
April	17.00	0.00	45.42	28.42	-4.22							
May	65.00	30.14	99.86	34.86	-5.00							
June	130.00	94.70	165.30	35.30	-1.78							
July	98.00	58.80	137.20	39.20	19.22							
August	77.00	4.33	149.67	72.67	5.33							
September	139.00	115.16	162.84	23.84	-5.56							
October	112.00	5.25	218.74	106.74	18.78							
November	116.00	1.84	230.16	114.16	3.33							
December	75.00	0.00	185.14	110.14	6.67							
Mean	77.75	1.98	153.52	75.77	5.45							
PET												
January	87.90	72.14	103.66	15.76	-2.98							
February	94.10	82.42	105.78	11.68	-2.40							
March	133.00	118.44	147.56	14.56	-0.80							
April	132.10	115.74	144.46	12.36	-1.08							
May	143.70	131.61	155.79	12.09	-0.84							
June	124.90	115.39	134.41	9.51	-0.01							
July	127.80	120.77	134.83	7.03	0.66							
August	129.80	120.53	139.07	9.27	1.24							
September	115.20	107.61	122.79	7.59	-1.01							
October	102.30	92.28	112.32	10.02	-2.63							
November	84.20	74.22	94.18	9.98	-2.29							

- d. Use one of the following formulas to calculate your R value using P as the Average Yearly Precipitation (in mm/year). Use the appropriate value (separated by location) based from similar topography, climate, or proximity to your location.

Table 1 - Summary of previously developed relationships

Location	Equation
Indonesia (Bols, 1978)	$R \approx \frac{2.5P^2}{100(0.073P + 0.73)}$
Malaysia (Teh, 2011)	
Honduras (Mikhailova et al., 1997)	$R = -3172 + 7.562P$
Italy (Torri et al., 2006)	$R = -944 + 3.08P$
Conterminous U.S. (Renard, Fremund, 1994)	$R = 0.04830P^{1.510}$
S.E. Australia (Yu, Rosewell, 1996)	$R = 0.0438P^{1.61}$

9. Find the K value of your watershed catchment.
 - a. Download and Install the Harmonized World Soil Database (HWSD) found here: <http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/>
 - b. Open HWSD and zoom in to your catchment manually. Use the GPS coordinates to guide you (seen on the bottom of the window) and compare it to the GPS coordinates you found via google maps. Select the SMU Table (look for the cursor and white square symbol in the menu bar) and click on the map with the correct GPS coordinates. Look for and record the soil unit name, soil texture, drainage class, and USDA texture classification). See below for the example.



- c. Use the table below to find your K factor using the data you recorded:

Table 6. Generalized values of the soil erodibility factor (*E*) in the universal soil loss equation (based on FAO, 1979, pp. 44–45). Soil types and textural classes are those of the first version of the FAO classification (FAO/UNESCO, 1974).

Step 1. Erodibility class of soil type.			
Low	Moderate	High	
Arenosols	Greyzems	Podzoluvisols	
Chernozems	Kastanozems	Vertisols	
Ferralsols		Xerosols	
Histosols		Yermosols	
Lithosols			
Nitosols			
Phaeozems			
Rendzinas			
Rankers			
Ferric and Humic Acrisols	Other Acrisols	Plinthic Acrisols	
Mollic and Humic Andosols	Other Andosols		
Ferralic and Humic Cambisols	Other Cambisols	Gelic and Vertic Cambisols	
Calcaric Fluvisols	Other Fluvisols	Thionic Fluvisols	
Calcaric, Humic, Mollic Gleysols	Other Gleysols	Gelic Gleysols	
Ferric Luvisols	Other Luvisols	Albic, Plinthic, Vertic	
Mollic and Humic Planosols	Vertic Luvisols	Other Planosols	
Humic and Leptic Podzols		Other Podzols	
Calcaric Regosols	Other Regosols	Gelic Regosols	
Step 2. Soil erodibility factor.			
Erodibility class	Low	Moderate	High
Textural class			
Coarse	0.1	0.2	0.4
Medium	0.15	0.3	0.6
Fine	0.05	0.1	0.2

d. However, due to the age of the FAO report, other tables may be more accurate.

