Open-source
Nonpoint Source Pollution and Erosion Comparison Tool (OpenNSPECT)

Technical Guide

Version 2.0, 2012

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Introduction

This document is the technical guide for the Open-source Nonpoint Source Pollution and Erosion Comparison Tool (OpenNSPECT), developed by the NOAA Coastal Services Center to accompany the Waiʻanae Ecological Characterization. The tool is a plug-in to the free, open-source Geographic Information System (GIS), MapWindow GIS and allows users to examine relationships between land cover, nonpoint source pollution, and erosion. OpenNSPECT is useful for understanding and predicting the impacts of management decisions on water quality and, potentially, on nearshore ecosystem health.

The technical guide is aimed at more advanced users and explains the underlying science and mathematical equations that drive the tool's processing and functionality.

OpenNSPECT is a very flexible tool and addresses several issues of concern to water quality specialists and coastal managers. Tool capabilities include

- Estimating runoff volume
- Estimating pollutant loads and concentrations
- Identifying areas highly susceptible to erosion by water
- Estimating sediment loads
- Assessing the relative impacts of land use changes with scenario analysis

Pollutant concentrations are estimated using coefficients that represent the contribution of each land cover class to the overall pollutant load. These coefficients are derived from local water quality sampling data using a new procedure detailed in the Pollutant Concentration section of this document. Erosion rates and sediment loads are calculated using the Revised Universal Soil Loss Equation (RUSLE) and Modified Universal Soil Loss Equation (MUSLE). Lastly, an overall water quality rating is assigned to the stream network within each watershed or sub-watershed by comparing estimated total pollutant and sediment concentrations to local water quality standards. This water quality rating will help resource managers make informed decisions about water quality and identify areas to target for improvement.

Model Setup

OpenNSPECT is delivered with data sets specific to the Waiʻanae region of Oʻahu, Hawaiʻi, and very little user interaction is required to run a basic analysis for this area. However, applying the tool in other regions may require the specification of several input data sets:

- Elevation data (digital elevation model, or DEM)
- Land cover data (raster format)
- Rainfall data (raster format)
- Soil data (shapefile format)
- R-factor data (raster format)
- Local pollutant coefficients (table format)
- Water quality standards (table format)

Many of the grids driving OpenNSPECT's functionality are derived from the DEM and for this reason it is perhaps the most important of these data sets. OpenNSPECT automatically sets the raster analysis environment to the parameters of the DEM file. This is an important step because it ensures that all grids produced have the same cell size, spatial reference, and extent. Otherwise, the cells of input and output grids may or may not overlay properly.

Watershed Delineation

A typical OpenNSPECT project begins with the user running a watershed delineation. OpenNSPECT removes artificial sinks and other imperfections that are commonly found in raw topography data sets using the FILL command. Next, a flow direction grid is generated from the DEM by calculating the downstream flow path of water leaving each cell. Flow direction is determined by evaluating the relative elevation of the eight cells surrounding the cell in question. The neighboring cell with the lowest elevation is identified as the direction of outflow from the cell in consideration. The flow direction value assigned to the cell in consideration is based on the value of the cell it flows into, as given in Figure 1 below, where the center cell is being evaluated.

32	64	128
16		1
8	4	2
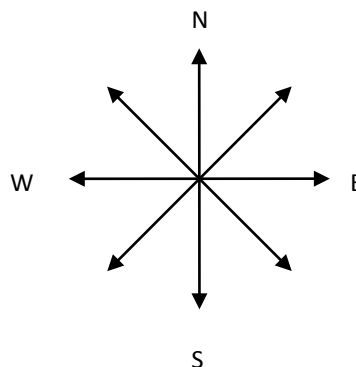
Figure 1. Flow direction grid values.

For instance, a cell that flows into the cell to its immediate left would have a value of 16 in the resulting flow direction grid. Assuming that the above diagram is oriented in a north-south direction, the values of the output flow direction grid are given below:

- East   1
- Southeast   2
- South   4
- Southwest   8
- West   16
- Northwest   32
- North   64
- Northeast   128

The flow accumulation grid is created based on the flow direction grid and is used to derive stream networks. The values of the cells in a user-specified weight grid are summed according to the hydrologic linkages represented by the flow direction grid. Each cell contains the total value of all upstream cells that flow through it along the flow paths dictated by the flow direction grid (Jenson and Domingue, 1988).

The maximum value from the flow accumulation grid is multiplied by one of the predefined threshold values (0.03, 0.06, 0.1), which correspond to small, medium, and large watershed sizes, respectively. OpenNSPECT then extracts a stream network by giving all cells in the flow accumulation grid that exceed the defined threshold (3%, 6%, 10% of total flow accumulation) a numeric value, and coding all other grid cells as NoData. Therefore, the number of upstream grid cells flowing into a given cell must be greater than the threshold percentage of the total flow accumulation to be classified as part of the stream network.

The STREAMLINK command partitions the larger stream network into links where one or more reaches come together. The WATERSHED command delineates all of the cells that flow directly into each of the individual stream links. The resulting grid is the basis for the watershed polygons that are the primary product of OpenNSPECT's watershed delineation process. The results of the water quality assessment are reported using a stream network grid.

Upstream and Local Effects

OpenNSPECT allows users to examine both local and upstream contributions to pollutant loads. "Local effects" refers to pollution generated by a single cell or group of cells with no input from upstream sources. Upstream effects include local effects but also incorporate pollutants flowing into the current cell from upstream cells according to the flow direction grid.

Local effects are simple to calculate within a grid environment, but upstream effects present a challenge. In order to accurately estimate upstream pollutant contributions for a given cell, OpenNSPECT needs to be able to easily determine all of the cells that flow into the current cell.

The BASIN command delineates the major drainage basins within a given DEM. This is accomplished by identifying ridge lines and watershed pour points, and then using the flow direction grid to determine all cells that drain the same area.

OpenNSPECT executes the BASIN command on the DEM and converts the resulting grid to a shapefile. Intersecting this basin shapefile with a user-defined area of interest (polygon shapefile) yields an approximation of the upstream contributing area and the relevant polygons from the basin layer are used to clip the DEM and other input grids. Although this approach is not ideal, it provides a reasonable estimate of contributions from upstream sources.

Resources

Jenson, S.K. and J.O. Domingue. 1988. "Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis." *Photogrammetric Engineering and Remote Sensing*. Vol. 54, No. 11, November 1988, pp. 1593–1600.

Data Inputs

OpenNSPECT makes use of a variety of data sets, but only a few are required for basic analyses. Many are freely available from federal and state online data distributors. This section of the technical guide provides an overview of the required input data sets.

Elevation Data

OpenNSPECT was developed and tested using U.S. Geological Survey (USGS) 10-meter digital elevation model (DEM) data re-sampled to a 30-meter grid. Although other digital elevation models may be used, USGS 10-meter DEMs are downloadable at no charge from the following GeoCommunity web site:

> data.geocomm.com/dem/demdownload.html

The DEM files each represent one USGS topographic quadrangle and are distributed in SDTS format. The files for Honolulu County were imported to. Care must be taken to ensure the grid cells of the DEM and land cover data sets (and all other grid data sets) are aligned to each other.

The entire runoff and pollutant routing process is based on flow direction and flow accumulation grids derived from the DEM. Although it is possible to use higher resolution DEMs with OpenNSPECT, these data sets will result in increased processing times.

Digital elevation data can also be obtained directly from the USGS National Map Seamless Server:

> seamless.usgs.gov

Land Cover Data

Coastal Change Analysis Program (C-CAP) data sets are produced by the NOAA Coastal Services Center and are considered the default source of land cover data for use with OpenNSPECT. The tool is distributed with C-CAP land cover data for the Waiʻanae region but is designed to also accommodate land cover data sets produced by other agencies or for other regions of the world. For general information on the C-CAP program and land cover data sets, please visit the following Web sites:

> www.csc.noaa.gov/crs/lca/ccap.html
> www.csc.noaa.gov/digitalcoast/data/ccapregional/details

When applying OpenNSPECT outside of the Waiʻanae region, a few steps are necessary to obtain and prepare the land cover data. To download C-CAP land cover data for a new study area, visit the link below and follow the directions:

> www.csc.noaa.gov/crs/lca/locateftp.html

After downloading the data, the next steps are to subset and reproject the data using ERDAS Imagine®, ArcGIS, MapWindow or a similar software package. All input data sets must be converted to a common projection; in the case of Waiʻanae, this projection was UTM Zone 4 with datum NAD83. Finally, export the image file as a grid.

Again, make sure the grid cells of the DEM and land cover data sets (and all other grid data sets) match.

Runoff Curve Numbers (CN)

Runoff curve numbers represent the infiltration capacity of the soil and range from 0 to 100, with 0 being no runoff and 100 indicating no infiltration. Curve numbers play an important role in OpenNSPECT's runoff depth estimation calculations.

OpenNSPECT includes default curve number values for use with C-CAP land cover data sets. Table 1 shows C-CAP land cover classifications and the corresponding curve number values for each of the four hydrologic soil types. OpenNSPECT also allows the user to modify these default values or specify entirely new values. Refer to *Urban Hydrology for Small Watersheds: Technical Release 55* for more information on determining appropriate curve numbers for other land cover classes.

For instances in which a dual hydrologic group is assigned (e.g., A/D, B/D, C/D), the highest curve number of the two components will be used. For instance, B/D areas will be assigned a value of D for that land cover class. Higher curve numbers are given for landscapes with more impervious cover, surface soils with high clay content, or lands with low soil cover.

