**Please note that these instructions are old, and make use of tools specific to ArcGIS, although equivalents are likely to exist in QGIS etc. Also, it’s unfinished, it is missing instructions for 2 services included in RIOS – groundwater recharge and dry season baseflow. Since RIOS is deprecated, we no longer support this at all, so sorry if you need this info and it’s missing. You can try looking at the ArcGIS preprocessor python code to see how it works, that might help, especially for the two services that are missing in this document.**

**I. Erosion Control**

**Required Data Sets and Pre-processing:**

**1. Digital elevation model (DEM).**  A GIS raster dataset with an elevation value for each cell. Make sure the DEM is corrected by filling in sinks, and if necessary 'burning' hydrographic features into the elevation model (recommended when you see unusual streams.) See the Working with the DEM section of this manual for more information. The DEM must be filled before calculating any of the derived factors listed below.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with elevation value for each cell given in meters above sea level.

*\* Note: The model does not require the DEM itself as input at this time, but a properly processed and filled DEM is required to derive many of the other inputs described below.*

**2. Slope (typically derived from DEM).**  A GIS raster dataset with a percent slope value for each cell. Slope can be calculated using the Slope function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with slope value for each cell given in percent.

**3. Flow Direction (derived from DEM).**  A GIS raster dataset with an flow direction value for each cell. Flow direction can be calculated using a filled DEM and the Flow Direction function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a flow direction value for each cell. There are eight possible flow direction values that can be assigned: 1,2,4,8,16,32,64,128.

**4. Flow Accumulation (derived from Flow Direction grid).**  A GIS raster dataset with a flow (cell) accumulation value for each cell. Flow accumulation represents the total number of cells that contribute flow to that pixel. Flow accumulation can be calculated using the Flow Direction grid and the Flow Accumulation function in ArcGIS Spatial Analyst. For our purposes, it is NOT necessary to convert the cell accumulation value (unitless) to area (l2).

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with an integer flow accumulation value for each cell. If you create as a floating point you will run into problems later on with raster calculator.

**5. Rainfall erosivity index.** A GIS raster dataset, with an erosivity index value for each cell. This variable depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of the rain storm, the higher the erosion potential.

The erosivity index is widely used, but in case of its absence, there are methods and equations to help generate a grid using climatic data.

Name: File can be named anything, but no spaces in the name and less than 13 characters Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a rainfall erosivity index value for each cell given in MJ\*mm\*(ha\*h\*yr)-1.

**6. Soil erodibility.** A GIS raster dataset, with a soil erodibility value for each cell. Soil erodibility, (sometimes noted as K), is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a soil erodibility value for each cell. K is in T.ha.h. (ha.MJ.mm)-1.

**7. Soil depth.** A GIS raster dataset with an average soil depth value for each cell. The soil depth values should be in millimeters.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a soil depth value for each cell given in mm.

**8. Downslope retention index (Sed).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Slope (see #2 above)

Land Cover (see Section II, #4 above)

Flow Direction (see #3 above)

Flow Accumulation (see #4 above)

Calculation:

*Slope Index*

First, slope must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the slope raster (or max value for Latin America). Use Raster Calculator to divide the slope raster by the maximum value. The resulting raster is the Slope Index.

Revised instructions:

1/ Join the user's LULC general mapping table to their land use raster using the lucode/VALUE fields   
  
2/ Export the joined raster to a new raster (call it lu\_gen)   
  
3/ Join lu\_gen to the RIOS coefficient table using the LULC\_general/General LULC Class fields (the latter field name, and one used for roughness, are a  problem for Arc, so I'm talking with James about what to do, I've worked around it for now by renaming.)   
  
4/ Export the joined raster to a new raster (call it lu\_coeff)   
  
5/ Use Spatial Analyst's ~~Reclassify~~/Lookup function to make an Index-R map from the Sed\_Ret field and Index-Exp map from the Sed\_Exp field.

*LULC Index-R*

The LULC raster must be re-classed into the LULC\_general categories given in Section II under LU Classification Table. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients Table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the Sed\_Ret field in Table VIII.1 as the new classification. The resulting raster is the LULC Index-R.

*Combined Weight-R*

Next, use Raster Calculator to average 1 - Slope Index and LULC Index-R ((1 – *Slope Index*) + *LULC index-R*) / 2. The resulting raster is the Combined Weight-R.

*Channel Definition*

To ensure that the flow length is calculated only to the nearest stream and not all the way to the watershed outlet (or raster edge), the stream channel must be given Null values in the Flow Direction grid.

