5.0 Watershed and Waterbody Layout

The 3MRA modeling system uses site-based data collected around industrial waste disposal facilities. To produce an example data set for system testing and demonstration, EPA collected data for 201 nonhazardous[1] industrial waste management unit sites randomly selected from EPA's *Screening Survey of Industrial Subtitle D Establishments* (Westat, 1987). As primary spatial data layers for the 3MRA modeling system (Figure 5-1), watershed and waterbody layout data define the spatial units for which soil and surface water concentrations are calculated to estimate human and ecological exposure through these media.

Delineation of the 3MRA modeling system watershed/waterbody layouts at the 201 sites in the example data set used both geographic information system (GIS) and conventional database programs. The GIS programs were used to

- Compile the hydrologic, topographic, land use, and wetlands data coverages needed for delineating and attributing watersheds and waterbodies;
- Extract site-specific data from these data sets for each of the 201 Industrial D sites;
- Delineate watershed subbasins, waterbodies, and local watersheds; and
- Export the resulting spatial parameters in data tables for further processing.

This section begins with a discussion of the conceptual framework for the 3MRA modeling system waterbody/watershed layout and a list of the input parameters collected (Section 5.1). The remainder of the document describes the data collection process. Section 5.2 documents the sources for the raw data used to generate the layout. The overall data collection methodology is reviewed in Section 5.3, while Section 5.4 discusses GIS programs and processing and Section 5.5 describes database compilation and processing of each input variable. Section 5.6 reviews quality assurance and quality control (QA/QC) measures. Significant uncertainties are discussed by parameter in Section 5.5 and summarized in Section 5.7. Section 5.8 provides a complete list of references for the data sources and data collection methods described in this chapter.

[1] Resource Conservation and Recovery Act [RCRA] Subtitle D.

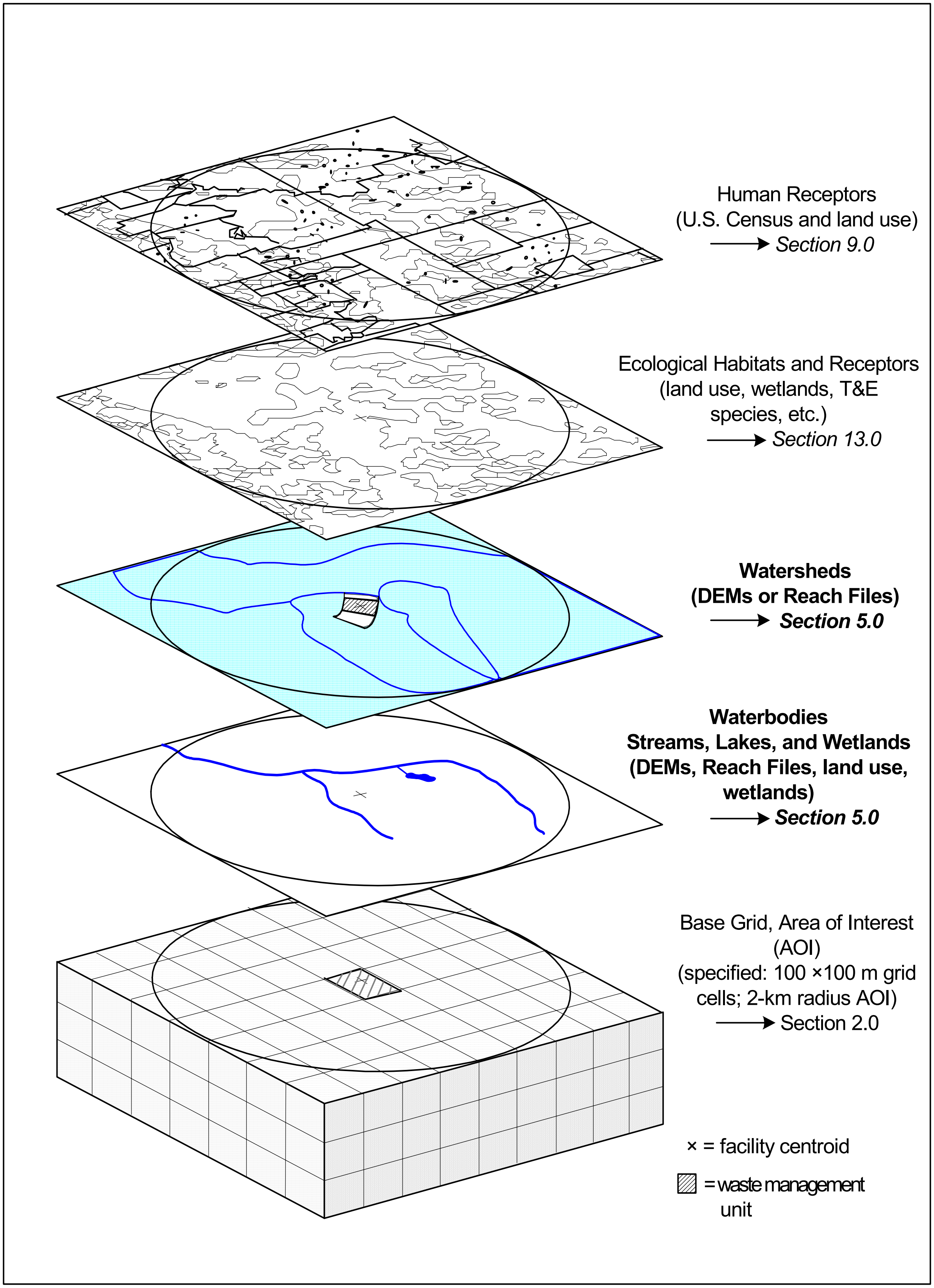


Figure 5-1. Site-specific spatial overlays for the 3MRA modeling system.