Table 1. Mapping C-CAP land cover classes to curve numbers

C-CAP Value	C-CAP Class	TR-55 Cover Type	TR-55 Treatment	TR-55 Condition	Group A	Group B	Group C	Group D
2	High Intensity Developed	Commercial and Business			89	92	94	95
3	Medium Intensity Developed				77	85	90	92
4	Low Intensity Developed	1/4 Acre Residential			61	75	83	87
5	Developed Open Space				49	69	79	84
6	Cultivated Land	Row Crops	Straight Row	Good	67	78	85	89
7	Pasture/Hay				39	61	74	80
8	Grassland	Pasture, Grassland, or Range		Good	30	58	71	78
9	Deciduous Forest	Woods		Good	30	55	70	77
10	Evergreen Forest	Woods		Good	30	55	70	77
11	Mixed Forest	Woods		Good	30	55	70	77
12	Scrub/Shrub	Brush		Good	30	48	65	73
13	Palustrine Forested Wetland				0	0	0	0
14	Palustrine Scrub/Shrub Wetland				0	0	0	0
15	Palustrine Emergent Wetland				0	0	0	0
16	Estuarine Forested Wetland				0	0	0	0
17	Estuarine Scrub/Shrub Wetland				0	0	0	0
18	Estuarine Emergent Wetland				0	0	0	0
19	Unconsolidated Shore				0	0	0	0
20	Bare Land	Fallow	Bare soil		77	86	91	94
21	Water				0	0	0	0
22	Palustrine Aquatic Bed				0	0	0	0
23	Estuarine Aquatic Bed				0	0	0	0

Source: USDA-NRCS, 1986

Rainfall Data

The runoff component of OpenNSPECT is driven by the precipitation grid. OpenNSPECT includes several precipitation grids for the Waiʻanae region of Oʻahu as a default, but the tool also allows users to import additional precipitation grids for other regions.

The National Climate Data Center (NCDC) is the primary repository for precipitation data collected by stations in the federal network. Data for individual stations can be accessed on-line by visiting this Web site:

> lwf.ncdc.noaa.gov/oa/climate/stationlocator.html

For users working in the United States, the NCDC also maintains links to state climate offices (SCOs), which serve as the point of contact and clearinghouse for state and local climate data. Additional information on how to access nonfederal precipitation data should be directed to the appropriate state climatologist's office.

The PRISM Group at Oregon State University also provides access to a suite of climate maps that are available at a variety of spatial and temporal scales for the conterminous United States. These products were created using the Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate mapping system.

> www.prism.oregonstate.edu

Annual Precipitation

The annual precipitation data set for Waiʻanae was developed in conjunction with the Hawaiʻi State Climatologist. Historical precipitation records for the island of Oʻahu are available from the National Climatic Data Center (NCDC). However, the federal precipitation network is fairly sparse and the gaps in coverage must be filled by data from state precipitation gages. Combining data from the state and federal networks yields a spatial coverage representative of microclimate rainfall variations common in Hawaiʻi. Monthly and annual rainfall records for stations on the Waiʻanae coast were interpolated as grids based on both federal and state precipitation records.

Event Precipitation

The Hawaiʻi State Climatologist's Office also generated data for the event type precipitation scenarios for Waiʻanae. These grids represent short-term rainfall events of varying duration and intensity typical of the study area. Precipitation grids representing frontal, upper-level low, and Kona storm events, the major source of rainfall for the Waiʻanae coast, were derived from the historical meteorological data available from both federal and state sources.

Soil Data

The soil data used to run OpenNSPECT is taken from the U.S. Department of Agriculture's (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database. These data are available for download from the following website:

> soils.usda.gov/survey/geography/ssurgo/

Once the selected county soil data is downloaded from the USDA's ftp site, a few modifications are necessary before the data can be loaded into OpenNSPECT. In addition to the polygon shapefile representing soil units, two tables are needed to obtain the data necessary for running OpenNSPECT. The *component* table contains the hydrologic soil group attributes and the *chorizon* table contains the kfactor values. These tables are joined in sequence using following protocol.

	From table or layer	To table or layer	Field used for join
1.	SSURGO polygon shapefile	component	mukey
2.	component	chorizon	cokey

While each soil unit is typically associated with one unique component, each component may be associated with many horizons. This one-to-many relationship must be simplified before the soil features are converted to rasters. There are a couple of methods that can be used to accomplish this. The simplest is to select only the first horizon associated with each component. A more complex method is to calculate a weighted average of all horizons associated with each component. The *SSURGO Database Data Use Information* publication provides detailed background on the data structure and how to access the tables in a GIS.

Once all the joins have been established, the shapefile can be exported and cleaned to eliminate the unnecessary fields contained in the attribute table. Occasionally (usually when a polygon is over water) the records do not contain kfactor or hydrologic soil group data. In these instances, the user must populate these fields with conservative data. Set the kfactor to 0 and the hydrologic soil group to D, unless prior knowledge indicates that different values are more appropriate. OpenNSPECT has a tool (in OpenNSPECT → Advanced Settings → Soils) that allows a user to define a new soils data set. Use the newly created shapefile and select the appropriate fields for kfactor and hydrologic soil group.

Hydrologic Soil Group

The hydrologic group attribute is used to assign runoff curve numbers when working with new land cover data sets or classes (Table 2). The hydrologic group (hydgrp) is an attribute found in the *component* table of the SSURGO database and is assigned based on soil infiltration rates. These are grouped into four categories, A through D, based on decreasing infiltration (A = high infiltration, D = very slow infiltration).

Occasionally, there are polygons without a value defined. This implies one of two scenarios: (1) the area covered by the polygon represents water, or (2) this area has highly disturbed soils and the actual soil type can no longer be determined (as in urbanized areas). Another potential problem is that some polygons may have a compound hydrologic group specified (e.g., A/D, C/D). In these cases, the right-most soil group is assigned for that polygon (A/D becomes D).

After all of the polygons have been assigned a single hydrologic soil group, convert them to a numeric classification scheme. Polygons coded as A become 1, B becomes 2, C becomes 3, and D becomes 4. This numeric attribute should be specified as the source of the hydrologic soil group when creating new soils grids in OpenNSPECT.

Areas covered by water should be recoded as hydrologic group D. All other polygons without values should be considered disturbed soils and should be coded as hydrologic group D. In some cases, Appendix A of the NRCS publication ***Urban Hydrology for Small Watersheds: Technical Release 55*** can be used to populate this value based on the soil series name. Another option is to assign a hydrologic group based on the defined soil texture.

Table 2. Hydrologic soil group definitions

Hydrologic Soil Group	Soil Texture	Soil Group Characteristics
A	Sand, loamy sand, or sandy loam	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well- to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Silt loam or loam	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, and moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Sandy clay loam	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Basic Concept: Runoff Estimation

Stormwater runoff and nonpoint source pollution are problematic for several reasons. Reduced capacities for infiltration and storage associated with impervious surfaces lead to larger and more rapid discharges to receiving waters. Downstream flooding, changes in stream morphology (straightening, downcutting, etc.), and erosion are a few of the problems that can result from too much water leaving a site too quickly. Stormwater runoff from developed areas also tends to carry higher pollutant loads than runoff from undisturbed sites. Nutrients such as phosphorus and nitrogen, suspended solids or sediments, hydrocarbons like oil and grease, and metals (zinc, copper, lead) are all commonly found in stormwater runoff from developed sites (Schueler 2000).

OpenNSPECT allows users to investigate the impacts of land use changes on stormwater runoff and water quality, in general. Although there is no user interface that is directly related to the estimation of runoff, these calculations are the basis of many of the other OpenNSPECT functions and processes. This section of the technical guide discusses the procedures OpenNSPECT uses to estimate runoff depth and volume.

SCS Curve Number Method

OpenNSPECT uses the method presented in the Natural Resources Conservation Service's *Urban Hydrology for Small Watersheds: Technical Release 55* as the basis for its runoff estimates. Retention, initial abstraction, and runoff depth are all derived according to the following equations:

$Q = (P - I_a)^2 / [(P - I_a) + S]$

$I_a = 0.2 * S$

$S = (1000 / CN) - 10$

Where:

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in)
I_a = initial abstraction (in)
CN = runoff curve number

Note: If $(P - I_a) \leq 0$, then $Q = 0$

If the initial abstraction at a given cell is greater than the rainfall at that cell, OpenNSPECT sets runoff depth to zero. This prevents the reintroduction of artificial sinks to the runoff analysis. Figure 5 provides a basic overview of the runoff estimation process.
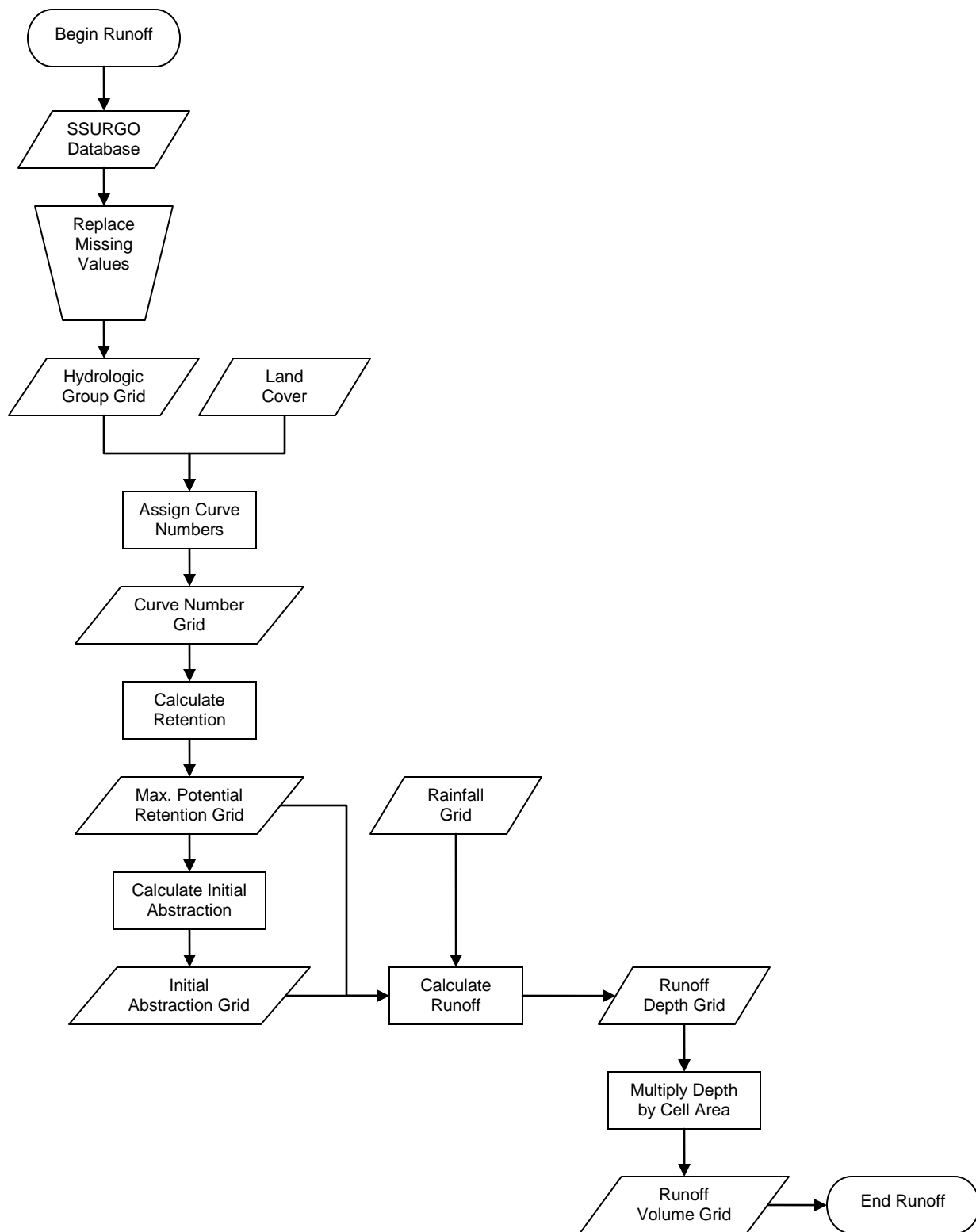
Figure 2. OpenNSPECT runoff process.