Table 8. Calculated values of *K*-factors for the soil types, subtypes and varieties of Czech Taxonomic Classification System of Soils (Němec *et al.* 2001) in SI units

Soil type	Subtype	Variety	<i>K</i> -factor (SI units)	Soil type	Subtype	Variety	<i>K</i> -factor (SI units)
Ranker	modal		0.26	Orthic Greyzem	modal		0.57
	cambic		0.25		luvic		0.59
	podzolic		0.24				
Rendzina	modal		0.22	Orthic Luvisol	modal		0.53
	cambic		0.30		luvic		0.58
					pseudogleyic		0.53
Pararendzina	modal		0.26	Luvisol	modal		0.60
	cambic		0.36		pseudogleyic		0.56
					arenic		0.31
Regosol	modal		0.22	Cambisol	modal		0.33
	psephitic		0.18		modal	eutrophic	0.32
	arenic		0.17		luvic		0.50
	pellic		0.18		pseudogleyic		0.34
Fluvisol	modal		0.40		dystic		0.32
	gleyic		0.42		arenic		0.20
	arenic		0.26		pellic		0.30
					psephitic		0.30
Pellic Vertisol	modal		0.28	Cryptopodzol	modal		0.20
Chernozem	modal		0.40	Podzol	modal		0.25
	luvic		0.54		arenic		0.20
	phaeozemic		0.35				
	arenic		0.16	Pseudogley	modal		0.42
	pellic		0.28		luvic		0.54
				gleyic		0.24	
Phaeozem	modal		0.30				
	gleyic		0.34	Gleysol	modal		0.42
	pellic		0.32		modal	peaty	0.46

10. Find the C and P factors of your watershed.

- a. Use the table below to find your C and P factors. If there is 2 or more variables in determining C or P, use the weighted average of those variables based from area percentage it takes up in the watershed.

Table 2 Vegetative cover (C) and field support practice (P) for land use land cover classes (LULC).

LULC Class	LULC Code	C Value	P Value
Mixed crops (MC)	A0	0.255	1
Paddy field (PF)	A1	0.280	0.1
Field crops (FC)	A2	0.525	1
Perennial trees (PT)	A3	0.150	1
Orchards (Oc)	A4	0.300	1
Horticulture crops (HC)	A5	0.600	1
Grassland (GL)	A7	0.100	1
Shifting cultivation (SC)	A9	0.250	1
Evergreen forest (EF)	F1	0.003	1
Deciduous forest (DF)	F2	0.048	1
Forest plantation (FP)	F5	0.088	1
Agro forestry (AF)	F6	0.088	1
Natural grassland (NG)	M	0.015	1
Water body	W	0	0
Urban	U	0	0

Source: Land Development Department (2002)

11. The average annual sediment yield (A) is determined by the following formula where A is in tons/(hectacre*year): $A = R * K * LS * C * P * Area * SDR$. The sediment delivery ratio (SDR) is determined by this formula where A is the basin area (in square kilometers):

$$SDR = 0.41 \times A_t^{-0.3}$$

There is 100 hectacres in one square kilometer.

12. Now you need to determine the peak discharge of the catchment.

- a. Use the following formula to determine Peak Discharge (Qp) for catchments less than 1 square kilometer: $Q_p = 0.278 * C * I * A$ where basin area (A) is in hectares, intensity (I) is in mm/hour, and C is runoff coefficient. Intensity is related to storm events with a return period. Sometimes you must choose what is your return period and then you'll get an intensity of rainfall. Use this table to find your runoff coefficient:

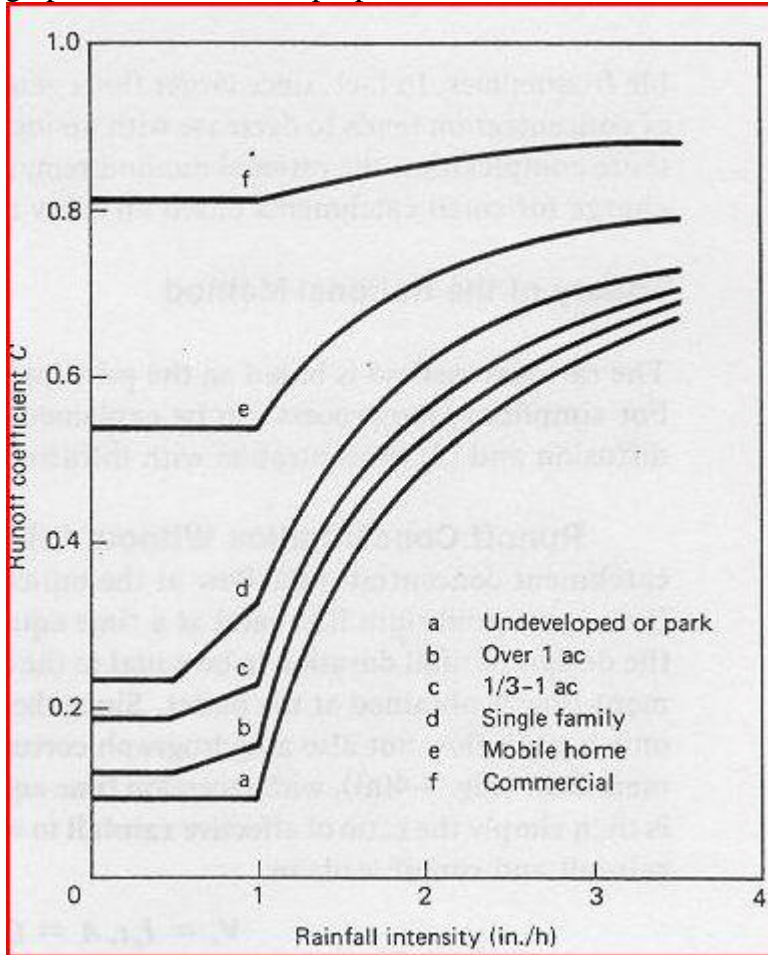
TABLE 4-1(b) AVERAGE RUNOFF COEFFICIENTS FOR RURAL AREAS

Topography and Vegetation	Soil Texture		
	Open Sandy Loam	Clay and Silt Loam	Tight Clay
<i>Woodland¹</i>			
Flat	0.10	0.30	0.40
Rolling	0.25	0.35	0.50
Hilly	0.30	0.50	0.60
<i>Pasture</i>			
Flat	0.10	0.30	0.40
Rolling	0.16	0.36	0.55
Hilly	0.22	0.42	0.60
<i>Cultivated Land</i>			
Flat	0.30	0.50	0.60
Rolling	0.40	0.60	0.70
Hilly	0.52	0.72	0.82

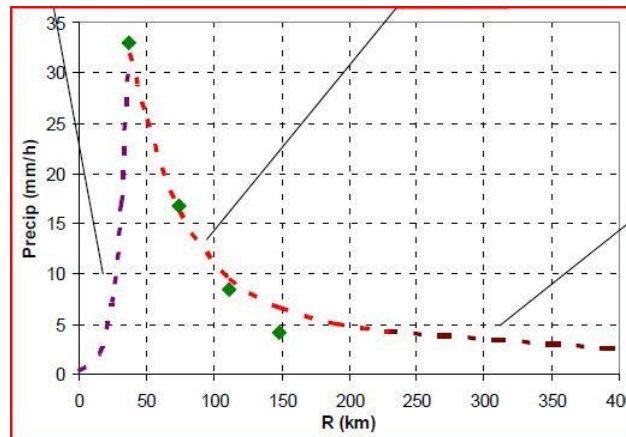
¹Note: Flat (0-5% slope); rolling (5-10%); hilly (10-30%).

Source: Schwab, R. J. et al. (1971). *Elementary Soil and Water Engineering*. 2d. ed. New York: John Wiley.