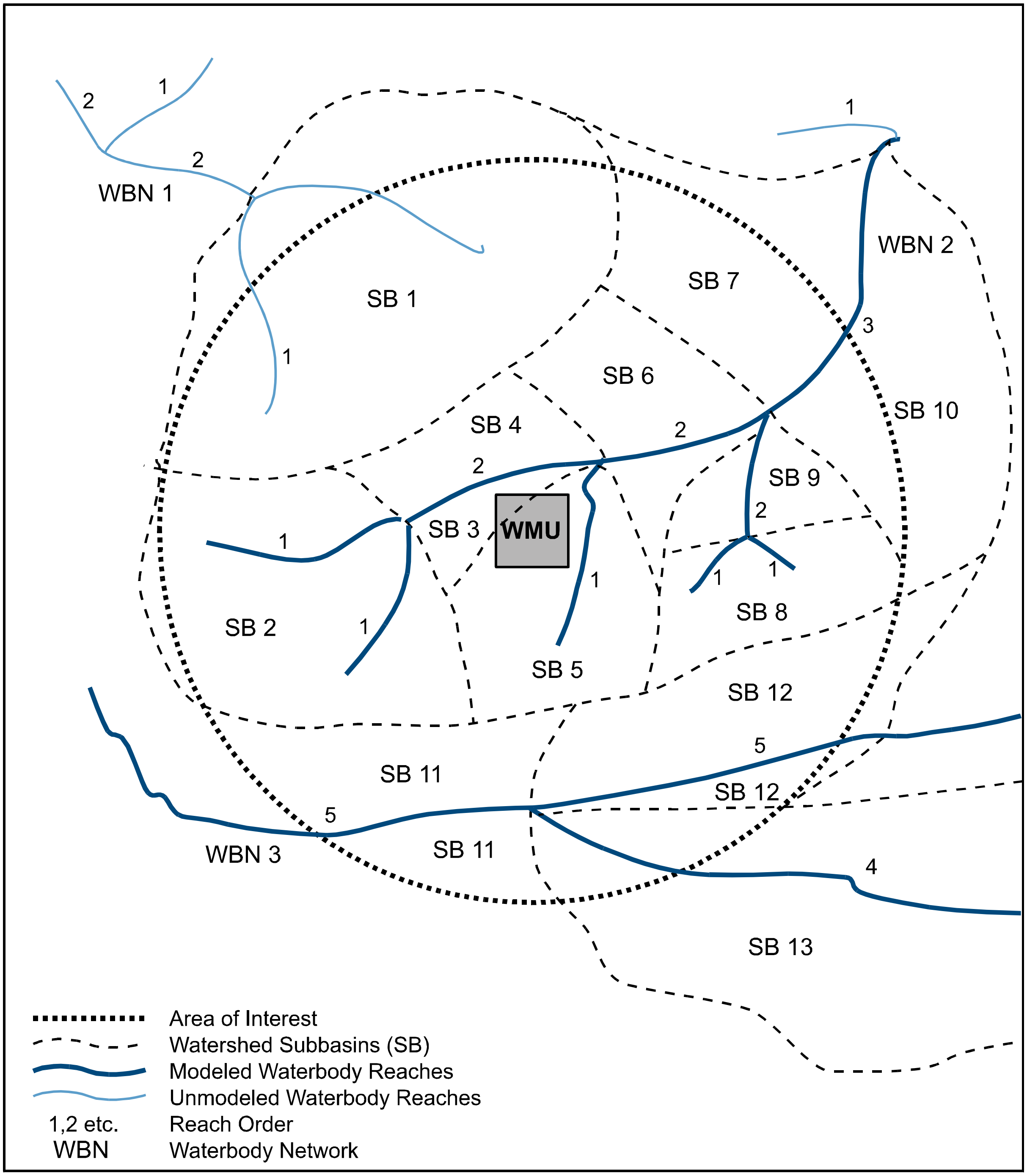


Figure 5-2. Regional watershed subbasin delination.

5.1 Parameters Collected and Conceptual Framework

Site-specific watershed and waterbody layout inputs addressed in this section are shown in Table 5-1 along with the primary model components that use these variables. The waterbody layout includes freshwater lakes, stream rivers, and wetlands within the area of interest (AOI)

Table 5-1. 3MRA Waterbody and Watershed Inputs by Module

Model Input	Code	LAU	Waste Pile	Surface Water	Watershed	Aquifer	Aquatic Food Web	Site Layout Processor
Waterbody								
Fraction of local watershed impacting a reach	WBNRchSrcLWSFrac			●				
Fraction of reach impacted by another reach	WBNRchRchFrac			●				
Fraction of aquifer impacting a reach	WBNRchAquFrac			●				
Fraction of watershed subbasin impacting a reach	WBNRchWSSubFrac			●				
Index of aquifer that impacts a reach	WBNRchAquIndex			●		●		
Index of local watershed that impacts a reach	WBNRchSrcLWSIndex			●				
Index of reaches that are fishable	WBNFishableRchIndex						●	
Index of reach that impacts a reach	WBNRchRchIndex			●				
Index of watershed subbasin that impacts a reach	WBNRchWSSubIndex			●				
Number of aquifers that impact a reach	WBNRchNumAqu			●		●		
Number of fishable reaches	WBNNumFishableRch						●	
Number of reaches in waterbody network	WBNNumRch			●		●	●	
Number of waterbody networks	NumWBN			●		●	●	
Number of reaches that impact a reach	WBNRchNumRch			●				
Number of watershed subbasins that impact a reach	WBNRchNumWSSub			●				
Reach length	WBNRchLength			●		●		
Reach surface area (nonstream reaches)	WBNRchArea			●				
Stream order	WBNRchOrder						●	
Type of waterbody for a reach (lake, stream, wetland)	WBNRchBodyType			●			●	
Type of reach (headwater, exiting or other)	WBNRchType			●				
x,y coordinates for waterbodies	*WBNRch table*[a]							●
Watershed								
Area (local watershed subarea)	SrcLWSSubAreaArea	●	●					
Area (regional watershed subbasin)	WSSubArea				●			
Flow length (local watershed subarea; watershed subbasin)	X	●	●		●			
Ground water flow direction	AquDir					●		
Index of subarea containing WMU	SrcLWSSubAreaIndex	●	●					
Number of local watersheds	SrcNumLWS	●	●					
Number of local watershed subareas	SrcLWSNumSubArea	●	●					
Number of watershed subbasins	NumWSSub				●			
Slope (local watershed; watershed subbasin)	Theta	●	●		●			
x, y coordinates for watersheds	*WSSub table*[a]							●

[a] Data table in 3MRA grid database.

around each Industrial D facility.[2] The watershed layout includes the watersheds that contribute flow to waterbodies within the AOI.

Although the waterbody/watershed layout is important for several modules in the 3MRA modeling system, the layout primarily supports the Surface Water and Watershed Modules, and the overland transport (local watershed) component of the Land Application Unit (LAU) and Waste Pile Modules. These modules function as follows:

- The Surface Water Module estimates water column and sediment contaminant concentrations for use in the Aquatic Food Web and Ecological Exposure Modules.

- The Watershed Module estimates surficial soil concentrations within the AOI for the Farm Food Chain, Terrestrial Food Web, Human Exposure, and Ecological Exposure Modules; generates hydrologic inputs (runoff, baseflow, soil loads) for the Surface Water Module; and generates annual average infiltration estimates for use as recharge for the Aquifer Module.

- The local watershed (LWS) component of the Waste Pile and LAU Modules estimates runoff, soil loads, and contaminant loadings resulting from water erosion and overland transport from the LAU or waste pile to the nearest downslope waterbody.

Additional details on these models and their conceptual and scientific basis can be found in U.S. EPA (1999a, 1999b, 1999c).

Within the context of these models and the 3MRA modeling system, certain assumptions and definitions were required to develop the procedures for delineating the watershed subbasins and waterbodies to be modeled within the 3MRA modeling system. Figure 5-2 illustrates the conceptual framework for the 3MRA modeling system waterbody and watershed layout, which is described below.

5.1.1 Area of Interest for Data Collection

As described in Section 2.0, the area of interest for the representative national data set is the waste management unit (WMU) area plus the area encompassed by a 2-km radius extending from the corner of the square WMU. For Industrial D sites with multiple WMU types, there are multiple AOIs; this results in 419 unique site/WMU settings[3] across the 201 sites selected for the example data set. Although the 3MRA modeling system models each of these settings, data for waterbody and watershed layout were collected only once per site, within an AOI corresponding to the largest WMU present at each site. This was done to help ensure consistency in watershed

[2] For coastal sites, estuarine and other brackish and salt waterbodies also are included in the waterbody network, but they are not modeled by the current 3MRA modeling system.