Calculating Runoff

This section of the technical guide walks through the processing that occurs behind the scenes when OpenNSPECT estimates runoff volume.

Step 1: Create the Curve Number Grid

Runoff curve numbers were developed by NRCS based on soil properties and represent overall permeability. This number varies from 0 (100 percent rainfall infiltration) to 100 (0 percent infiltration—i.e., pavement) and is used to estimate runoff depth. OpenNSPECT generates a curve number grid based on the combination of land cover and hydrologic soil group at each cell within a given analysis area (see Table1).

Step 2: Calculate Maximum Potential Retention

Retention represents the ability of the soil to absorb or retain moisture. Precipitation that is absorbed or retained by the soil does not contribute to runoff. OpenNSPECT calculates retention at each grid cell as shown below:

$$\text{Retention} = (1000 / \text{Curve Number}) - 10$$

Units associated with the abstraction grid are inches.

Step 3: Calculate Initial Abstraction

Abstraction refers to the losses that occur before runoff begins. This can include water stored by surface depressions and water intercepted by vegetation, evaporation, and infiltration. OpenNSPECT calculates abstraction at each grid cell as shown below:

$$\text{Abstraction} = (0.2 \times \text{Retention})$$

Units associated with the abstraction grid are inches.

Step 4: Precipitation Grid

The next step is to either choose a preexisting input precipitation grid or create a new precipitation grid using a GIS. This grid must be in inches, as the Technical Release 55 (TR-55) equation for estimating runoff assumes precipitation inputs are in inches. Users can use a grid that represents precipitation in centimeters, and OpenNSPECT will convert it to inches during the analysis.

Step 5: Calculate Runoff

Event-based runoff depth is estimated according to the following equation taken directly from TR-55:

$$\text{Runoff Depth} = (\text{Rainfall} - \text{Abstraction})^2 / (\text{Rainfall} - \text{Abstraction}) + \text{Retention}$$

OpenNSPECT checks for instances where abstraction is greater than rainfall and sets runoff to zero. This method is designed for average conditions, does not explicitly account for rainfall intensity or duration, and is less accurate when precipitation is 0.5 inches or less.

Annual runoff depth is estimated based on the following equation, which accounts for the average number of days it rains per year. The estimated abstraction and retention are multiplied by the number of rain days, thus reducing estimated runoff.

$$\text{Runoff depth} = \frac{(\text{Rainfall} \times (\text{Abstraction} \times \text{RainDays}))^2}{[(\text{Rainfall} \times (\text{Abstraction} \times \text{RainDays})) + (\text{Retention} \times \text{RainDays})]}$$

Step 6: Convert Units

The next step in the runoff estimation process is to convert the runoff depth grid to runoff volume and to other units that will be used as inputs to subsequent processing.

Because the TR-55 runoff equation yields the depth (inches) of excess water that runs off the landscape for a given total rainfall depth, this grid must be multiplied by the cell area in order to produce a true runoff volume grid. The cell area is simply the length times the width of the cell. For example, a grid with 30 x 30 meter cells would have a cell area of 900 square meters. This cell area value can be converted to other units by multiplying it by the appropriate conversion factor.

Input Data Sets

The following data sets are required for runoff estimation. Refer to the *Model Setup: Data Inputs* section to learn how to obtain and preprocess these data sets.

- Rainfall data
- Elevation data
- Land cover data
- Soil data

Output Data Sets

Data sets produced by the runoff calculation process include:

- Runoff volume (L)
- *Runoff depth**
- *Runoff curve number**

   *Data sets in italics are temporary and are not reported.

OpenNSPECT uses each of these data sets as input to subsequent processes like the estimation of sediment concentrations. Runoff volume is also a required input to the pollutant concentration module.

Resources

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with Revised Universal Soil Loss Equation (RUSLE)*. United States Department of Agriculture, Agriculture Handbook 703, United States Government Printing Office, Washington D.C.

Schueler, Thomas R. "Why Stormwater Matters." *The Practice of Watershed Protection*. Eds. Thomas R. Schueler and Heather K. Holland. Ellicott City, MD: Center for Watershed Protection, 2000. pp 365–370.

USDA-NRCS. 1986. *Urban Hydrology for Small Watersheds. Technical Release 55 (TR-55)*. Second Edition. Washington, D.C. Available at *ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf.*

Basic Concept: Pollutant Loading

Nonpoint source pollution has proven to be a difficult problem to address due to its complex nature. It is not always clear exactly where the most significant pollution sources are located, and it is even more difficult to monitor and enforce relatively small contributions from many widely dispersed sources.

The effects of nonpoint source pollution range from eutrophication and algal blooms to closed beaches and shellfish beds, and can cause human health impacts through the food chain (Arnold and Gibbons, 1996).

OpenNSPECT estimates pollutant concentrations by using land cover as a proxy. This is accomplished by applying pollutant contribution coefficients (similar to event mean concentrations) to land cover classes and introducing a runoff volume grid.

The pollutant concentration estimation procedure does not explicitly take duration or intensity of rainfall into account.

Estimating Pollutant Loading

OpenNSPECT estimates concentrations for four default pollutants (nitrogen, phosphorus, lead, and zinc) as well as additional user-specified pollutants.

The runoff volume grid is converted to liters by multiplying each cell by a conversion factor (Figure 6). Next, the accumulated runoff grid is created from the flow direction grid and the new runoff volume grid. Each cell in the accumulated runoff grid represents the total amount of water that passes through that cell, including contributions from upstream cells.

A pollutant concentration grid is then created from either the default pollutant coefficients or a new set derived from local sampling data where each cell is assigned a value based on its land cover classification. The pollutant coefficient value represents an average concentration (mg/L) for a given land cover classification. When the pollutant concentration grid is multiplied by the runoff volume grid, the result is a new grid that indicates the mass of the pollutant produced by each individual cell. This grid does not take into account upstream contributions.

The pollutant mass grid is accumulated using the flow direction grid, which yields an accumulated pollutant mass grid in which the value of each cell represents the total mass of pollutant that passes through that cell, including contributions from upstream cells.

An accumulated pollutant concentration grid is derived by dividing the accumulated pollutant mass grid by the accumulated runoff grid. However, this grid does not include the pollutant mass and runoff volume generated at the current cell, instead including only the total value of all upstream cells that flow through the current cell. The final pollutant concentration grid is created by adding the pollutant mass grid and accumulated pollutant mass grid, then dividing this quantity by the sum of the runoff volume grid and the accumulated runoff grid.

Input Data Sets

The following data sets are required for runoff estimation. Refer to the *Model Setup: Data Inputs* section to learn how to obtain and preprocess these data sets.

- Rainfall data
- Elevation data
- Land cover data
- Soil data (hydrologic group)

Output Data Sets

OpenNSPECT produces a concentration grid for each pollutant specified in the initial analysis setup. If the Local Effects Only option is unchecked, the resulting grid represents the expected pollutant concentration value if a sample were taken at a given cell location. If the "Local Effects Only" option is checked, the resulting grid represents the ratio of pollutant to runoff produced at each individual cell with no input from upstream cells.

- Accumulated Pollutant (kg)
- Pollutant Concentration (mg/L)
- Comparison to Pollutant Standard (exceeds standard or below standard)

The pollutant concentration grids are used as inputs to the water quality assessment and reporting component of OpenNSPECT.
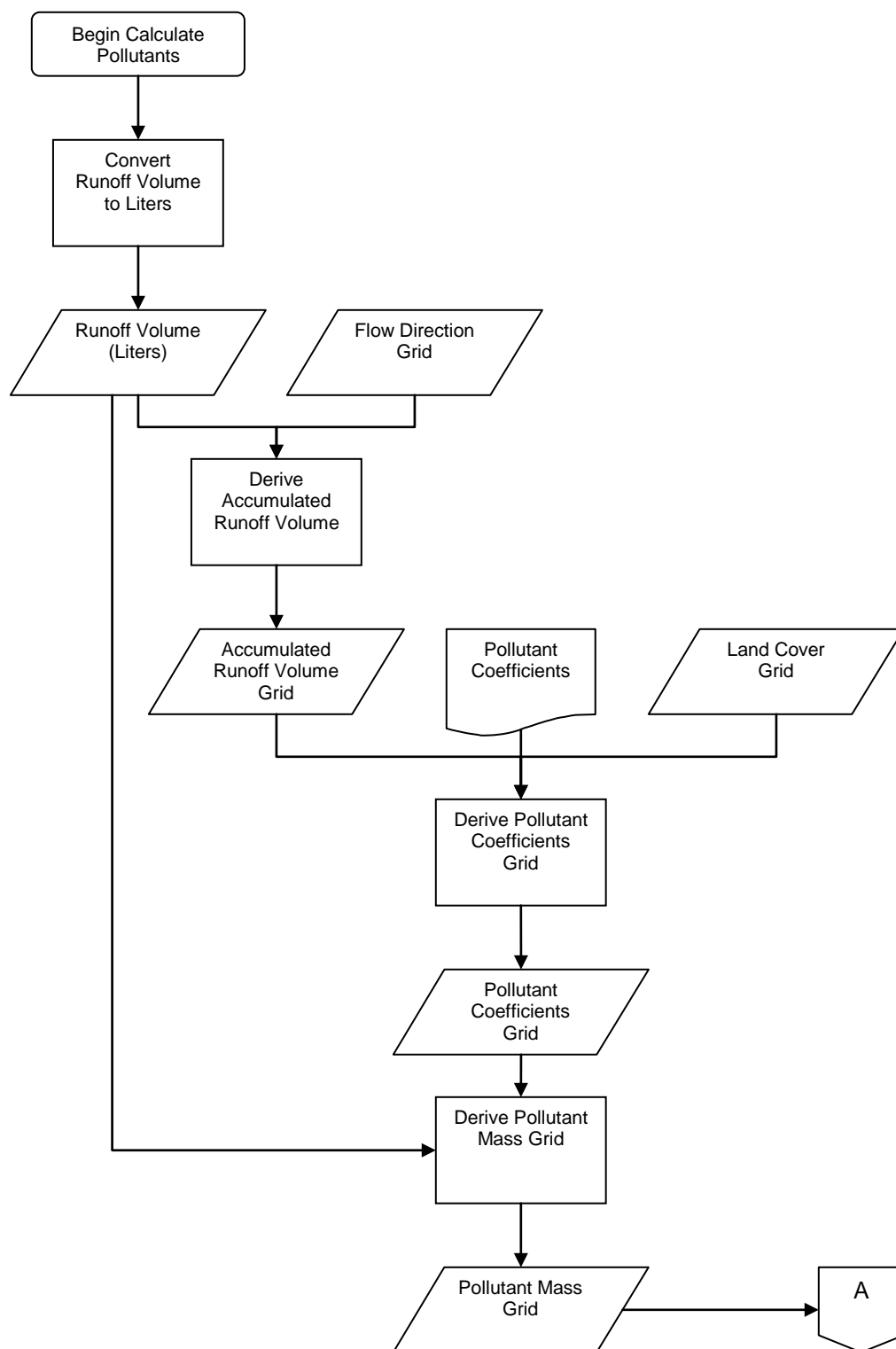
Figure 3. Pollutant concentration estimation process.