1. Determine a threshold flow accumulation value necessary to form a stream channel. You can do this by comparing the Flow Accumulation grid with a shapefile of the stream network, by visual approximation, or any preferred method. The higher the threshold flow accumulation value chosen, the longer the average flow path will be and the fewer branches the channel network will have.
2. Use SetNull Function in ArcGIS Spatial Analyst to assign <Null> values in the Flow Direction grid to any cells with flow accumulation over the threshold value:

SetNull("*flowaccum*", ”*flowdir*”, "VALUE > *threshold*")

Where *flowaccum* is the Flow Accumulation raster

*flowdir* is the Flow Direction raster

*Threshold* is the threshold flow accumulation value chosen

The resulting raster is a Flow Direction grid with the stream channel assigned <Null> values, creating an edge where flow length calculation will end.

*Downslope Retention Index*

1. Use the resulting flow direction grid and the Combined Weight-R raster described above to perform a weighted flow length calculation on each pixel. This can be done using the Flow Length function in ArcGIS Spatial Analyst, using the Flow Direction raster with null stream channels and the Combined Weight-R as the weighting raster. The resulting raster gives a weighted flow length for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow length value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the Downslope Retention Index.

**9. Upslope Source Index (Sed).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Slope Index (see #8 above)

Land Cover (see Section II, #4 above)

LULC Index-R (see #8 above)

Flow Direction (see #3 above)

Rainfall erosivity (see #5 above)

Soil erodibility (see #6 above)

Soil depth (see #7 above)

Calculation:

*Slope Index*

You can use the same Slope Index raster that was calculated for the Downstream Retention Index.

*Rainfall Erosivity Index*

Rainfall erosivity must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the Rainfall Erosivity raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value. The resulting raster is the Rainfall Erosivity Index.

*Soil Erodibility Index*

Soil erodibility must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the Soil Erodibility raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value. The resulting raster is the Soil Erodibility Index.

*Soil Depth Index*

Soil Depth must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1, **where 0 represents the highest soil depth, and 1 represents the lowest**. Determine the maximum value of the Soil Depth raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value (resulting raster = *normalized*). Use Raster Calculator again to subtract the resulting values from 1 (1 – *normalized*). The resulting raster is the Soil Depth Index.

*LULC Index-R*

You can use the same LULC Index-R raster that was calculated for the Downstream Retention Index.

*LULC Index-Exp*

The LULC raster must be re-classed into the LULC\_general categories given in Section II under LU Classification Table. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients Table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the Sed Exp field in Table VIII.1 as the new classification. The resulting raster is the LULC Index-Exp.

*Combined Weight-Exp*

Next, use Raster Calculator to average the all the above rasters:

*(Slope Index* + *Rainfall Erosivity Index* + *Soil Erodibility Index* + *Soil Depth Index* + (1 – *LULC Index-R*) + *LULC Index-Exp) / 6*

The resulting raster is the Combined Weight-Exp.

*Upslope Source Index*

1. Use the Flow Direction and Combined Weight-Exp rasters to perform a weighted flow accumulation calculation on each pixel. This can be done using the Flow Accumulation function in ArcGIS Spatial Analyst, using the Combined Weight-Exp as the weighting raster. The resulting raster gives a weighted flow accumulation upstream for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow accumulation value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the Upslope Source Index.

**10. Riparian Continuity Index (Sed).** This is a GIS raster data set, with an index value for each cell. The goal of the riparian continuity index is to rank pixels highly that are next to existing riparian buffers along the stream, or areas with high retention efficiency. This raster must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

LULC Index-R (see #8 “Downslope retention index” above)

Stream network shapefile

Calculation:

The goal is to create a raster that gives an integer index value that represents the amount of retention from vegetation that is within a certain distance of each pixel, along the stream network.

1. Create a shapefile of riparian buffer areas. This requires a shapefile of the stream network. Choose a buffer width (30-60 meters recommended). You need to generate a buffer for each side of the stream separately, so that the final score reflects the continuity of a buffer along one side of a river, not across the river. This can be done using the Buffer tool in ArcGIS Analysis (Proximity) toolset. Do this twice, once for the RIGHT buffer, and once for the LEFT. Dissolve Type should be “ALL.” This step generates two new buffer shapefiles.
2. Clip the LULC Index-R raster to each buffer shapefile, generating two new rasters. This can be done using the Clip function in ArcGIS Data Management (Raster) toolset. Be sure to check the box “Use Input Features for Clipping Geometry” so the raster is clipped as close as possible to the buffer extents. The result is two rasters with the LULC Index-R, one for each buffer.
3. Calculate the Continuity Index for each buffer raster created in step (b). This can be done using Focal Statistics in ArcGIS Spatial Analyst. Choose Neighborhood Type – Rectangle, and enter 3x3 for the size. Statistics Type should be Mean. Perform this calculation twice, once for each buffer raster. Finally, the resulting Focal Statistics rasters will have a greater extent than the original buffer input, so do Extract by Mask again, using the two buffer shapefiles before moving on to the next step. The resulting rasters are Focal Statistics-Clipped.
4. Mosaic the Focal Statistics-Clipped rasters together. This can be done using the Mosaic to New Raster function in ArcGIS Data Management (Raster) toolset. For Mosaic Operator, choose “Maximum.” Be sure that the settings for Pixel Type and Number of Bands are the same as the two input rasters, otherwise the result could contain significant errors. The resulting raster is *mosaic*.
5. Finally, use Raster Calculator to subtract the resulting values from 1 (1 – *mosaic*). The resulting raster is the *Riparian Continuity Index*.