[3] A setting was defined for each unique WMU type/site combination. Thus a site with a landfill and a waste pile would constitute two settings. See Section 2 for additional information on the 419 settings used in this analysis.

and waterbody layout between the different settings at a site and to reduce data collection requirements, especially with respect to the manual aspects of the delineation process.

5.1.2 Definitions

The 3MRA modeling system relies on a consistent set of definitions to ensure consistency between models and data. For watersheds and waterbodies, these definitions include the following:

- A *waterbody reach (WBNRch)* can be a stream segment between tributaries, a lake (or pond),[4] a wetland, or an estuary. A waterbody reach is the basic modeling unit for the waterbody model.

- A *headwater reach* (i.e., first-order reach) is a reach that flows into another reach downstream but has no upstream reaches draining into it

- An *exiting reach* is a nonheadwater reach that flows out of the AOI.

- A *waterbody network (WBN)* is a series of connected (possibly branching) reaches that defines a stream network (there are three waterbody networks in Figure 5-2).

- A *regional watershed* is the entire drainage basin associated with an individual, modeled waterbody network, extending outside of the AOI as necessary with the following exception. Upstream watersheds were not delineated for any waterbody reaches entering the AOI greater than order 5 (see the order 6 reach in WBN 2 in Figure 5-2); however, their tributary lands lying *within* the AOI were delineated as regional watershed subbasin(s) to simulate soil concentrations. Such subbasin delineations may not include all adjoining land—just such land within the AOI (see subbasins 11 and 12 in Figure 5-2). The upstream boundary of any regional watershed is its natural, upstream boundary (i.e., its headwater basin, except as noted above for order 6 and greater waterbodies).

- A *regional watershed subbasin (WSSub)* is a subdrainage of the regional watershed that drains into a reach. A regional watershed is composed of a set of mutually exclusive (nonoverlapping) subbasins. The set of all subbasins for a given regional watershed will completely cover the regional watershed, except for watersheds for order 6 and higher order streams. Depending on waterbody layout, one or more watershed subbasins can drain into a reach or a watershed subbasin can drain into one or more reaches. The watershed subbasin is the basic spatial modeling unit for the Watershed Module.

- A *local watershed (LWS)* is defined as a drainage area that contains a WMU. For waste piles or LAUs, the LWS is subject to runoff and erosional processes. An LWS extends from the upslope drainage divide downslope to the first defined

[4] All lakes and ponds were designated as lakes in the waterbody layout data.

drainage channel, lake, or pond. The LWS is divided into subareas upslope and downslope of the WMU and the WMU itself. These LWS subareas (LWSSubArea) are the basic modeling units for the local watershed model.

5.1.3 Assumptions—Waterbodies and Regional Watersheds

The following assumptions were considered and used to develop and collect data associated with the watershed and waterbody layout.

- All order 1 through 5 waterbodies are passed to the model, except for headwater (order 1) stream reaches exiting the AOI (see reaches in subbasin [SB] 1, Figure 5-2). Many of the reaches in the waterbody layout will be subject to chemical loads from indirect runoff (i.e., from aerial deposition of a chemical on the watershed). Some will be subject to both indirect and direct loads (i.e., direct runoff/erosion from the WMU). Lakes and wetlands also will be subject to aerial deposition of vapors and particulates.

- All waterbody reaches passed to the Surface Water Module, including all lakes, ponds, and wetlands connected to a waterbody network, are modeled regardless of order. Waterbody reaches sent to the system are limited to those reaches lying completely or partially within the AOI.[5]

- Order 3 and higher stream reaches, along with lakes, ponds, and certain wetlands, are assumed to support fish populations suitable for recreational anglers (i.e., are fishable).

- Each reach ordered 2 through 5 within the AOI will be modeled in its entirety or until it exits the AOI. This required extending the reaches intersecting the AOI boundary upstream to the waterbody network headwaters (e.g., the upstream order 5 reach in WBN 2, Figure 5-2).

- Upstream watershed subbasins are delineated and passed to the 3MRA modeling system for all order 1 through 5 waterbody reaches within the AOI.

- Every unit of land within the AOI will be modeled for soil concentrations and runoff/erosion loads as part of a regional watershed subbasin except when no aerial deposition of chemical occurs (e.g., in the case of a metal or other nonvolatile chemical undergoing treatment in a tank or surface impoundment [for which there are no particulate emissions]).

In summary, the set of all subbasins for a given regional watershed is the minimum number necessary to model inputs (flows, solids loads, and chemical loads) to the waterbody reaches modeled, including delineation of adjacent, distinct (nonadjoining) areas as individual subbasins. If the headwater subbasins of a regional watershed are not within the AOI, the most

[5] Except for reaches entering and exiting the AOI with 1,000 m or less stream length within the AOI, which were not delineated.

upstream subbasin for that regional watershed delineated that entire portion of the regional watershed lying upstream of the AOI boundary as a single subbasin. This subbasin could be very large, but was limited, at most, to the basin draining an order 5 reach. For order 6 and higher streams, only the contributing watershed within the AOI was delineated.

5.1.4 Headwater Criterion

The headwater criterion was used by the GIS in delineating stream reaches. It specifies to the DEM where, in a headwater area, a stream (i.e., a defined drainage channel) starts. This headwater area was used in the GIS process that uses the DEM to create a stream network. The headwater criterion was critical for correctly delineating the stream hydrography so that, when a stream reach of order 1 was generated, any tributary areas above the order 1 reach were in fact sheet flow areas. If the sheet flow distance from an eroding WMU was overestimated (the headwater criterion is too loose), the estimated soil and chemical load was too high, and vice versa.

From 1,570,000 first-order reaches in the United States, Leopold (1962) found the average tributary area to be approximately 1 mi^2 (2.59 million m^2). This estimate was used as a starting point to determine the appropriate headwater criterion to use to establish the DEM stream network. Comparison of DEM-generated streams with the Reach File 3 (RF3) stream network at several sites was used to refine this value until good agreement was achieved between the RF3 and DEM streams. The final criterion used was 700,000 m^2, or about 70 10,000-m^2 DEM grid cells. A final check between RF3 and DEM streams over all sites using DEMs showed very close agreement (i.e., the criteria appear valid at practically all DEM-delineated Industrial D sites).

5.1.5 Assumptions—Local Watershed

Assumptions and definitions associated with the LWS component of the Waste Pile and LAU Modules include the following:

- If the waste pile or LAU overlaps a drainage divide, multiple LWSs will result (see Figure 5-3, which is a closeup of Figure 5-2 in the vicinity of the WMU).

- For waste piles and LAUs, the LWS will have either two or three subareas. Those subareas are, respectively, in the subarea indexing scheme as follows: Subarea 1—any land area upslope of the WMU extending to the drainage divide, Subarea 2—the WMU or portion thereof, and Subarea 3—a buffer zone between the WMU and the first waterbody encountered.