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                │     Derive      │
                │   Accumulated   │
                │  Pollutant Mass │
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                │     Derive      │
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                │  Concentration  │
                │      Grid       │
                └────────┬────────┘
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Derive Accumulated Pollutant Mass Grid

Accumulated Pollutant Mass Grid

Derive Accumulated Concentration Grid

Accumulated Concentration Grid

Pollutant Mass Grid

Runoff Volume (Liters)

Accumulated Runoff Volume Grid

Derive Total Pollutant Concentration Grid

Total Pollutant Concentration Grid

End Calculate Pollutants

Note: Shading indicates output data set.

Resources

Adamus, C.L., and M. Bergman. 1995. "Estimating Nonpoint Source Pollution Loads with a GIS Screening Model." *Water Resources Bulletin*. 31(4): 647–655.

Arnold, C.L., and C.J. Gibbons. 1996. "Impervious Surface Coverage: The Emergence of a Key Environmental Indicator." *Journal of the American Planning Association*. 62(2): 243–258.

CH2M HILL. 2000. *Technical Memorandum 1, Urban Stormwater Pollution Assessment*. Prepared for North Carolina Department of Environment and Natural Resources, Division of Water Quality, August, 2000.

USDA-NRCS. 1986. *Urban Hydrology for Small Watersheds. Technical Release 55 (TR-55)*. Second Edition. Washington, D.C. Available at *ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf*

US EPA. 1983. *Final Report of the Nationwide Urban Runoff Program*. U.S. Environmental Protection Agency (US EPA), Water Planning Division, Washington, DC.

Basic Concept: Erosion

Erosion and sedimentation are significant problems in the Waiʻanae region and suspended sediments are one of the most serious and widespread nonpoint source pollution issues in the nation. This section of the technical guide documents the equations and processes OpenNSPECT uses to estimate suspended sediment concentrations.

The Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) was developed in the late 1970s, based on empirical research, as a tool for soil conservation. Originally intended for use on croplands, subsequent changes to the USLE expanded its applicability to additional land cover types (RUSLE) and individual storm events (MUSLE).

Annual Erosion

The current standard for estimating annual erosion is the Revised Universal Soil Loss Equation (RUSLE), a variant of the original USLE. The Revised Universal Soil Loss Equation is:

$A = R * K * L * S * C * P$

> Where:
>
> A = average annual soil loss   S = slope steepness factor
> R = rainfall/runoff erosivity factor   C = cover management factor
> K = soil erodibility factor   P = supporting practices factor
> L = slope length factor

R Factor Grid: The rainfall/runoff erosivity factor was estimated from the R factor map for Oahu given in the NRCS Field Office Technical Guide. A line shapefile approximation of the printed map was generated via "heads-up" digitizing. The units are feet * tonfeet * inch/acre * hour * year.

K Factor Grid: The soil erodibility factor was taken directly from the SSURGO data set. Polygons without a K factor value (urban soils) were assumed to carry a K value of 0.30. The units are ton * acre * hour/acres * tonfeet * feet * inch.

LS Factor Grid: LS calculations are based on the RUSLE research of Renard et al. (1997). The LS factor will be generated using an ArcGIS version of an AML script written by Bob Hickey at Central Washington University. Slope length is calculated by deriving the downslope angle for each cell in degrees. Next, a grid showing relative change in downslope angle is created. Areas where downslope angle exceeds 5 percent and the relative change in downslope angle exceeds 50 percent are flagged as breaks in the cumulative slope. Areas where downslope angle is less than or equal to 5 percent and the relative change in downslope angle exceeds 70 percent are also flagged as breaks in the cumulative slope.

A modified flow direction grid is created where the slope break points are recoded as zeros and all other cells retain their original flow direction values. A weight grid is created where each output cell receives a value of 1 (times the cell size) if water flows through it in a cardinal direction, and 1.4142 (times the cell size) if water flows through it in a diagonal direction (Pythagorean Theorem). The FLOWLENGTH command is then used to sum these values along the flow paths until one of the break points, a ridge, or a pour point is encountered. This yields the estimate of slope length *lamda* used to calculate the L factor in the equation on page 105 of Renard et al. (1997).

> $L = (lamda / 72.6)^{m}$

Table 3 presents the slope-length exponent m, derived from Table 4-5 in Renard et al. (1997).

Table 3. Slope-Length exponent derivation

Downslope Angle Is…		M Value
Less than or equal to 0.1		0.01
Greater than 0.1	and less than 0.2	0.02
Greater than or equal to 0.2	and less than 0.4	0.04
Greater than or equal to 0.4	and less than 0.85	0.08
Greater than or equal to 0.85	and less than 1.4	0.14
Greater than or equal to 1.4	and less than 2.0	0.18
Greater than or equal to 2.0	and less than 2.6	0.22
Greater than or equal to 2.6	and less than 3.1	0.25
Greater than or equal to 3.1	and less than 3.7	0.28
Greater than or equal to 3.7	and less than 5.2	0.32
Greater than or equal to 5.2	and less than 6.3	0.35
Greater than or equal to 6.3	and less than 7.4	0.37
Greater than or equal to 7.4	and less than 8.6	0.40
Greater than or equal to 8.6	and less than 10.3	0.41
Greater than or equal to 10.3	and less than 12.9	0.44
Greater than or equal to 12.9	and less than 15.7	0.47
Greater than or equal to 15.7	and less than 20.0	0.49
Greater than or equal to 20.0	and less than 25.8	0.52
Greater than or equal to 25.8	and less than 31.5	0.54
Greater than or equal to 31.5	and less than 37.2	0.55
Greater than 37.2		0.56

The S factor is calculated using the following equations (Renard, 1997):

    Where slope < 9% $S = 10.8 * (\sin theta) + 0.03$

    Where slope > 9% $S = 16.8 * (\sin theta) - 0.50$

The LS factor units are feet.

C Factor Grid: Default cover management factor values are drawn from the table 4 below:

Table 4. Default C Factor values

C-CAP Value	C-CAP Class	C Factor
2	High-Intensity Developed	0.000
3	Medium-Intensity Developed	0.010
4	Low-Intensity Developed	0.030
5	Developed, Open Space	0.005
6	Cultivated Land	0.240
7	Pasture/Hay	0.005
8	Grassland	0.120
9	Deciduous Forest	0.009
10	Evergreen Forest	0.004
11	Mixed Forest	0.007
12	Scrub/Shrub	0.014
13	Palustrine Forested Wetland	0.003
14	Palustrine Scrub/Shrub Wetland	0.000
15	Palustrine Emergent Wetland	0.000
16	Estuarine Forested Wetland	0.003
17	Estuarine Scrub/Shrub Wetland	0.003
18	Estuarine Emergent Wetland	0.003
19	Unconsolidated Shore	0.500
20	Bare Land	0.700
21	Water	0.000
22	Palustrine Aquatic Bed	0.000
23	Estuarine Aquatic Bed	0.000

C Factor values are unitless.

P Factor Grid: The supporting practices factor is not included in this version of OpenNSPECT but may be incorporated in future releases as data availability permits.

The annual soil loss grid will be generated by multiplying the R factor, C factor, K factor, and LS factor grids.

Sediment Delivery Ratio

RUSLE produces an estimate of gross erosion, but does not indicate how much eroded soil is actually transported by streams.

$$SDR = 1.366 * 10^{-11} * (DA)^{-0.0998} * (ZL)^{0.3629} * (CN)^{5.444}$$ (Williams, 1977)

Where:

DA = drainage area (km^2)
ZL = the relief-length ratio (m/km)
CN = SCS curve number

Drainage Area (DA): The sediment delivery ratio is applied at the cell level rather than at the watershed or catchment level. The drainage area parameter represents the area of each individual grid cell.

Relief-Length Ratio (ZL): This ratio is calculated based on the DEM and flow direction grid. The elevation change along the downslope flow path is calculated from the DEM and divided by the distance from the center of the current cell to the center of the next cell along the flow path.

Curve number (CN): The runoff curve number grid is derived from the land cover grid and SSURGO shapefile.

Multiplying the resulting sediment delivery ratio grid by the annual soil loss grid from the previous step will produce a true annual sediment yield grid.