**11. Beneficiaries.** A GIS raster dataset, that indicates the location and number of beneficiaries.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell representing the number of beneficiaries that are impacted by activities on that pixel.

**II. Nutrient Retention – Phosphorus**

**Required Data Sets and Pre-processing:**

**1. Digital elevation model (DEM).**  A GIS raster dataset with an elevation value for each cell. Make sure the DEM is corrected by filling in sinks, and if necessary 'burning' hydrographic features into the elevation model (recommended when you see unusual streams.) See the Working with the DEM section of this manual for more information. The DEM must be filled before calculating any of the derived factors listed below.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with elevation value for each cell given in meters above sea level.

*\* Note: The model does not require the DEM itself as input at this time, but a properly processed and filled DEM is required to derive many of the other inputs described below.*

**2. Slope (typically derived from DEM).**  A GIS raster dataset with a percent slope value for each cell. Slope can be calculated using the Slope function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with slope value for each cell given in percent.

**3. Flow Direction (derived from DEM).**  A GIS raster dataset with an flow direction value for each cell. Flow direction can be calculated using a filled DEM and the Flow Direction function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a flow direction value for each cell. There are eight possible flow direction values that can be assigned: 1,2,4,8,16,32,64,128.

**4. Flow Accumulation (derived from Flow Direction grid).**  A GIS raster dataset with a flow (cell) accumulation value for each cell. Flow accumulation represents the total number of cells that contribute flow to that pixel. Flow accumulation can be calculated using the Flow Direction grid and the Flow Accumulation function in ArcGIS Spatial Analyst. For our purposes, it is NOT necessary to convert the cell accumulation value (unitless) to area (l2).

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with an integer flow accumulation value for each cell.

**5. Rainfall erosivity index.** A GIS raster dataset, with an erosivity index value for each cell. This variable depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of the rain storm, the higher the erosion potential.

The erosivity index is widely used, but in case of its absence, there are methods and equations to help generate a grid using climatic data.

Name: File can be named anything, but no spaces in the name and less than 13 characters Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a rainfall erosivity index value for each cell given in MJ\*mm\*(ha\*h\*yr)-1.

**6. Soil erodibility.** A GIS raster dataset, with a soil erodibility value for each cell. Soil erodibility, (sometimes noted as K), is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a soil erodibility value for each cell. K is in T.ha.h. (ha.MJ.mm)-1.

**7. Soil depth.** A GIS raster dataset with an average soil depth value for each cell. The soil depth values should be in millimeters.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a soil depth value for each cell given in mm.

**8. Downslope retention index (P).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Slope (see #2 above)

Land Cover (see Section II, #4 above)

Flow Direction (see #3 above)

Flow Accumulation (see #4 above)

Calculation:

*Slope Index*

First, slope must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the slope raster (or max value for Latin America). Use Raster Calculator to divide the slope raster by the maximum value. The resulting raster is the Slope Index.

*LULC Index-R*

The LULC raster must be re-classed into the LULC\_general categories given in Section II under LU Classification Table. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients Table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the P\_Ret field in Table VIII.1 as the new classification. The resulting raster is the LULC Index-R.

*Combined Weight-R*

Next, use Raster Calculator to average 1 - Slope Index and LULC Index-R ((1 – *Slope Index*) + *LULC index-R*) / 2. The resulting raster is the Combined Weight-R.

*Channel Definition*

To ensure that the flow length is calculated only to the nearest stream and not all the way to the watershed outlet (or raster edge), the stream channel must be given Null values in the Flow Direction grid.