- For waste piles and LAUs, the LWS will contain, at a minimum, 2 subareas—the WMU (or portion thereof) and a 30.5-meter-wide (100-foot-wide) buffer.

- For landfills, surface impoundments, and aerated tanks, runoff and erosional processes are not modeled in the 3MRA modeling system. Therefore the LWS has only one subarea, which is the WMU itself.

- The geometric shape and orientation of WMUs at Industrial D sites is often unknown. It was assumed that all land area associated with a given WMU type is connected. To delineate the LWS for waste piles and LAUs *only* this area was assumed to be circular. The circular geometry was necessary because it does not vary with orientation.

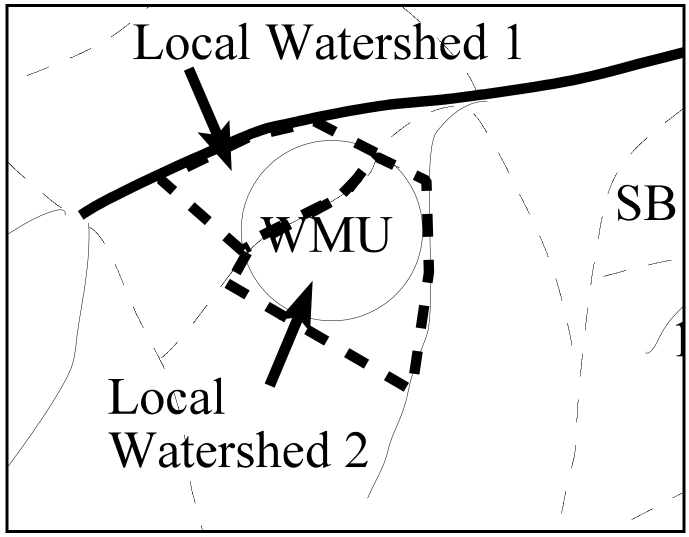


Figure 5-3. Local watershed delineation.

5.2 Data Sources

Many of the watershed and waterbody inputs were obtained using multiple GIS data sources. Table 5-2 provides an overview of the GIS data sources.

Table 5-2. Source Data for Watershed and Waterbody Delineations

Data Source	Brief Description	Scale	Data type	Internet Address
Reach Files, Version 3 (RF3)	Surface water hydrography	1:100,000	ARC/INFO coverages	http://www.epa.gov/OST/BASINS/download.htm[a]
One degree digital elevation models (DEMs)	Elevations for creating DEM streams and watersheds	1:250,000	ARC/INFO coverages	http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html
National Wetlands Inventory (NWI)	Lakes and wetlands	1:24,000	ASCII text file	http://www.nwi.fws.gov/download.htm
Geographic Information Retrieval and Analysis System (GIRAS)	Lakes, wetlands and rivers without NWI	1:250,000	ARC/INFO coverages	ftp://ftp.epa.gov/pub/spdata/EPAGIRAS/

[a] Data set also is available as part of the EPA Office of Water's (OW's) Better Assessment Science Integrating Point and Nonpoint Sources (BASINS), Version 2, software. More information about BASINS software is available online at http://www.epa.gov/OST/BASINS/download.htm.

5.2.1 Surface Water Hydrography

Reach File Version 3 (RF3) is EPA's national hydrographic indexing, mapping, and networking system (U.S. EPA, 1994b). RF3-Alpha is divided into 18 regions based on the surface water hydrography and is based on the 1:100,000 U.S. Geological Survey (USGS) Digital Line Graph (DLG) data sets, which offer the finest resolution available on a national level. Being a national system, RF3-Alpha can provide the base hydrologic network in context with the rest of the network, so that waterbodies of interest for the 3MRA modeling system can be considered within the fuller stream network surrounding them. Data within RF3-Alpha include the stream connectivity, intermittent/perennial status, type of reach (stream, lake, coast, wide river shoreline, etc.), length, name (as available), and detailed trace coordinates. The reach origination flag identifies the version of the Reach File a given Reach first appeared. RF1 is the first version, circa 1982; RF2 is the second circa 1988; and RF3-Alpha is the third, circa 1992 to the present. RF2 is a subset of RF3, and RF1 is a subset of RF2.

5.2.2 One-Degree Digital Elevation Models

One-degree DEMs are produced by the Defense Mapping Agency (DMA) from cartographic and photographic sources (USGS, 1990). Elevation data from cartographic sources are collected from any map series 7.5 min through 1 degree (1:24,000 to 1:250,000). Elevation data from photographic sources are collected using manual and automated correlation techniques. In reformatting the DMA product to create the DEMs, the USGS restructures the header records and data but does not change the basic elevation information.

5.2.3 National Wetlands Inventory

The National Wetlands Inventory (NWI) contains information on wetland and deepwater habitats in the United States (U.S. Fish and Wildlife Service [FWS], 1995). The FWS produces the NWI, which is available at the 7.5-min quadrangle level. At the time of production, only 39 percent of the lower 48 states (the geographical extent of the example data set) had been digitized and made available by the FWS.

5.2.4 Geographic Information Retrieval and Analysis System

GIRAS is a land use/land cover data set produced by the USGS and converted into ARC/INFO GIS format by EPA (U.S. EPA, 1994a). It is distributed by 1 arc s (1:250,000) quadrangle sections for the entire conterminous United States. Although production dates vary for different GIRAS quads, USGS produced the majority of the data from the late 1970s to the early 1980s. Land use was mapped and coded using the Anderson classification system (Anderson et al., 1976). Anderson codes corresponding to waterbodies, listed below, were primarily used for watershed and waterbody delineations:

- 51 streams and canals
- 52 lakes
- 53 reservoirs
- 54 bays and estuaries
- 61 forested wetland
- 62 nonforested wetland.

For more information on GIRAS land use, see Section 7.0.

5.3 Overview of Methodology

Data collection of the regional and local watersheds and waterbodies was conducted concurrently and based on the 2-km radius AOI that corresponded to the largest WMU at each site. Figure 5-4 is a brief overview of the data collection methodology for watersheds and