Figure 4. Solving RUSLE.

```
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                                  │    A    │
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                                       │
                 ┌─────────────────────┴─────────────────────┐
                 ▼                                             ▼
        ╱─────────────────╲                          ╱─────────────────╲
       ╱  Soil Loss Grid   ╲                        ╱    Sediment        ╲
      ╱   (mg per year)     ╲                      ╱  Delivery Ratio      ╲
     ╱─────────────────────╱                      ╱       Grid            ╱
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                       │ Derive Sediment Yield  │
                       │                        │
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                                   ▼
                        ╱─────────────────╲
                       ╱  Sediment Yield    ╲
                      ╱       Grid           ╲
                     ╱   (kg per year)        ╱
                    ╱─────────────────────────╱
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                         │   End RUSLE    │
                         ╰───────────────╯
```
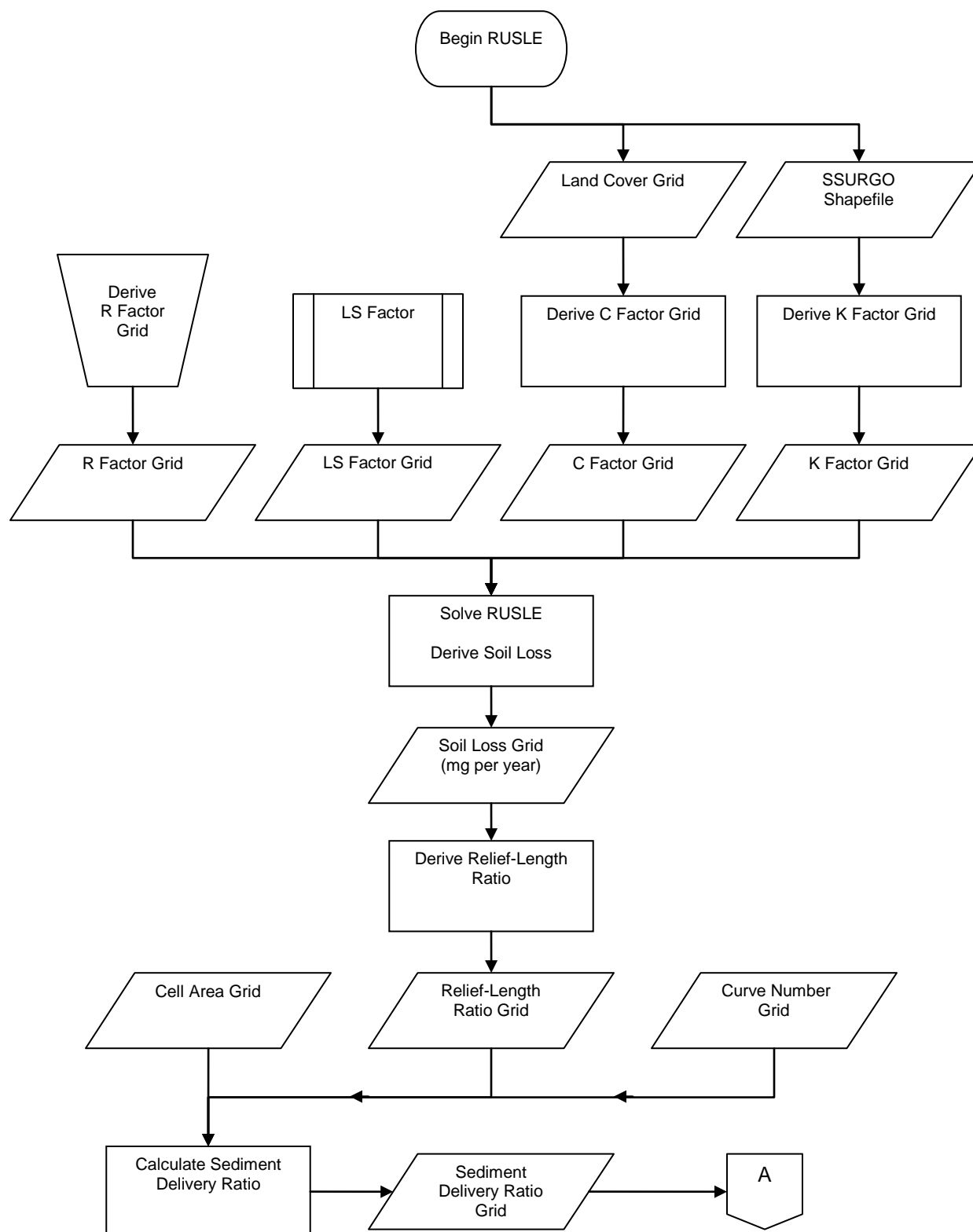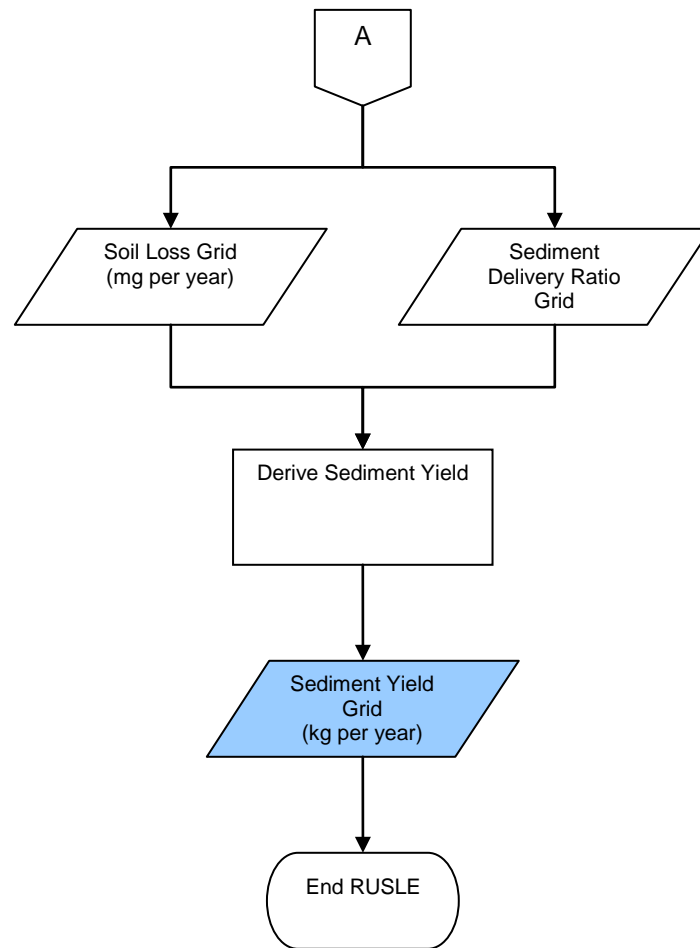
Note: Shading indicates output data set.

Figure 5. Calculate LS factor.

```
                                    ┌───────┐
                                    │   B   │
                                    └───┬───┘
          ┌─────────────────────────────┴─────────────────┐
  ┌───────────────────┐                          ┌───────────────────┐
  │     Modified      │                          │   Slope Change    │
  │    Downslope      │                          │       Grid        │
  │    Angle Grid     │                          │                   │
  └───────────────────┘                          └───────────────────┘
                                          │
                              ┌───────────────────────┐
                              │  Identify Breakpoints  │
                              │                        │
                              │  Create Modified Flow  │
                              │     Direction Grid     │
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                                          │
                        ┌───────────────────┐     ┌───────────────────┐
                        │  Modified Flow     │     │   Weight Grid     │
                        │  Direction Grid    │     │                   │
                        └───────────────────┘     └───────────────────┘
  ┌───────────────────┐     ┌───────────────────┐
  │ Calculate Slope   │     │ Create Cumulative │
  │ Length Exponent   │     │ Slope Length Grid │
  │    Value "M"      │     │                   │
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  │  Slope Length     │     │   Cumulative      │
  │  Exponent Grid    │     │  Slope Length     │
  │                   │     │      Grid         │
  └───────────────────┘     └───────────────────┘
  ┌───────────────────┐     ┌───────────────────┐
  │ Calculate S Factor│     │ Calculate L Factor│
  │      Grid         │     │       Grid        │
  └───────────────────┘     └───────────────────┘
  ┌───────────────────┐     ┌───────────────────┐
  │   S Factor Grid   │     │   L Factor Grid   │
  └───────────────────┘     └───────────────────┘

  ┌───────────────────┐  ┌───────────────────┐  ┌───────────────────┐
  │ Calculate LS      │  │  LS Factor Grid   │  │   End LS Factor   │
  │   Factor Grid     │  │                   │  │                   │
  └───────────────────┘  └───────────────────┘  └───────────────────┘
```

Event-Driven Erosion

In many cases, the effects of a single storm event on erosion and sediment yield are of primary interest. The Modified Universal Soil Loss Equation (MUSLE), given below, is appropriate for use under these circumstances:

$$S = a * (Q * q_p)^b * K * C * P * LS$$

Where

S = sediment yield from an individual storm (tons)
Q = storm runoff volume (acre-feet)
q_p = peak runoff rate (cubic feet per second)
K = soil erodibility factor
C = cover management factor
P = supporting practices factor
L = slope length factor
S = slope steepness factor
a = 95
b = 0.56