1. Determine a threshold flow accumulation value necessary to form a stream channel. You can do this by comparing the Flow Accumulation grid with a shapefile of the stream network, by visual approximation, or any preferred method. The higher the threshold flow accumulation value chosen, the longer the average flow path will be and the fewer branches the channel network will have.
2. Use Raster Calculator with SetNull to assign <Null> values in the Flow Direction grid to any cells with flow accumulation over the threshold value:

SetNull("*flowaccum*", ”*flowdir*”, "VALUE > *threshold*")

Where *flowaccum* is the Flow Accumulation raster

*flowdir* is the Flow Direction raster

*Threshold* is the threshold flow accumulation value chosen

The resulting raster is a Flow Direction grid with the stream channel assigned <Null> values, creating an edge where flow length calculation will end.

*Downslope Retention Index*

1. Use the resulting flow direction grid and the Combined Weight-R raster described above to perform a weighted flow length calculation on each pixel. This can be done using the Flow Length function in ArcGIS Spatial Analyst, using the Combined Weight-R as the weighting raster. The resulting raster gives a weighted flow length for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow length value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the Downslope Retention Index.

**9. Upslope Source Index (P).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Slope Index (see #8 above)

Land Cover (see Section II, #4 above)

LULC Index-R (see #8 above)

Flow Direction (see #3 above)

Rainfall erosivity (see #5 above)

Soil erodibility (see #6 above)

Soil depth (see #7 above)

Calculation:

*Slope Index*

You can use the same Slope Index raster that was calculated for the Downstream Retention Index.

*Rainfall Erosivity Index*

Rainfall erosivity must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the Rainfall Erosivity raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value. The resulting raster is the Rainfall Erosivity Index.

*Soil Erodibility Index*

Soil erodibility must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the Soil Erodibility raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value. The resulting raster is the Soil Erodibility Index.

*Soil Depth Index*

Soil Depth must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1, where 0 represents the highest soil depth, and 1 represents the lowest. Determine the maximum value of the Soil Depth raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value (resulting raster = *normalized*). Use Raster Calculator again to subtract the resulting values from 1 (1 – *normalized*). The resulting raster is the Soil Depth Index.

*LULC Index-R*

You can use the same LULC Index-R raster that was calculated for the Downstream Retention Index.

*LULC Index-Exp*

The LULC raster must be re-classed into the LULC\_general categories given in Section II under LU Classification Table. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients Table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the P\_Exp field in Table VIII.1 as the new classification. The resulting raster is the LULC Index-Exp.

*Combined Weight-Exp*

Next, use Raster Calculator to average the all the above rasters:

*(Slope Index* + *Rainfall Erosivity Index* + *Soil Erodibility Index* + *Soil Depth Index* + (1 – *LULC Index-R*) + *LULC Index-Exp) / 6*

The resulting raster is the Combined Weight-Exp.

*Upslope Source Index*

1. Use the Flow Direction and Combined Weight-Exp rasters to perform a weighted flow accumulation calculation on each pixel. This can be done using the Flow Accumulation function in ArcGIS Spatial Analyst, using the Combined Weight-Exp as the weighting raster. The resulting raster gives a weighted flow accumulation upstream for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow accumulation value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the Upslope Source Index.

**10. Riparian Continuity Index (P).** This is a GIS raster data set, with an index value for each cell. The goal of the riparian continuity index is to rank pixels highly that are next to existing riparian buffers along the stream, or areas with high retention efficiency. This raster must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

LULC Index-R (see #8 “Downslope retention index” above)

Stream network shapefile

Calculation:

The goal is to create a raster that gives an integer index value that represents the amount of retention from vegetation that is within a certain distance of each pixel, along the stream network.

1. Create a shapefile of riparian buffer areas. This requires a shapefile of the stream network. Choose a buffer width (30-60 meters recommended). You need to generate a buffer for each side of the stream separately, so that the final score reflects the continuity of a buffer along one side of a river, not across the river. This can be done using the Buffer tool in ArcGIS Analysis (Proximity) toolset. Do this twice, once for the RIGHT buffer, and once for the LEFT. Dissolve Type should be “ALL.” This step generates two new buffer shapefiles.
2. Clip the LULC Index-R raster to each buffer shapefile, generating two new rasters. This can be done using the Clip function in ArcGIS Data Management (Raster) toolset. Be sure to check the box “Use Input Features for Clipping Geometry” so the raster is clipped as close as possible to the buffer extents. The result is two rasters with the LULC Index-R, one for each buffer.
3. Calculate the Continuity Index for each buffer raster created in step (b). This can be done using Focal Statistics in ArcGIS Spatial Analyst. Choose Neighborhood Type – Rectangle, and enter 3x3 for the size. Statistics Type should be Mean. Perform this calculation twice, once for each buffer raster. Finally, the resulting Focal Statistics rasters will have a greater extent than the original buffer input, so clip these rasters back to the two buffer shapefiles before moving on to the next step. The resulting rasters are Focal Statistics-Clipped.
4. Mosaic the Focal Statistics-Clipped rasters together. This can be done using the Mosaic to New Raster function in ArcGIS Data Management (Raster) toolset. For Mosaic Operator, choose “Maximum.” Be sure that the settings for Pixel Type and Number of Bands are the same as the two input rasters, otherwise the result could contain significant errors. The resulting raster is *mosaic*.
5. Finally, use Raster Calculator to subtract the resulting values from 1 (1 – *mosaic*). The resulting raster is the *Riparian Continuity Index*.