Please note that an increase in intensity will increase the runoff coefficient. See the graph below to find the proper value of runoff coefficient:



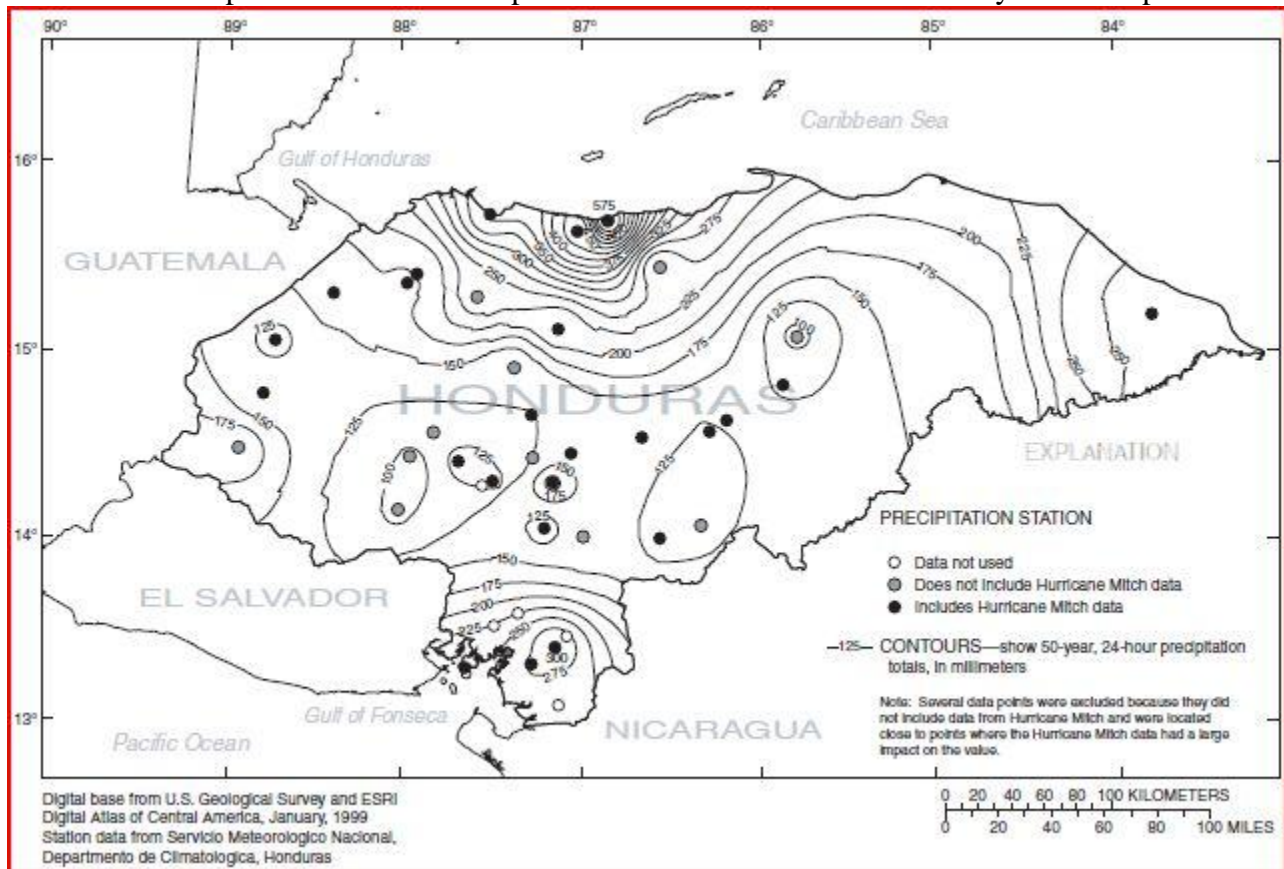
- b. You can find intensity values by google searching intensity duration frequency curves or isopluvial maps. The picture below shows you intensity of a tropical storm or hurricane in the Gulf of Mexico where R is the radius of the storm event. Please note that the larger radius storms shows to be regular storms with a return period of one year and intensity greater than 10 mm/hr shows hurricane events with return periods of 50 to 500 years.



Use the table below to extract the intensity of any storm event with a different return period with a known return period and intensity. This table is for 24 hour rainfall depths as a function of 2 year, 24 hour storm event depths.