This version of MUSLE is considered the standard version of the equation and is most appropriate for most areas of the United States mainland. However, variations of the standard equation have been developed. Conaway and Curtis developed coefficients calibrated to the wet conditions persistent in the windward and mauka region of Oʻahu.
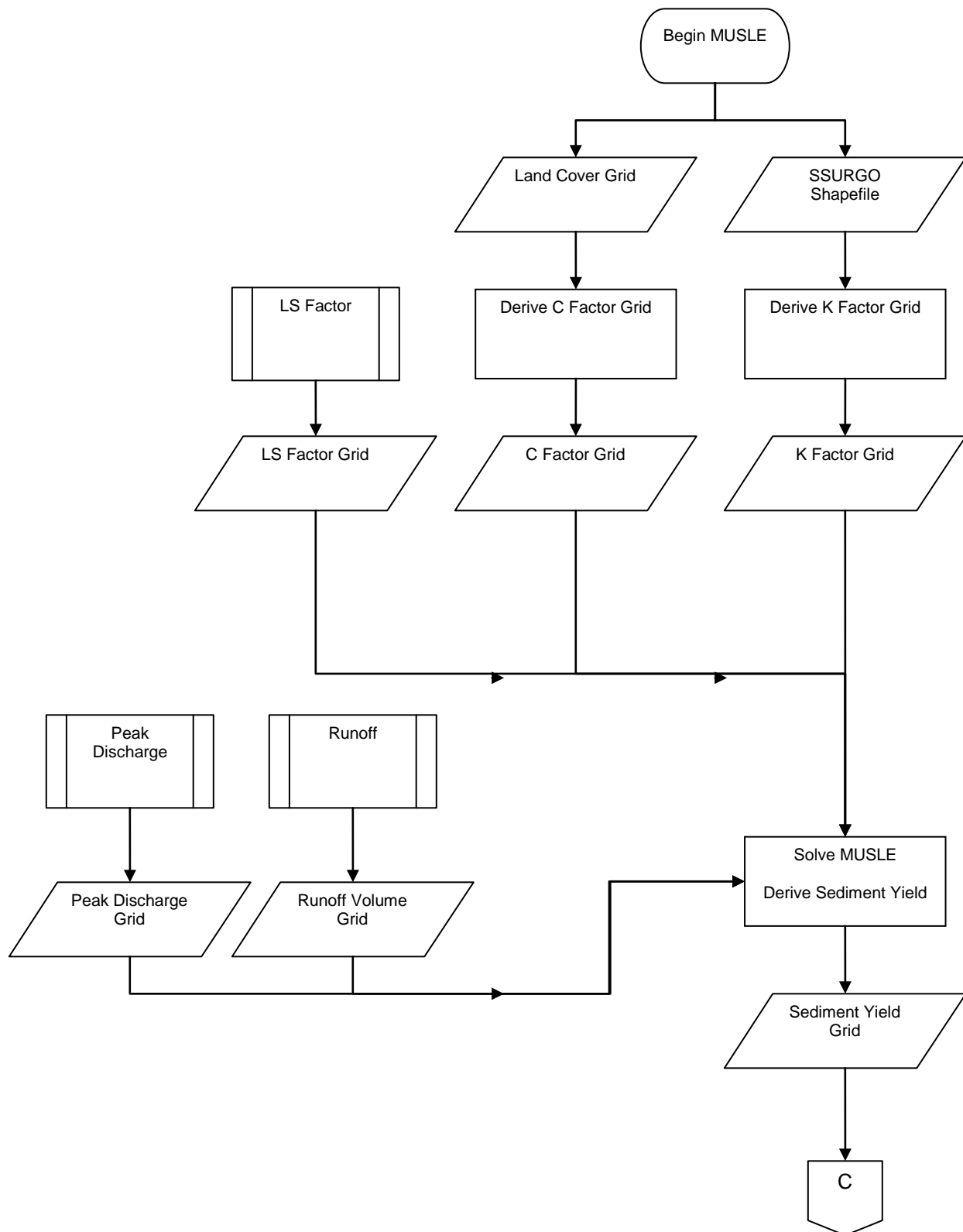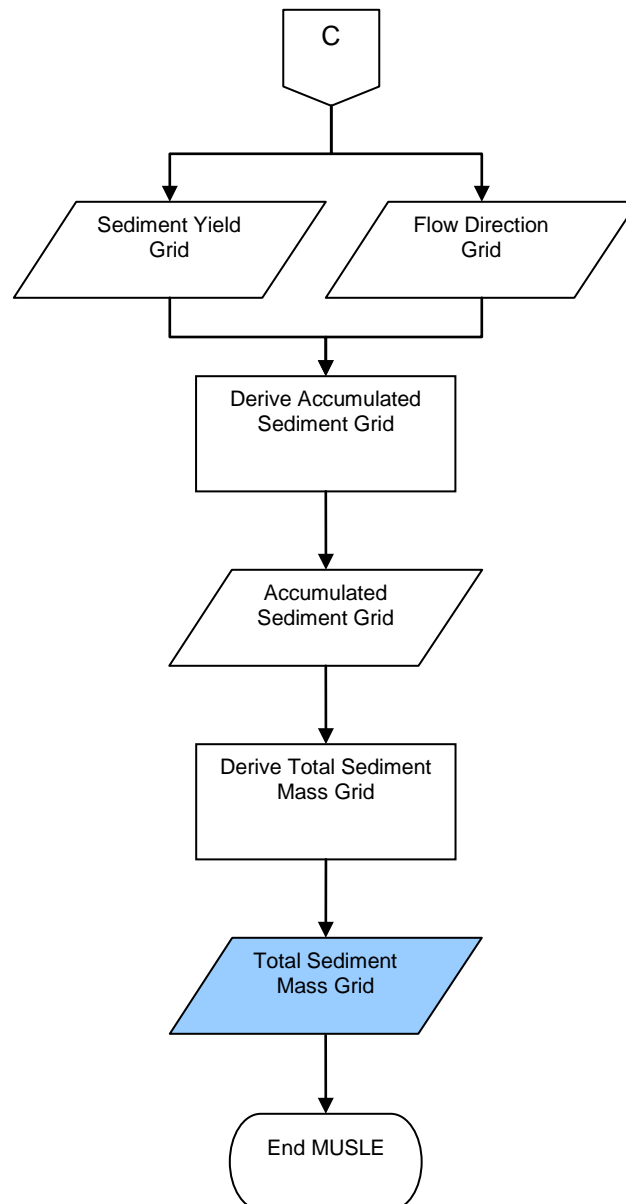
a = 18.943
b = 0.877

OpenNSPECT includes an interface menu where the user may change the coefficients to better reflect local conditions. The greater body of scientific literature contains other locally calibrated coefficients. It is important that the user understand that this form of the MUSLE equation was derived using English units (Q = acre-feet; q_p = cubic feet per second), and that the locally calibrated coefficients "a" and "b" should be derived accordingly.

Runoff Volume (Q)**:** Runoff is calculated according to the procedure outlined in the runoff section of this document. A conversion factor is applied to the existing runoff data set to produce a grid with units of acre-feet.

Peak Runoff (q_p)**:** This value represents the maximum volume of flow attained at a given point in a stream during a runoff event. OpenNSPECT incorporates the NRCS Graphical Peak Discharge method to estimate q_p (USDA-NRCS, 1986).

Figure 6. Solve MUSLE.

```mermaid
flowchart TD
    C([C])
    C --> SYG[/Sediment Yield Grid/]
    C --> FDG[/Flow Direction Grid/]
    SYG --> DASG[Derive Accumulated Sediment Grid]
    FDG --> DASG
    DASG --> ASG[/Accumulated Sediment Grid/]
    ASG --> DTSMG[Derive Total Sediment Mass Grid]
    DTSMG --> TSMG[/Total Sediment Mass Grid/]
    TSMG --> End([End MUSLE])
```

Calculating Peak Runoff

First, calculate time of concentration (minutes) using the SCS Lag Method:

$T_c = L / 0.6$ (Kent, 1972)

$L = W^{0.8} * [(1000 / CN) – 9]^{0.7} / 1900 * S^{0.5}$

> Where:

>> L = lag in hours
>> W = watershed length (feet) (the longest flow path in the watershed)
>> S = average watershed slope (%)
>> CN = SCS curve number for the basin

Watershed Length: This measure is calculated at each cell from the digital elevation model (length of one cell side).

Watershed Slope: This is calculated at each cell from the digital elevation model (rise over run times 100).

Curve Number: The curve number grid is created in a previous process.

Then, use T_c to calculate q_u with this equation:

$\log(q_u) = C_0 + C_1\log(T_c) + C_2[\log(T_c)]^2$
> (TR-55)
> Where:

>> q_u = unit peak discharge (csm/in)
>> T_c = time of concentration (hr)

The C constants will be populated using the Ia/P ratio at each cell. For instance, if the Ia/P ratio is less than or equal to 0.10, then $C_0 = 2.30550$, $C_1 = -0.51429$, and $C_2 = -0.11750$.

Table 5. Coefficient values for rainfall type I

Ia/P	C_0	C_1	C_2
0.10	2.30550	-0.51429	-0.11750
0.20	2.23537	-0.50387	-0.08929
0.25	2.18219	-0.48488	-0.06589
0.30	2.10624	-0.45695	-0.02835
0.35	2.00303	-0.40769	0.01983
0.40	1.87733	-0.32274	0.05754
0.45	1.76312	-0.15644	0.00453
0.50	1.67889	-0.06930	0.00000

To solve for q_u, raise 10 to the $\log(q_u)$ power.

Finally, calculate peak discharge:

$$q_p = q_u * A_m * Q * F_p \hspace{4cm} \text{(TR-55)}$$

Where:

q_p = peak discharge (ft^3/s)
q_u = unit peak discharge (csm/in)
A_m = drainage area (mi^2)
Q = runoff (in)
F_p = pond and wetland factor
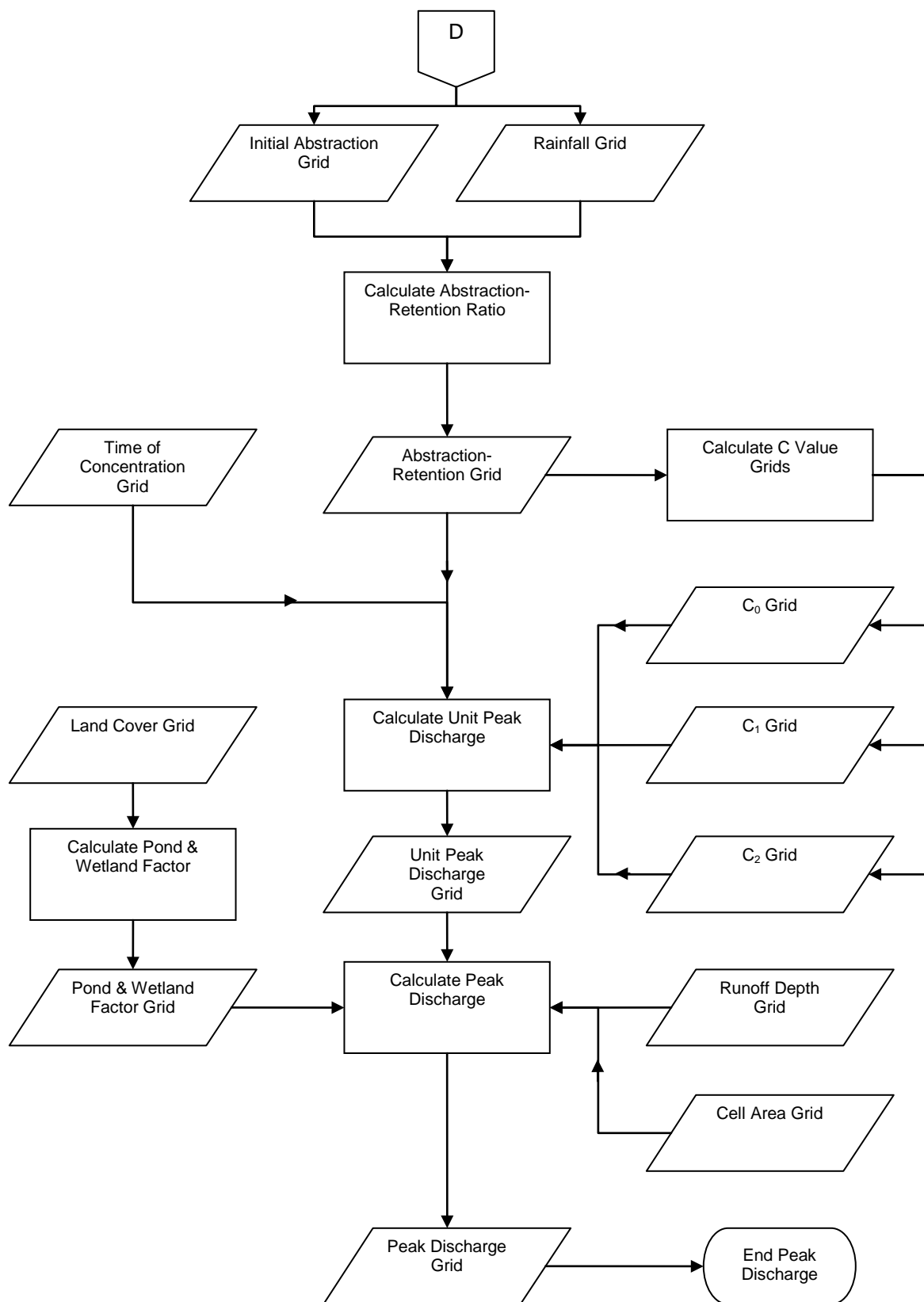
Drainage Area: This is the area of each cell in mi^2.