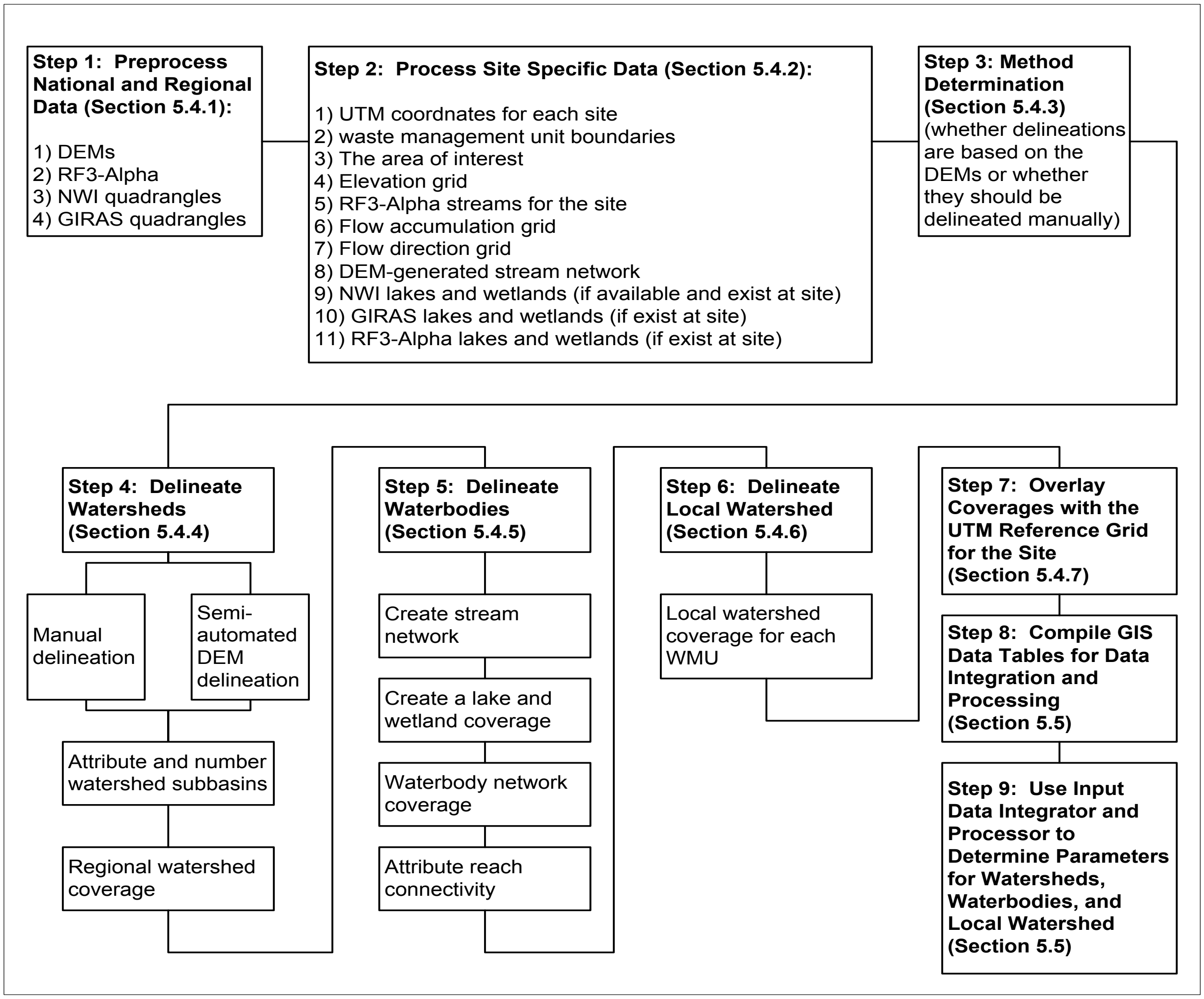


Figure 5-4. Overview of the 3MRA modeling system data collection methodology for watersheds and waterbodies.

waterbodies. The watershed and waterbody layout data required GIS processing to delineate the watersheds and waterbodies and to obtain spatially related parameters (steps 1 through 8). Further database processing of the GIS data was required to provide the exact data and format for the 3MRA modeling system (step 9).

Section 5.4 describes GIS data collection and processing. Section 5.5 describes the database processing conducted to generate the model inputs from the GIS data and prepare model-ready data tables. To obtain the available data coverages for each site, coverages were first gathered on a national scale (step 1), and then the coverages around each site were extracted from them (step 2). Using these site-based data coverages (Figure 5-5), watersheds and waterbodies were delineated by manual and automated processes (steps 3 through 7). The GIS data were passed as a set of data tables for further processing to create the model input data set (step 8). The Input Data Integrator and Processor (IDIP), comprised of multiple databases and SQL (structured query language) and VBS (Visual Basic Script) script files, was designed to integrate collected data from multiple sources, perform any necessary calculations, and format the data as the 3MRA modeling system input variable database (step 9).

Table 5-3 provides, for each parameter appropriate references to Section 5.4 (where GIS data collection is discussed) and to Section 5.5 (where database processing is discussed).

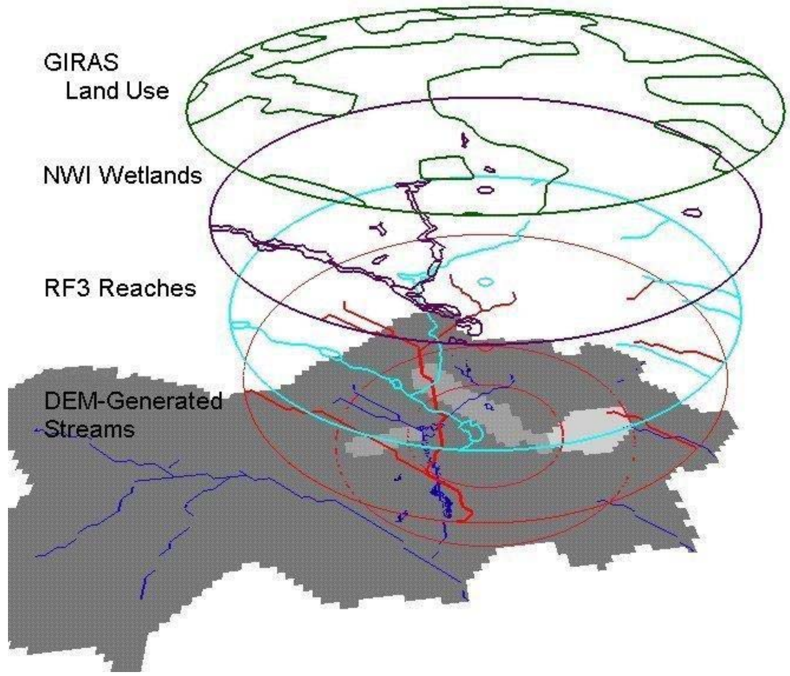


Figure 5-5. GIS data coverages for waterbody and watershed delineation.

5.4 GIS Processing

All of the processing took place within the framework of a series of arc macro language (AML) macros. Table 5-4 lists the AML macros written and used for GIS processing, along with the processing steps to which they apply and the output that they produce.[6] After GIS processing, all the data was passed as a series of data tables for use by the IDIP (see Section 5.5).

Table 5-3. 3MRA Modeling System Watershed and Waterbody Processing by Parameter

Parameter	Code	Report Section	
		GIS Processing	Data Processing
Waterbody			
Number of reaches in waterbody network	WBNNumRch		
Number of waterbody networks	NumWBN		5.5.1
Fraction of reach impacted by another reach	WBNRchRchFrac		
Index of reach that impacts a reach	WBNRchRchIndex		
Number of reaches that impact a reach	WBNRchNumRch	5.4.5 - waterbody delineation	5.5.2
Reach length	WBNRchLength		5.5.3

(continued)

[6] Copies of the AML programs are available in a separate package of zipped files delivered with this report.