**11. Beneficiaries.** A GIS raster dataset, that indicates the location and number of beneficiaries.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell representing the number of beneficiaries that are impacted by activities on that pixel.

**III. Nutrient Retention – Nitrogen**

**Required Data Sets and Pre-processing:**

**1. Digital elevation model (DEM).**  A GIS raster dataset with an elevation value for each cell. Make sure the DEM is corrected by filling in sinks, and if necessary 'burning' hydrographic features into the elevation model (recommended when you see unusual streams.) See the Working with the DEM section of this manual for more information. The DEM must be filled before calculating any of the derived factors listed below.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with elevation value for each cell given in meters above sea level.

*\* Note: The model does not require the DEM itself as input at this time, but a properly processed and filled DEM is required to derive many of the other inputs described below.*

**2. Slope (typically derived from DEM).**  A GIS raster dataset with a percent slope value for each cell. Slope can be calculated using the Slope function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with slope value for each cell given in percent.

**3. Flow Direction (derived from DEM).**  A GIS raster dataset with an flow direction value for each cell. Flow direction can be calculated using a filled DEM and the Flow Direction function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a flow direction value for each cell. There are eight possible flow direction values that can be assigned: 1,2,4,8,16,32,64,128.

**4. Flow Accumulation (derived from Flow Direction grid).**  A GIS raster dataset with a flow (cell) accumulation value for each cell. Flow accumulation represents the total number of cells that contribute flow to that pixel. Flow accumulation can be calculated using the Flow Direction grid and the Flow Accumulation function in ArcGIS Spatial Analyst. For our purposes, it is NOT necessary to convert the cell accumulation value (unitless) to area (l2).

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with an integer flow accumulation value for each cell.

**5. Soil depth.** A GIS raster dataset with an average soil depth value for each cell. The soil depth values should be in millimeters.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a soil depth value for each cell given in mm.

**6. Downslope retention index (N).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Slope (see #2 above)

Land Cover (see Section II, #4 above)

Flow Direction (see #3 above)

Flow Accumulation (see #4 above)

Calculation:

*Slope Index*

First, slope must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the slope raster (or max value for Latin America). Use Raster Calculator to divide the slope raster by the maximum value. The resulting raster is the Slope Index.

*LULC Index-R*

The LULC raster must be re-classed into the LULC\_general categories given in Section II under LU Classification Table. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients Table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the N\_Ret field in Table VIII.1 as the new classification. The resulting raster is the LULC Index-R.

*Combined Weight-R*

Next, use Raster Calculator to average 1 - Slope Index and LULC Index-R ((1 – *Slope Index*) + *LULC index-R*) / 2. The resulting raster is the Combined Weight-R.

*Channel Definition*

To ensure that the flow length is calculated only to the nearest stream and not all the way to the watershed outlet (or raster edge), the stream channel must be given Null values in the Flow Direction grid.

1. Determine a threshold flow accumulation value necessary to form a stream channel. You can do this by comparing the Flow Accumulation grid with a shapefile of the stream network, by visual approximation, or any preferred method. The higher the threshold flow accumulation value chosen, the longer the average flow path will be and the fewer branches the channel network will have.
2. Use Raster Calculator with SetNull to assign <Null> values in the Flow Direction grid to any cells with flow accumulation over the threshold value:

SetNull("*flowaccum*", ”*flowdir*”, "VALUE > *threshold*")

Where *flowaccum* is the Flow Accumulation raster

*flowdir* is the Flow Direction raster

*Threshold* is the threshold flow accumulation value chosen

The resulting raster is a Flow Direction grid with the stream channel assigned <Null> values, creating an edge where flow length calculation will end.

*Downslope Retention Index*

1. Use the resulting flow direction grid and the Combined Weight-R raster described above to perform a weighted flow length calculation on each pixel. This can be done using the Flow Length function in ArcGIS Spatial Analyst, using the Combined Weight-R as the weighting raster. The resulting raster gives a weighted flow length for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow length value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the Downslope Retention Index.