Runoff Depth: This number is the runoff depth grid produced above.

Pond and Wetland Factor: If there is water or wetlands at the cell, F_p will be 0; otherwise, F_p is 1.

The storm event sediment yield grid is generated by multiplying the C factor, K factor, and LS factor grids by [95 * (Q * q_p)$^{0.56}$].

Figure 7. Calculate peak discharge.
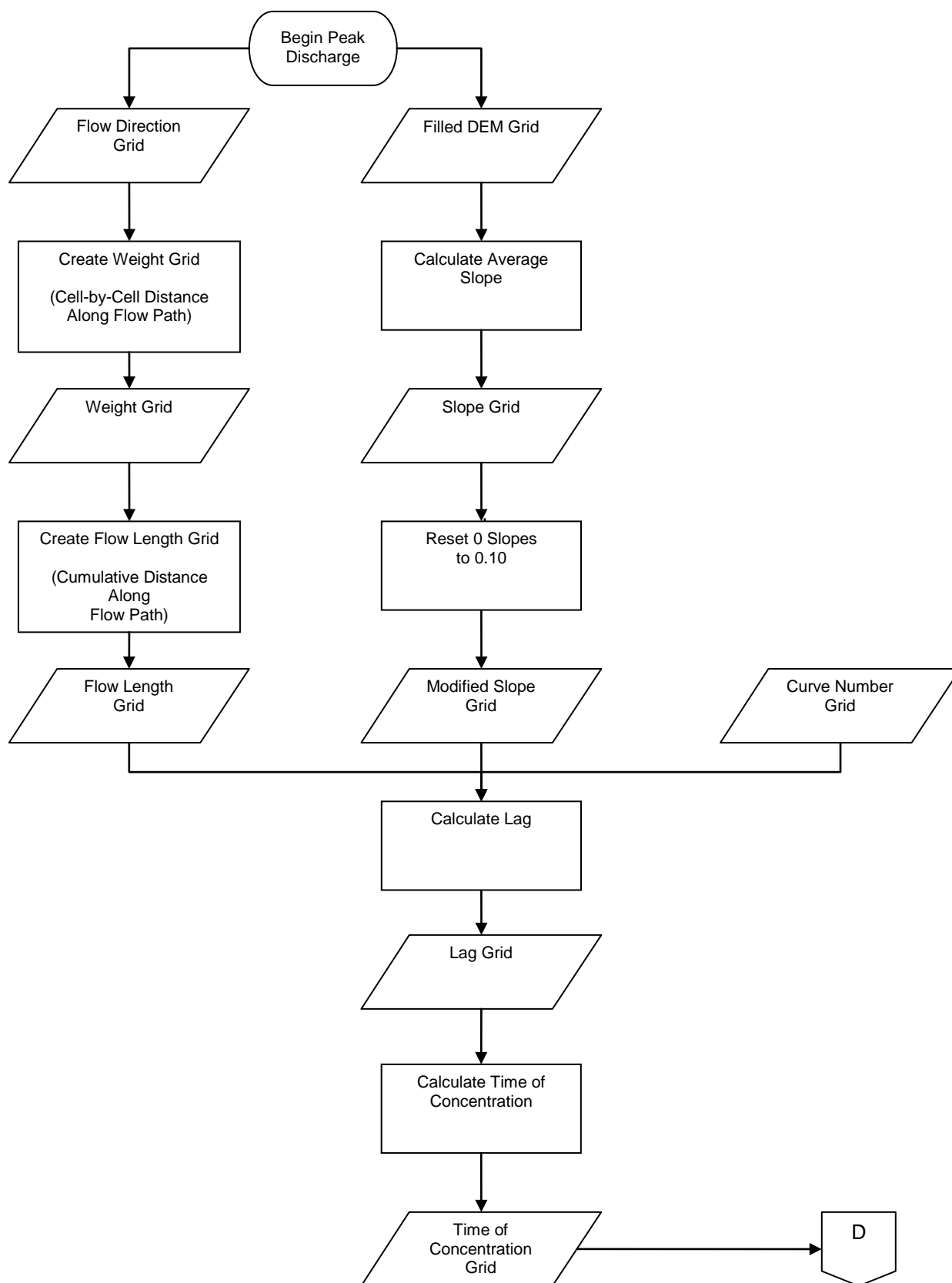
Input Data Sets

Input data sets used to estimate annual sediment yields using RUSLE include:

- Elevation data
- Land cover data
- Soils data
- R factor data

R Factor Grid

OpenNSPECT uses the Revised Universal Soil Loss Equation (RUSLE) to estimate annual rates of erosion. The R factor is one of the parameters that must be specified but unfortunately does not exist as a data layer for Hawaii. This issue was mitigated by creating a shapefile approximation from a hardcopy version of the R factor map created by the Hawaii State NRCS Office in 1995. View this map at:

> http://efotg.nrcs.usda.gov/references/public/HI/R_Oahu_110702.pdf

R factor maps for other regions can typically be found in the NRCS Electronic Field Office Technical Guide or by contacting the local NRCS office. Find your local office at the link below:

> www.nrcs.usda.gov/technical/efotg/

Section I of the technical guide has a subheading called Erosion Prediction, which is where the R factor map is likely to be found.

The first step to producing the R factor data set was to create a line shapefile that approximates, as closely as possible, the features of the R factor map. Each of the line features was attributed according to the values given on the hardcopy map. Then, a one-mile buffer was placed along the outside of the Oahu boundary shapefile. This buffer was created to ensure full coverage of the entire island once the interpolation process is completed. The geoprocessing wizard was used to union the buffer shapefile and the R factor shapefile. The line features were converted to points using an ArcView 3.x script (*pline2pt.ave*). ArcToolBox® was used to convert the point shapefile to a coverage, then clean and build the coverage. Using ArcGIS® and the Spatial Analyst extension, a grid surface based on the point coverage was interpolated. For our purposes, the kriging method was used with the R factor attribute specified as the Z value field. These steps are summarized below:

- Approximate the R Factor Map
- Buffer the Area of Interest
- Union and Convert Lines to Points
- Convert to Coverage
- Interpolate a Grid Surface

Input data sets for estimating event-driven sediment yields using MUSLE include:

- Elevation data
- Land cover data
- Soil data (SSURGO kfactor attribute)
- Rainfall data

The procedures for obtaining and preparing each of these data sets for use with OpenNSPECT are detailed in the runoff section of this document.

Output Data Sets

OpenNSPECT produces two primary output data sets for both annual and event-driven scenarios, depending on the user's specification of accumulated or non-accumulated sediment yield:

- Sediment loss (local effects)
- Accumulated sediment yield

Each cell of the accumulated runoff grid represents the total value of all upstream cells, which flow into the current cell along the paths delineated in the flow direction grid.

Resources

Conaway, Gary, and Neville Curtis Jr. n.d. Calibration of the Modified Universal Soil Loss Equation. Portland, OR: West National Technical Center.

Kent, Kenneth M. 1972.   "Chapter 15: Travel Time, Time of Concentration, and Lag." In <u>*National Engineering Handbook*</u>, Section 4. Available at: *ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/neh630/630ch15.pdf*

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with Revised Universal *Soil Loss Equation (RUSLE).* United States Department of Agriculture, Agriculture Handbook 703, United States Government Printing Office, Washington D.C.

USDA-NRCS. 1986. *Urban Hydrology for Small Watersheds*. Technical Release 55 (TR-55). Second Edition. Washington, D.C.   Available at: *ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf*

Van Remortel, R.D., M.E. Hamilton, and R.J. Hickey. 2001. "Estimating the LS Factor for RUSLE through Iterative Slope Length Processing of Digital Elevation Data within ArcInfo Grid." *Cartography*. Vol. 30, No. 1. Pp 27–35.

Williams, J.R. 1977. Sediment Delivery Ratios Determined With Sediment and Runoff Models. In *Erosion and Solid Matter Transport in Inland Waters*. pp 168-179. IAHS-AISH pub No. 122.

Wischmeier, W.H. and D.D. Smith. 1978. *Predicting Rainfall Erosion Losses—A Guide to Conservation Planning*. Agriculture Handbook No. 537. U.S. Department of Agriculture, Washington, DC.