Table 5-3. (continued)

Parameter	Code	Report Section	
		GIS Processing	Data Processing
Reach surface area (non-stream reaches)	WBNRchArea		5.5.4
Stream order	WBNRchOrder		5.5.5
Index of reaches that are fishable	WBNFishableRchIndex		5.5.6
Number of fishable reaches	WBNNumFishableRch		
Type of reach (headwater, exiting or other)	WBNRchType		5.5.7
Type of waterbody for a reach (lake, stream, wetland)	WBNRchBodyType		5.5.8
x,y Coordinates for waterbodies	*WBNRch table*		5.5.12
Fraction of watershed subbasin impacting a reach	WBNRchWSSubFrac		
Index of watershed subbasin that impacts a reach	WBNRchWSSubIndex		
Number of watershed subbasins that impact a reach	WBNRchNumWSSub	5.4.4 - watershed delineation	5.5.9
Fraction of local watershed impacting a reach	WBNRchSrcLWSFrac		
Index of local watershed that impacts a reach	WBNRchSrcLWSIndex		5.5.10
Fraction of aquifer impacting a reach	WBNRchAquFrac		
Index of aquifer that impacts a reach	WBNRchAquIndex		
Number of aquifers that impact a reach	WBNRchNumAqu	5.4.6 - local watershed delineation	5.5.11
Watershed			
Area (watershed subbasin)	WSSubArea		
Number of watershed subbasins	NumWSSub		5.5.13
Slope (watershed)	Theta		5.5.14
Flow length (watershed subbasin)	X		5.5.17
x,y Coordinates for watershed subbasins	*WSSub table*	5.4.4 - watershed delineation	5.5.19
Number of local watersheds	SrcNumLWS		
Slope (local watershed)	Theta		5.5.15
Area (local watershed subarea)	SrcLWSSubAreaArea		
Index of subarea containing WMU	SrcLWSSubAreaIndex		
Number of local watershed subareas	SrcLWSNumSubArea		5.5.16
Flow length (local watershed subarea)	X		5.5.17
Ground water flow direction	AquDir	5.4.6 - local watershed delineation	5.5.18

Table 5-4. AMLs used in the 3MRA Modeling System Watershed and Waterbody Delineations

AML	Brief Description[a]	Output Table/Coverage
Step 2: Preprocessing of Site-Specific Input Data sets (Section 5.4.2)		
convert_utm_zones.aml	Produces an info file containing UTM zone data for each site	UTM_zones.dat = info file containing the UTM zone for all 201 sites and UTM x,y coordinates for the site
gen_supergrid	Produces a template of a UTM grid based on the largest WMU of all the 201 sites	template grid
site_prep.aml Calls: Run_gen_aoi.aml Run_gen_wmu.aml Nwi_create.aml	Processes site-specific input data	1) Composite DEM elevation grid 2) Flow direction and flow accumulation grids 3) DEM-generated stream network 4) Site-based Reach File coverage 5) Driver program for creation of other input data
run_gen_wmu.aml	Creates the WMU coverages for the site	wmu<site><type> = WMU coverage
run_gen_aoi.aml	Creates the AOI coverage for the site based on the largest WMU type at the site location	aoi<site> = AOI coverage
nwi_create.aml	Ceates the input lakes and wetlands coverages for a site based on a 1-km buffer of the AOI	NWI coverage GIRAS lakes and wetlands coverage RF3 lakes and wetlands coverage
Step 4A: Semiautomated DEM Method (Section 5.4.4)		
create_special.aml	Interactive selection of pour points; generates individual subbasins from each pour point	Individual subbasin coverages for each pour point
edit_wshd.aml	Merges the individual subbasins into one coverage, then allows for editing and attribution of that coverage	V2_<site> coverage = regional watershed coverage for site
Step 4B: Manual Method of Delineation of Regional Watersheds (Section 5.4.4)		
flat_prep.aml	Converts shapefiles to coverages	v2_<site> = regional watershed coverage (preliminary)
edit_wshd.aml	Allows editing and attribution of regional watershed coverage	v2_<site> = regional watershed coverage (completed)
Step 5: Delineation of Waterbodies (Section 5.4.5)		
edit_lake.aml	Creates and allows editing and attribution of the lakes and wetlands coverage at the site	lk_wet coverage [1]c<site>.data file (c_all)
edit_reach.aml	Creates a point coverage of all the reaches at the site and creates infofiles for reach connectivity	re_<site> coverage reach_reach.data (r_all) reach_sub.data (s_all)

(continued)

Table 5-4. (continued)

AML	Brief Description[a]	Output Table/Coverage
pop_reach.aml	Allows for interactive referencing of subbasins to reaches and reaches to upstream reaches	reach_reach.data (r_all) reach_sub.data (s_all)
pop_lake.aml	Allows for interactive referencing and attribution of lake and wetland features; lake/wetland connectivity to subbasins is automated; reaches, lake types, and in some cases stream orders are entered manually	c<site>.data (c_all)
prep_reaches.aml	Automated aml with an interactive visual inspection at completion; creates reach coverages for site	reaches = all the waterbodies at the site strms = only linear stream features at the site
Step 6: Delineation of Local Watershed (Section 5.4.6)		
create_special.aml	Interactive selection of pour points; generates individual subbasins from each pour point	Individual subbasin coverages for each pour point
edit_local.aml	Interactively allows user to create, edit, and attribute the l2_<site> coverage, which is the preliminary coverage to the local watershed	l2_<site> coverage m<site>.ele (M_all) wshd_both (L_all)
edit_reach.aml	Populates reach number 0 in the reach_sub.data file with the regional watershed subbasin number where the local watershed is located	reach_sub.data (s_all)
pop_reach.aml	Allows for interactive referencing of the watershed subbasin to the local watershed	reach_sub.data (s_all)
calc_local.aml	Creates individual local watresheds for each WMU type[b]; calculates average overland flow direction in the local watershed[c]	local watershed coverages local_watershed.data (K_all)
Postprocessing/ Calculations (Section 5.5)		
post_process_a.aml	Driver AML for postprocessing	
wshd.aml	Calculates watershed characteristics	a<site>.data (A_all) b<site>.data (B_all)
prep_reaches	See above	reaches strms
Locations of Coverages in UTM Coordinates by UTM Reference Cell Address (Sections 5.4.7, 5.5.12 and 5.5.19)		
gen_grids.aml	Produces a site-specific grid template based on the largest WMU at the 201 sites	grd<site>
post_process_b.aml	Driver AML for postprocessing	
convert_grid.aml	Creates an index on the UTM reference grid for use in future overlays	grd<site> = UTM reference grid for site g<site>.data (G_all)

(continued)

Table 5-4. (continued)

AML	Brief Description[a]	Output Table/Coverage
convert_aoi.aml	References the AOI to the UTM reference grid	aoi_grid.data (T_all)
convert_watershd.aml	References the regional watershed to the UTM reference grid; gets centroid label points of watershed subbasin in UTM coordinates	v2_grid.data (X_all) z<site>.tab (Z_all)
convert_lakes.aml	References the lake and wetland features to the UTM reference grid	lk_grid.data (V_all)
convert_streams_aoi	References the stream features to the UTM reference grid	stream_aoi.data (Q_all)
convert_local.aml	References the local watershed to the UTM reference grid	local_grid.data (E_all)
GIS Quality Control AMLs[d] (Section 5.6)		
qaqc.aml	Interactive AML that checks the delineation of watersheds and waterbodies and associated manually entered GIS data	

[a] Only part of the aml that pertains to the topic heading is mentioned in the description
[b] A full local watershed was created for LAUs, landfills, waste piles, and surface impoundments. However, only waste pile and LAU local watersheds were modeled.
[c] Calculates the average aspect within the l2_<site> coverage. If this average aspect does not rotate the local watershed in the direction of the stream reach, then the user rotates the local watershed to orient it toward the stream reach. The direction variable in the k_all table is then changed to the direction that the local watershed is interactively oriented in the watershed.
[d] Many AMLs contained routines that check data quality.