**7. Upslope Source Index (N).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Slope Index (see #6 above)

Land Cover (see Section II, #4 above)

LULC Index-R (see #6 above)

Flow Direction (see #3 above)

Soil depth (see #5 above)

Calculation:

*Slope Index*

You can use the same Slope Index raster that was calculated for the Downstream Retention Index.

*Soil Depth Index*

Soil Depth must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1, where 0 represents the highest soil depth, and 1 represents the lowest. Determine the maximum value of the Soil Depth raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value (resulting raster = *normalized*). Use Raster Calculator again to subtract the resulting values from 1 (1 – *normalized*). The resulting raster is the Soil Depth Index.

*LULC Index-R*

You can use the same LULC Index-R raster that was calculated for the Downstream Retention Index.

*LULC Index-Exp*

The LULC raster must be re-classed into the LULC\_general categories given in Section II under LU Classification Table. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients Table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the N Exp field in Table VIII.1 as the new classification. The resulting raster is the LULC Index-Exp.

*Combined Weight-Exp*

Next, use Raster Calculator to average the all the above rasters:

*(Slope Index* + *Soil Depth Index* + (1 – *LULC Index-R*) + *LULC Index-Exp) / 4*

The resulting raster is the Combined Weight-Exp.

*Upslope Source Index*

1. Use the Flow Direction and Combined Weight-Exp rasters to perform a weighted flow accumulation calculation on each pixel. This can be done using the Flow Accumulation function in ArcGIS Spatial Analyst, using the Combined Weight-Exp as the weighting raster. The resulting raster gives a weighted flow accumulation upstream for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow accumulation value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the Upslope Source Index.

**8. Riparian Continuity Index (N).** This is a GIS raster data set, with an index value for each cell. The goal of the riparian continuity index is to rank pixels highly that are next to existing riparian buffers along the stream, or areas with high retention efficiency. This raster must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

LULC Index-R (see #6 “Downslope retention index” above)

Stream network shapefile

Calculation:

The goal is to create a raster that gives an integer index value that represents the amount of retention from vegetation that is within a certain distance of each pixel, along the stream network.

1. Create a shapefile of riparian buffer areas. This requires a shapefile of the stream network. Choose a buffer width (30-60 meters recommended). You need to generate a buffer for each side of the stream separately, so that the final score reflects the continuity of a buffer along one side of a river, not across the river. This can be done using the Buffer tool in ArcGIS Analysis (Proximity) toolset. Do this twice, once for the RIGHT buffer, and once for the LEFT. Dissolve Type should be “ALL.” This step generates two new buffer shapefiles.
2. Clip the LULC Index-R raster to each buffer shapefile, generating two new rasters. This can be done using the Clip function in ArcGIS Data Management (Raster) toolset. Be sure to check the box “Use Input Features for Clipping Geometry” so the raster is clipped as close as possible to the buffer extents. The result is two rasters with the LULC Index-R, one for each buffer.
3. Calculate the Continuity Index for each buffer raster created in step (b). This can be done using Focal Statistics in ArcGIS Spatial Analyst. Choose Neighborhood Type – Rectangle, and enter 3x3 for the size. Statistics Type should be Mean. Perform this calculation twice, once for each buffer raster. Finally, the resulting Focal Statistics rasters will have a greater extent than the original buffer input, so clip these rasters back to the two buffer shapefiles before moving on to the next step. The resulting rasters are Focal Statistics-Clipped.
4. Mosaic the Focal Statistics-Clipped rasters together. This can be done using the Mosaic to New Raster function in ArcGIS Data Management (Raster) toolset. For Mosaic Operator, choose “Maximum.” Be sure that the settings for Pixel Type and Number of Bands are the same as the two input rasters, otherwise the result could contain significant errors. The resulting raster is *mosaic*.
5. Finally, use Raster Calculator to subtract the resulting values from 1 (1 – *mosaic*). The resulting raster is the *Riparian Continuity Index*.

**9. Beneficiaries.** A GIS raster dataset, that indicates the location and number of beneficiaries.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell representing the number of beneficiaries that are impacted by activities on that pixel.

**IV. Flood Mitigation**

**Required Data Sets and Pre-processing:**

**1. Digital elevation model (DEM).**  A GIS raster dataset with an elevation value for each cell. Make sure the DEM is corrected by filling in sinks, and if necessary 'burning' hydrographic features into the elevation model (recommended when you see unusual streams.) See the Working with the DEM section of this manual for more information. The DEM must be filled before calculating any of the derived factors listed below.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with elevation value for each cell given in meters above sea level.

*\* Note: The model does not require the DEM itself as input at this time, but a properly processed and filled DEM is required to derive many of the other inputs described below.*

**2. Slope (typically derived from DEM).**  A GIS raster dataset with a percent slope value for each cell. Slope can be calculated using the Slope function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with slope value for each cell given in percent.