Return Period (year)	Depth (% of 2 year depth)
1	78
2	100
5	140
10	160
25	182
50	200
100	222

Example of an isometric map for a 24 hour storm event with a 50 year return period.



- c. You can use also use the Curve Number to determine the peak discharge. This works for midsize catchments (10-50 square kilometers). Use the website calculator to find the depth of a storm event based on either intensity (mm/hour) or storm event (total precipitation depth/duration of storm event):

<http://onlinecalc.sdsu.edu/onlinecurvenumber.php>

The online calculator is using these formulas: $Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$ $S = \left(\frac{1000}{CN}\right) - 10$

where P is Intensity (in inches) (derived from mm/hour or total precipitation depth/duration of storm event), Q is unit discharge (inches), and CN is curve number.

- d. To obtain the curve number, you must know soil characteristics from the HWSD program (like soil texture, drainage class, and USDA texture classification). Use that info to obtain the proper soil group (shown as two tables below):

Hydrologic Soil Group	Minimum Infiltration Rate (mm/hr)	Soil Description
A	7.6-11.4	Deep well drained sands and gravels, deep loess, or aggregated silts. Characterized as sand, loamy sand, or sandy loam with high infiltration.
B	3.8-7.6	Moderately deep, well drained soils of moderately fine to moderately coarse texture such as shallow loess and sandy loams. Characterized as silt loam or loams with moderate infiltration.
C	1.2-3.8	Soils with a layer that impedes downward movement of water and soils of moderately fine to fine texture such as clay loams, shallow sandy loams, soils of low organic content, and soils high in clay content. Characterized as sandy clay loams with low infiltration.
D	0-1.2	Chiefly clay soils with high swelling potential soils with permanent high water table, soils with claypan at or near the surface, shallow soils over nearly impervious material, heavy plastic clays, and certain saline soils. Characterized as clay loams, silty clay loam, sandy clay, silty clay, or clay with very low infiltration.

Description of Land Use	Hydrologic Soil Group			
	A	B	C	D
Paved parking lots, roofs, driveways	98	98	98	98
Streets and Roads:				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89
Cultivated (Agriculture Crop) Land:				
Without conservation treatment (no terraces)	72	81	88	91
With conservation treatment (terraces, contours)	62	71	78	81
Pasture or Range Land:				
Poor (<50% ground cover or heavily grazed)	68	79	86	89
Good (50-75% ground cover, not heavily grazed)	39	61	74	80
Meadow (grass, no grazing, mowed for hay)	30	58	71	78
Bush (good, >75% ground cover)	30	48	65	73
Woods and Forest:				

Poor (small trees/bush destroyed by overgrazing or burning)	45	66	77	83
Fair (grazing but not burned; some brush)	36	60	73	79
Good (no grazing; bush covers ground)	30	55	70	77
Open Spaces (lawns, parks, golf courses, ect):				
Fair (grass covers 50-75% of area)	49	69	79	84
Good (grass covers >75% of area)	39	61	74	80
Commercial and Business Districts (85% impervious)	89	92	94	95
Industrial Districts (72% impervious)	81	88	91	93
Residential Areas:				
1/8 Acre lots about 65% impervious	77	85	90	92
1/4 Acre lots about 38% impervious	61	75	83	87
1/2 Acre lots about 25% impervious	54	70	80	85
1 Acre lots about 20% impervious	51	68	79	84

e. Your peak discharge (Q_p) will be: Q_p (in m^3/s) = (0.000044276 * Q (in mm) * Basin Area (in hectares) / Time (in hours; duration of storm event). Convert inches to mm using conversion rate: 1 inch = 25.4 mm.