5.4.1 Step 1: Preprocessing of National and Regional Data

<u>Goal</u>: To prepare all national and regional data sets and coverages to be used in processing watershed and waterbody data for the 201 sites.

<u>Outputs</u>:
1) DEM grids for all sites
2) Reach Files for all sites
3) GIRAS quadrangle coverages for conterminous United States
4) NWI quadrangle coverages for all sites (where available)

5.4.1.1 <u>Procedures</u>. (1) *One degree Digital Elevation Models*—All 1:250,000 DEMs needed for the 201 sites were downloaded from the USGS Website as American Standard Code for Information Interchange (ASCII) text files, converted into ARC/INFO Grid, and projected into an Albers projection for the continental United States.

(2) *Reach Files*—The RF3-Alpha data used to develop the representative national data set were downloaded from the EPA computers by catalogue unit (CU) and processed into a single coverage associated with each of the 18 hydrologic regions in the conterminous United States.

The Pacific Northwest (PNW) Reach Files, which have a different structure from the rest of RF3-Alpha, have only recently become available. This region includes all of the state of Washington, most of Oregon and Idaho, and parts of Montana, Nevada, Wyoming, California, and Utah. The PNW data were downloaded and processed separately. One key difference with the PNW data is that nonlinear features such as lake and wetland boundaries are stored in a separate coverage. In the stream arc coverage, centerlines represent these nonlinear features. Key attributes such as the RF3RCHID (unique Reach File identifier composed of the CU, segment number, and mileage point on the reach) are associated with the centerlines but not with the feature boundaries. For consistency with the rest of the Reach Files used in the data set, the non-linear features were added to the stream arc and centerline coverage.

To simplify the referencing and avoid confusion with other Reach Files both the RF3-Alpha and PNW will be referred to as RF3-Alpha throughout the rest of this report.

(3) *GIRAS*—The GIRAS coverages were downloaded from the EPA website: ftp://ftp.epa.gov/pub/spdata/EPAGIRAS, as ARC/INFO coverages. No further processing was required.

(4) *NWI*—NWI quadrangles were downloaded from the United States Fish and Wildlife Service website: http://nwi.fws.gov/download.html, as ARC/INFO coverages. Only the quadrangles needed for the 201 sites were downloaded. No further processing was required.

5.4.2 Step 2: Process Site-Specific Input Data

<u>Goal</u>: To create site-specific input data for each site

<u>Outputs</u>:
1) UTM coordinates for each site location
2) waste management unit boundaries
3) the Area of Interest (AOI)
4) elevation grid
5) RF3-Alpha streams for site
6) flow accumulation grid
7) flow direction grid
8) DEM-generated streams (DEM Streams)
9) NWI lakes and wetlands (if coverage available and features exist for site)
10) GIRAS lakes and wetlands (if features exist for site)
11) RF3-Alpha lakes and wetlands (if exist for site)

5.4.2.1 <u>Procedures</u>. Step 2 was an automated step. It prepared a set of site-specific input tables and coverages that were used in later steps to process model inputs. This step involved two AML macros, one that created the Universal Transverse Mercator (UTM) zone coordinates table for each site and another that prepared each site for processing. The order of implementation was important because the square WMU was needed to create the AOI coverage, which, in turn, was needed to create most of the other files (except the UTM coordinates table).

(1) *UTM Coordinates Table*—UTM coordinates were generated for each site using the projection command in ARC/INFO. A coverage of site locations was overlaid with a UTM zone coverage, and a UTM zone field was added to the attribute table of the 3MRA modeling system site point file. Then, each point was projected according to the proper UTM zone where it was located. These values were then stored in a table for use later in the processing.

(2) *Models of the WMU*—Using the area for each WMU type at the site, a square and a circular WMU were created.[7]

(3) *AOI*—Watersheds and waterbodies were delineated with a ring 2,000 m (2 km) from the corner of the largest WMU at a site (assuming a square WMU). A second, smaller ring extending 1,000 m from the corner of the square WMU was used to assist in defining smaller watershed subbasins close to the WMU.

(4) *Elevation Grid*—To define the watershed subbasins in the 2-km-radius AOI, it was necessary to combine several DEM quadrangles for most sites. First, the AOI was overlaid with a map containing the hydrological unit boundaries (HUCs). Each HUC that intersected the AOI was then overlaid with a national 1:250,000 DEM coverage. The DEM grids that overlaid these HUCs were appended together to form one composite elevation model for each site, hereafter called the elevation grid.

Once the elevation grid was created, it was clipped by a coverage of the United States coastline to delete unnecessary elevation values over the oceans and lakes. This was done because the software is unable to generate a stream network over a water surface.

(5) *RF3-Alpha Streams for Site*—A coverage of all the RF3-Alpha regions in the United States was overlaid with the boundary of the DEM elevation grid. Stream arcs located within the outline of the DEM grid were appended to make one RF3-Alpha coverage for the site. This coverage was then clipped by a 30-km^2 box around the site.

(6) *DEM-Generated Hydrography Model*—A DEM-generated hydrography model was used as the stream model for sites where relief was adequate to generate a reasonable DEM stream network. RF3-Alpha coverages are at a larger scale than the DEMs used in the study, are not well-registered with the DEMs, and could not be used in conjunction with the DEMs to delineate watersheds. A macro created by the University of Texas at Austin, agree.aml (Hellweger, 1997), was used to recondition the DEM so that it better modeled the RF3-Alpha stream network.

The agree.aml macro performs the reconditioning by:

- Dropping/raising the elevation of the cells corresponding to the vector lines a certain amount (smoothdist)

[7] Note that the circular WMU was used only for local watershed delineation (see Step 6, Section 5.4.6) because its geometry does not vary with orientation. For all other cases, the representative national data set assumes WMUs are square.

- Buffering the vector lines
- Assigning elevation to the cells inside the buffer so that there is a straight line path from the vector line to the original elevation just outside the buffer
- Dropping/raising the elevation of the cells corresponding to the vector lines a certain amount (sharpdist) (Hellweger, 1997).

More information on agree.aml is available online at http://www.ce.utexas.edu/prof/maidment/~gishydro/ferdi/research/agree/agree.html.