**3. Flow Direction (derived from DEM).**  A GIS raster dataset with an flow direction value for each cell. Flow direction can be calculated using a filled DEM and the Flow Direction function in ArcGIS Spatial Analyst.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a flow direction value for each cell. There are eight possible flow direction values that can be assigned: 1,2,4,8,16,32,64,128.

**4. Flow Accumulation (derived from Flow Direction grid).**  A GIS raster dataset with a flow (cell) accumulation value for each cell. Flow accumulation represents the total number of cells that contribute flow to that pixel. Flow accumulation can be calculated using the Flow Direction grid and the Flow Accumulation function in ArcGIS Spatial Analyst. For our purposes, it is NOT necessary to convert the cell accumulation value (unitless) to area (l2).

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with an integer flow accumulation value for each cell.

**5. Average Precipitation of Wettest Month.**  This is a GIS raster dataset, with a value for rainfall depth for each cell.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell that gives the average total rainfall in the wettest month in mm.

**6. Soil Texture Index.** This is a GIS raster dataset, with an index value for each cell.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

The Soil Texture Index can be derived from a soils data layer, such as the FAO Harmonized World Soil Database. Each soil type must be assigned a rank, based on the texture. The textures and ranks are given in the table below.

**Table VI.2. Soil Texture and Rank Values.**

|  |  |
| --- | --- |
| **Texture** | **Rank** |
| Sandy | 0.2 |
| Light | 0.4 |
| Medium | 0.6 |
| Heavy | 0.8 |
| Heavy to Rock | 1.0 |

**7. Slope Index (flood).** This is a GIS raster dataset, with an index value for each cell.

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

The Slope Index is derived from the Slope raster (#2 above). Each slope class is assigned a rank, based on the percent slope. The classes and ranks are given in the table below. The resulting raster is the Slope Index.

**Table VI.3. Percent Slope and Rank Values.**

|  |  |
| --- | --- |
| **Percent Slope** | **Rank** |
| 0 to 5% | 0.33 |
| 5.1 to 10% | 0.66 |
| 10.1 to 30% | 1.0 |

**8. Vegetative Cover Index.** This is a GIS raster dataset, with an index value each cell. This raster must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

The Vegetative Cover Index is derived from the LULC raster you provide (Section II, #4), and the Land Use Classification Table (Section II, #5). To calculate the index, first re-class your LULC raster into the LULC\_General categories given in Section II, #5. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients for Flood Mitigation table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the Cover Rank field as the new classification. The resulting raster is the Cover Index.

**9. On-pixel Roughness (n).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

On-pixel Roughness (n) is derived from the LULC raster you provide (Section II, #4), and the Land Use Classification Table (Section II, #5). To calculate the index, first re-class your LULC raster into the LULC\_General categories given in Section II, #5. Next, each cell in the resulting LULC\_general raster is assigned a value from the Coefficients for Flood Mitigation table (see Data Inputs Provided with WATER Tool, below). This can be done using the Reclassify function in ArcGIS Spatial Analyst. For each general LULC class, enter the value from the Roughness (n) Rank field as the new classification. The resulting raster is the On-pixel Roughness (n).

**10. Riparian Index.** This is a GIS raster dataset, with an index value for each cell. The goal of the riparian continuity index is to rank pixels highly that are next to existing riparian buffers along the stream, or areas with high retention efficiency. This raster must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

On-pixel Roughness (n) (see #9, above)

Stream network shapefile

Calculation:

The goal is to create a raster that gives an integer index value that represents the amount of retention from vegetation that is within a certain distance of each pixel, along the stream network.

1. Create a shapefile of riparian buffer areas. This requires a shapefile of the stream network. Choose a buffer width (60 meters, or two pixels width, is recommended). You need to generate a buffer for each side of the stream separately, so that the final score reflects the continuity of a buffer along one side of a river, not across the river. This can be done using the Buffer tool in ArcGIS Analysis (Proximity) toolset. Do this twice, once for the RIGHT buffer, and once for the LEFT. Dissolve Type should be “ALL.” This step generates two new buffer shapefiles.
2. Clip the On-pixel Roughness raster to each buffer shapefile, generating two new rasters. This can be done using the Clip function in ArcGIS Data Management (Raster) toolset. Be sure to check the box “Use Input Features for Clipping Geometry” so the raster is clipped as close as possible to the buffer extents. The result is two rasters with the On-pixel Roughness, one for each buffer.
3. Calculate the Continuity Index for each buffer raster created in step (b). This can be done using Focal Statistics in ArcGIS Spatial Analyst. Choose Neighborhood Type – Rectangle, and enter 3x3 for the size. Statistics Type should be Mean. Perform this calculation twice, once for each buffer raster. Finally, the resulting Focal Statistics rasters will have a greater extent than the original buffer input, so clip these rasters back to the two buffer shapefiles before moving on to the next step. The resulting rasters are Focal Statistics-Clipped.
4. Mosaic the Focal Statistics-Clipped rasters together. This can be done using the Mosaic to New Raster function in ArcGIS Data Management (Raster) toolset. For Mosaic Operator, choose “Maximum.” Be sure that the settings for Pixel Type and Number of Bands are the same as the two input rasters, otherwise the result could contain significant errors. The resulting raster is *mosaic*.
5. Finally, use Raster Calculator to subtract the resulting values from 1 (1 – *mosaic*). The resulting raster is the *Riparian Index*.