13. This modeling exercise does show two very important limitations:
- The first being that high intensity storm events will generally carry more sediments than low intensity storm events. Because of this, a percentage of the annual sediment yield will be “discharged” during one storm event. There is a need to figure out the percentage of annual sediment yield will be discharge in relationship with the design storm event with a predetermined return period. It is probable that you can design structures that may hold sediments during storm events for 24-72 hour storm events with a return period of 50 years for annual sediment removal of those structures. [Is this an overestimation? Confirm with research papers.]
 - The second being that the annual sediment yield (A) is overestimated beyond realistic expectations in steep tropical rainforest catchments. Maybe take 10-33% of the annual sediment yield to get to realistic expectations. [Is this a function of SDR? Confirm with research papers.]
14. Confirm the assumptions through actually going down to the catchment and obtain water samples during two or more storm events with determined return periods to find the sediment concentrations and eventually sediment yields for those storm events.
- Notice the greatest intensity of rainfall over an hour (within a 24 hour period) to predict its return period. Draw a graph between intensity (or return period) and sediment concentration to obtain an equation (either linear or nonlinear) that can predict the sediment concentrations for any storm event with a return period or intensity. You can also take turbidity measurements during this sampling so you can correlate turbidity to sediment concentration to make future predictions easier (by not sampling for sediment concentrations).
 - You can obtain 24 hour precipitation data from www.mundomanz.com. You can obtain 1 hour precipitation data (for finding intensity) for the Caribbean area from <http://pr.water.usgs.gov>. You may need to search for weather stations or organizations within those areas to get accurate precipitation data.

- b. To find the sediment concentration of your water samples, simply take a few samples at your sampling point in the river. Take the sample 0.5-0.66 of the height (from the bottom) of the river. Remember to write down the volume of your sample. Then dry your samples in a 105 degree Celcius oven overnight to evaporate all the water. Weight your sample with a balance to find its mass. Divide the mass by the volume of the sample to obtain sediment concentration.
- c. You may need to determine the time of concentration of the catchment to figure out when you need to get to the point you want to measure from the start of a storm event. Generally take the samples from the start of the storm leading to peak flow and again when the 'wave' of influx water subsides (usually equal in time with the time it took from start of storm event to peak flow but it could be until the end of the storm event plus the time of concentration).
1. Use these equations to find time of concentrations (in hours). Remember that Sheet Flow is for slopes with travel paths less than 300 feet, Shallow Concentrated Flow is for slopes greater than 300 feet, and Channel Flow is the for the flow in the streams or rivers. L is length of slope or channel (ft). n is mannings coefficient from density of vegetation as groundcover (see <http://www.lmnoeng.com/manningn.htm>). V is velocity (ft/s). S is slope (ft/ft). P2 is 2 year return period 24 hour duration precipitation depth (in inches).

$$T_c = T_{t(\text{sheet})} + T_{t(\text{shallow concentrated})} + T_{t(\text{channel})}$$

$$\text{Sheet Flow: } T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

$$\text{Shallow Concentrated Flow: } T_t = \frac{L}{3600 V}$$

If paved surface, $V = 20.3282 S^{0.5}$ Unpaved: $V = 16.1345 S^{0.5}$

$$\text{Channel Flow: } T_t = \frac{L}{3600 V} \quad V = \frac{1.49}{n} R^{2/3} S^{0.5} \text{ (Manning Equation)}$$

2. You can also use this online calculator to find the time of concentration: <http://onlinecalc.sdsu.edu/onlinetimeofconcentration.php>
 3. Typically you can have a time of concentration of 60-90 minutes for a small catchment though it could be less for steep mountainous rainforest catchments.
- d. After obtaining sediment concentrations, multiply the sediment concentrations by the water discharge at that moment (measure the height of the river and use open channel hydraulics to find the Q or water discharge (use <http://onlinecalc.sdsu.edu/onlinechannel15.php>); remember that Q will always be less than peak discharge) to find the mass of sediments at that moment in time. Take a weighted time average of those sediments at those times and sum it all up to figure out the total mass of sediment loss during that storm event.
1. Remember that you could have a first flush concept in play; meaning that the majority of sediment will be discharged during the time from the start of the storm leading to peak flow and will subside afterwards. If you get the first rainstorm of the rainy season, that will produce the greatest amount of sediments compared to other storm event after it.

2. There is also potential for mudslides from saturated soils. This could mean that reoccurring storm events can produce mudslides and increase sediment concentrations. Every storm event at all times during storm event will probably be important.
- e. You can also use this method: http://www.ehow.com/how_7927609_calculate-suspended-sediment-load.html