Basic Concept: Assessment and Reporting

OpenNSPECT allows users to estimate pollutant concentrations and the effects of erosion, but the reporting component of the tool is equally important. This section of the technical guide explains how the reporting scheme is organized and how to interpret the output. A brief discussion of scenario analysis with OpenNSPECT is also provided.
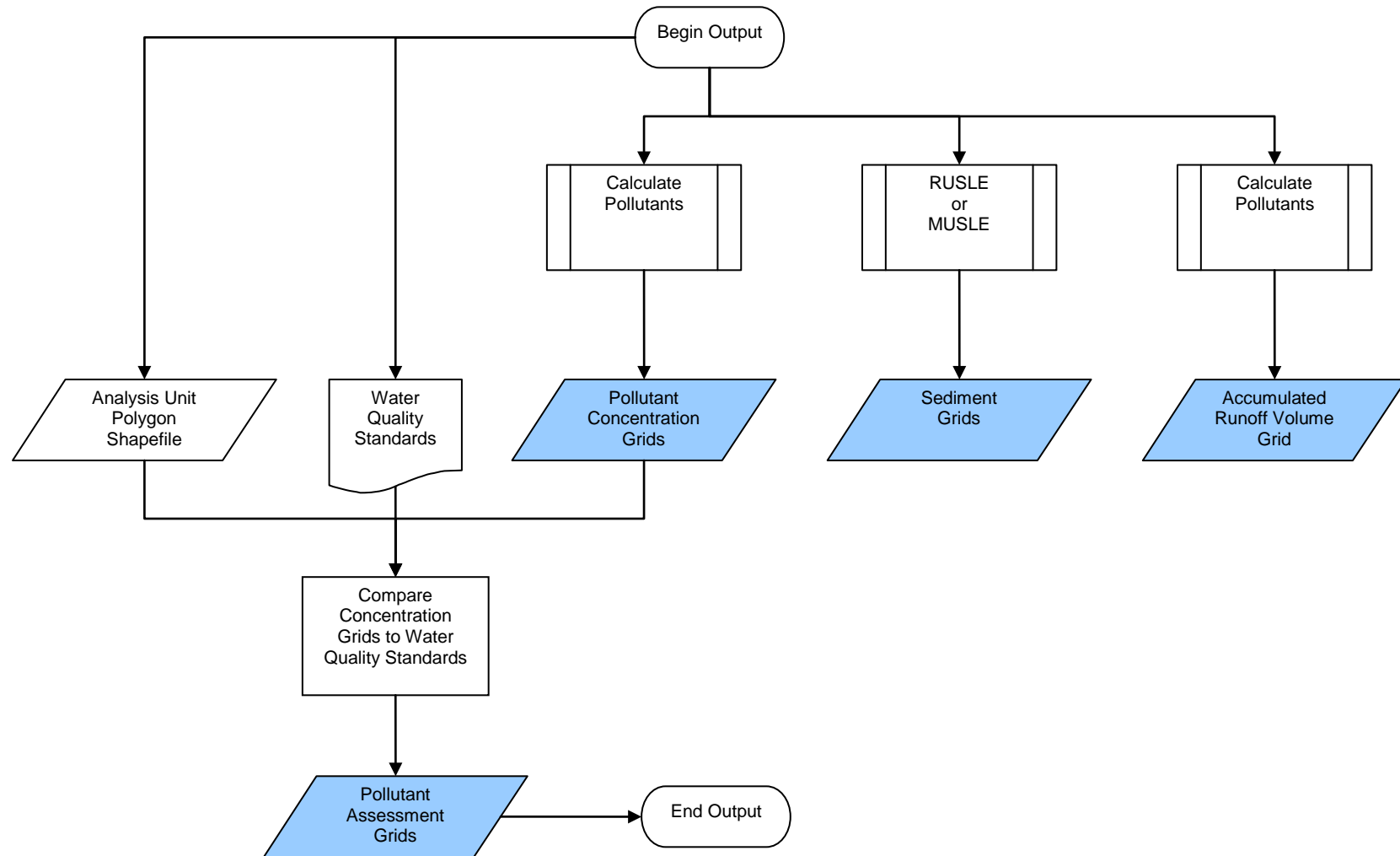
Assessment and Reporting Method

Pollutant grids are compared with user-specified water quality standards, and a rasterized stream network is color-coded to indicate deviation from the target level. Output data sets are organized and displayed in the ArcGIS® table of contents using group layers.

OpenNSPECT allows users to perform basic scenario analysis. Using the management scenarios functionality, a user can change the land cover inside a polygon shapefile to a different (but preexisting) land cover class. An interesting application of this functionality might involve the conversion of wetland areas to a low-intensity developed classification. A comparison of the output data sets produced by this run with those produced under the initial conditions would highlight the impacts of development and emphasize the linkages between land cover and water quality.

Users may also specify a land use (new land cover class) and attach it to the features of a polygon shapefile. This functionality is accessed through the Land Uses tab on the main menu. In addition to a polygon shapefile, the user must specify runoff curve numbers, the erosion cover management factor, and pollutant coefficients. For example, users could specify the location of landfills with a polygon shapefile, create a new land use, and then enter the supporting curve numbers and coefficients. Assuming the parameters provided for the new land use are accurate, the larger analysis also becomes more accurate.

Figure 8. Assessment and reporting process.

Note: Shading indicates output data set.

Input Data Sets

Data sets produced by other components of OpenNSPECT become inputs to the reporting and assessment process. OpenNSPECT evaluates pollutant and sediment concentration grids against default or user-defined standards to provide insight into the overall water quality of a particular area. Relevant data sets include:

- Pollutant grids
- Sediment/erosion grids
- Runoff grids
- Water quality standards
- Analysis unit polygons

The only input data sets that may require user interaction are the water quality standards and analysis unit polygons. Default water quality standards are included for Waianae based on Hawaii Department of Health guidelines, but users may specify new standards as well. The analysis unit polygons are used to organize data for output reporting. Typically, this shapefile will consist of delineated watersheds but can be anything that fits the user's needs.

Output Data Sets

Each cell in a pollutant concentration grid has a unique value, but these grids alone do not necessarily answer questions about larger water quality issues. The pollutant assessment grids provide a cell-by-cell evaluation of how the local conditions compare with an established or user-defined standard for water quality. Output data sets include:

- Accumulated runoff volume grid (L)
- Accumulated pollutant grid(s) (kg)
- Pollutant concentration grid(s) (mg/L)
- Pollutant assessment grid(s) (exceeds standard or below standard)
- Accumulated sediment grid (kg)

The pollutant assessment grids and shaded analysis unit polygons are the primary products of the reporting process. The grids show how the estimated pollutant concentration compares with the selected water quality standard at each cell. This approach allows the user to more easily identify specific areas of concern that may be logical targets for further investigation and monitoring. The shaded polygon shapefile focuses on larger areas and reports the degree of compliance by comparing a weighted average of the pollutant concentration of all cells within a given polygon to the water quality standard. This ensures that a single cell with an unusually high pollutant concentration does not skew the overall assessment for its analysis polygon.

Resources

State of Hawaii Department of Health, Environmental Planning Office/Clean Water Branch. 2000. Hawaii Administrative Rules. "Title 11, Chapter 54: Water Quality Standards."

Appendix A: Default Pollutant Coefficients

Default Pollutant Coefficients (Literature Sources)

C-CAP Value	C-CAP Land Cover Class	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	Total Zinc (mg/L)	Total Lead (mg/L)	Source
2	High-Intensity Developed	0.47	2.22	71.00	0.06	0.09	Adamus and Bergman, 1995 (High-Density Residential)
3	Medium-Intensity Developed	0.30	2.29	27.00	0.06	0.06	Adamus and Bergman, 1995 (Low-Density Residential)
4	Low-Intensity Developed	0.18	1.77	19.10	0.03	0.04	Adamus and Bergman, 1995 (Low-Density Residential)
5	Developed Open Space	0.05	1.25	11.10	0.03	0.03	Adamus and Bergman, 1995 (Low-Density Residential)
6	Cultivated Land	0.42	2.68	107.00	0.03	0.03	Adamus and Bergman, 1995 (Crops)
7	Pasture/Hay	0.48	2.48	55.30	0.03	0.02	Adamus and Bergman, 1995 (Crops)
8	Grassland	0.05	1.25	55.30	0.03	0.03	Adamus and Bergman, 1995 (Pasture)
9	Deciduous Forest	0.05	1.25	11.10	0.01	0.00	Adamus and Bergman, 1995 (Recreation, Open Space, Range)
10	Evergreen Forest	0.05	1.25	11.10	0.01	0.00	Adamus and Bergman, 1995 (Recreation, Open Space, Range)
11	Mixed Forest	0.05	1.25	11.10	0.01	0.00	Adamus and Bergman, 1995 (Recreation, Open Space, Range)
12	Scrub/Shrub	0.05	1.25	11.10	0.01	0.00	Adamus and Bergman, 1995 (Recreation, Open Space, Range)
13	Palustrine Forested Wetland	0.20	1.10	19.00	0.02	0.00	CH2M Hill, 2000 (Forested Wetland)
14	Palustrine Scrub/Shrub Wetland	0.20	1.10	19.00	0.02	0.00	CH2M Hill, 2000 (Forested Wetland)
15	Palustrine Emergent Wetland	0.20	1.10	19.00	0.02	0.00	CH2M Hill, 2000 (Forested Wetland)
16	Estuarine Forested Wetland	0.20	1.10	19.00	0.02	0.00	CH2M Hill, 2000 (Forested Wetland)
17	Estuarine Scrub/Shrub Wetland	0.20	1.10	19.00	0.02	0.00	CH2M Hill, 2000 (Forested Wetland)

C-CAP Value	C-CAP Land Cover Class	Total Phosphorus (mg/L)	Total Nitrogen (mg/L)	Total Suspended Solids (mg/L)	Total Zinc (mg/L)	Total Lead (mg/L)	Source
18	Estuarine Emergent Wetland	0.20	1.10	19.00	0.02	0.00	CH2M Hill, 2000 (Forested Wetland)
19	Unconsolidated Shore	0.12	0.97	70.00	0.20	0.03	NURP, 1983 (Open/Nonurban)
20	Bare Land	0.12	0.97	70.00	0.20	0.03	NURP, 1983 (Open/Nonurban)
21	Water	0.00	0.00	0.00	0.00	0.00	N/A
22	Palustrine Aquatic Bed	0.00	0.00	0.00	0.00	0.00	N/A
23	Estuarine Aquatic Bed	0.00	0.00	0.00	0.00	0.00	N/A

Appendix B: R Factor Grid

Figure 15: R Factor Map of Oahu.