**11. Downslope retention index (Flood).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Flow Direction (see #3, above)

Flow Accumulation (see #4, above)

Slope Index(see #7 above)

On-pixel Roughness (see #9, above)

Riparian Index (see #10, above)

Calculation:

*Combined Weight-R*

Use Raster Calculator to average 1 - Slope Index and On-pixel Roughness ((1 – *Slope Index*) + *On-pixel Roughness*) / 2. The resulting raster is the Combined Weight-R.

*Channel Definition*

To ensure that the flow length is calculated only to the nearest stream and not all the way to the watershed outlet (or raster edge), the stream channel must be given Null values in the Flow Direction grid.

1. Determine a threshold flow accumulation value necessary to form a stream channel. You can do this by comparing a Flow Accumulation grid with a shapefile of the stream network, by visual approximation, or any preferred method. The higher the threshold flow accumulation value chosen, the longer the average flow path will be and the fewer branches the channel network will have.
2. Use Raster Calculator with SetNull to assign <Null> values in the Flow Direction grid to any cells with flow accumulation over the threshold value:

SetNull("*flowaccum*", ”*flowdir*”, "VALUE > *threshold*")

Where *flowaccum* is the Flow Accumulation raster

*flowdir* is the Flow Direction raster

*Threshold* is the threshold flow accumulation value chosen

The resulting raster is a Flow Direction grid with the stream channel assigned <Null> values, creating an edge where flow length calculation will end.

*Weighted Flow Length*

1. Use the resulting flow direction grid and the Combined Weight-R raster described above to perform a weighted flow length calculation on each pixel. This can be done using the Flow Length function in ArcGIS Spatial Analyst, using the Combined Weight-R as the weighting raster. The resulting raster gives a weighted flow length for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow length value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the *Downslope Retention Index*.

**12. Upslope Source Index (Flood).** This is a GIS raster dataset, with an index value for each cell. This must be calculated by the user as follows:

Name: File can be named anything, but no spaces in the name and less than 13 characters.

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell, ranging between 0 and 1.

Data Required:

Rainfall depth (see #5, above)

Vegetative cover index (see #8, above)

Soil texture index (see #6, above)

Slope index (see #7, above)

On-pixel roughness (see #9, above)

Calculation:

*Rainfall Depth Index*

Rainfall depth must be normalized into a raster dataset where each cell is assigned an index value between 0 and 1. Determine the maximum value of the Rainfall Depth raster (or max value for Latin America). Use Raster Calculator to divide the raster by the maximum value. The resulting raster is the Rainfall Depth Index.

*Combined Weight-Source*

Next, use Raster Calculator to average the factor indices:

*(Rainfall Depth Index* + (1 - *Veg Cover Index*) + *Soil Texture Index* + *Slope Index* + (1 – *LULC Index-R*)*) / 5*

The resulting raster is the Combined Weight-Source.

*Upslope Source Index*

1. Use the Flow Direction and Combined Weight-Source rasters to perform a weighted flow accumulation calculation on each pixel. This can be done using the Flow Accumulation function in ArcGIS Spatial Analyst, using the Combined Weight-Source as the weighting raster. The resulting raster gives a weighted flow accumulation upstream for each pixel.
2. Normalize the resulting raster by determining the maximum weighted flow accumulation value. Use Raster Calculator to divide the raster by the maximum. The resulting raster is the Upslope Source Index.

**13. Beneficiaries.** A GIS raster dataset, that indicates the location and number of beneficiaries.

Name: File can be named anything, but no spaces in the name and less than 13 characters

Format: standard GIS raster file (e.g., ESRI GRID or IMG), with a value for each cell representing the number of beneficiaries that are impacted by activities on that pixel.

**V. Groundwater Recharge**

**Required Data Sets and Pre-processing:**

**VI. Dry Season Baseflow**

**Required Data Sets and Pre-processing:**