All nonlinear features were excluded from the RF3-Alpha coverages before being used as input into the agree.aml macro. The buffer distance was set either to 100 or 1,000 m, depending on the elevation change at the site. The 1,000-m buffer was used at sites with greater relief and the 100-m buffer was used in sites with less relief (flatter sites). Elevation was dropped by 10 m in cells corresponding to the RF3-Alpha stream arcs. Figure 5-6 is a visualization of the steps performed by the agree.aml macro in reconditioning the elevation grid. The fourth step, which allowed the cells corresponding to the stream arc to be further raised or dropped, was not needed to produce the DEM stream network for the example sites.

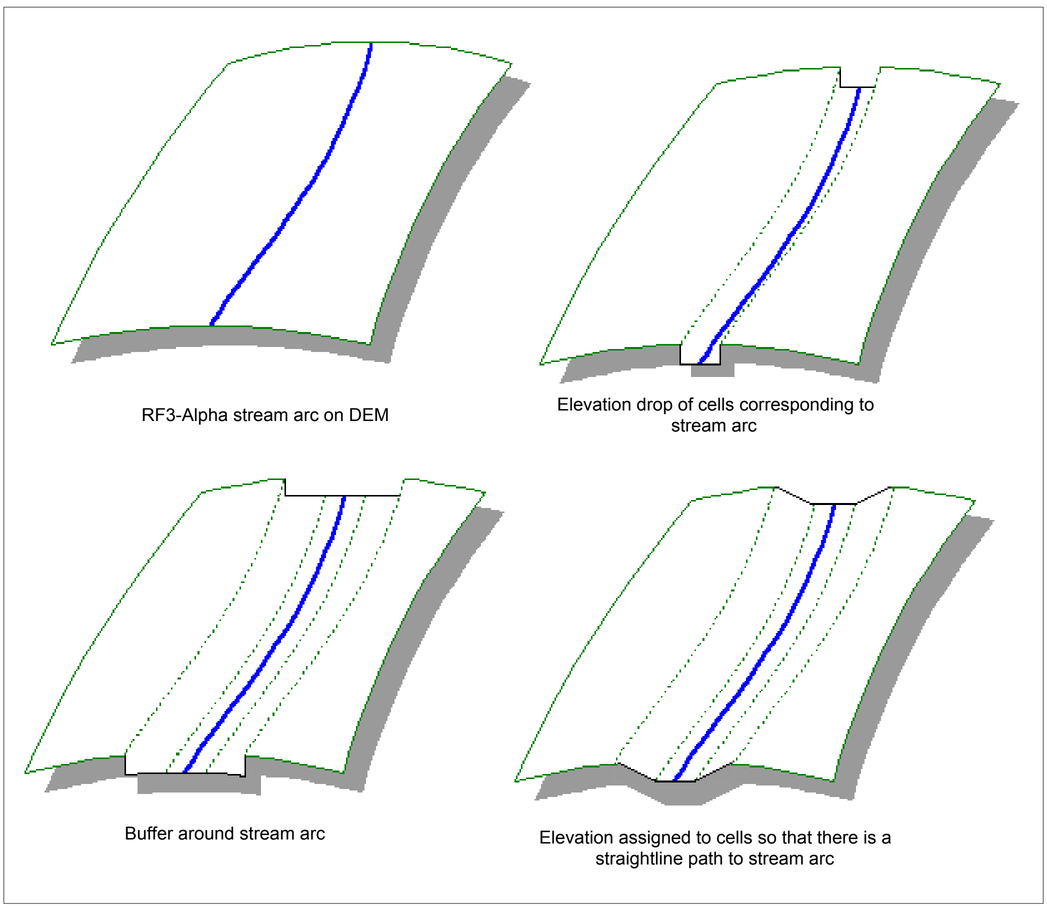


Figure 5-6. Reconditioning of the elevation grid (agree.aml).

Using the reconditioned elevation grid, a stream network was generated in the ARC/INFO Grid module. A headwater criterion was set to 70 cells (or 700,000 m^2) and was used by the GIS in delineating stream reaches. It specified to the DEM where, in a headwater area, a stream (i.e., a defined drainage channel) starts and sheet flow ends. The 70-cell headwater criterion produced good agreement between the DEM-generated headwater streams and those in RF3-Alpha for most sites (see Section 5.1.4).

Stream order was assigned based on the Strahler method (Strahler, 1957). Figure 5-7 represents the process used to delineate a DEM stream network in ARC/INFO.

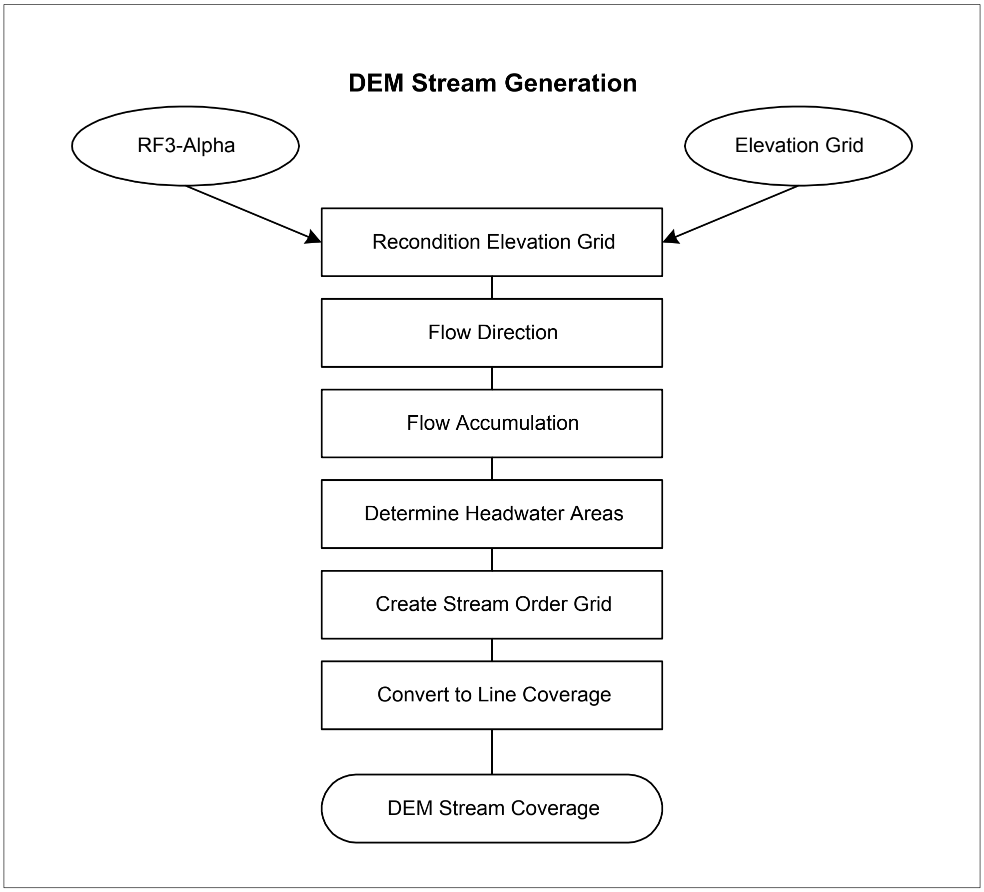


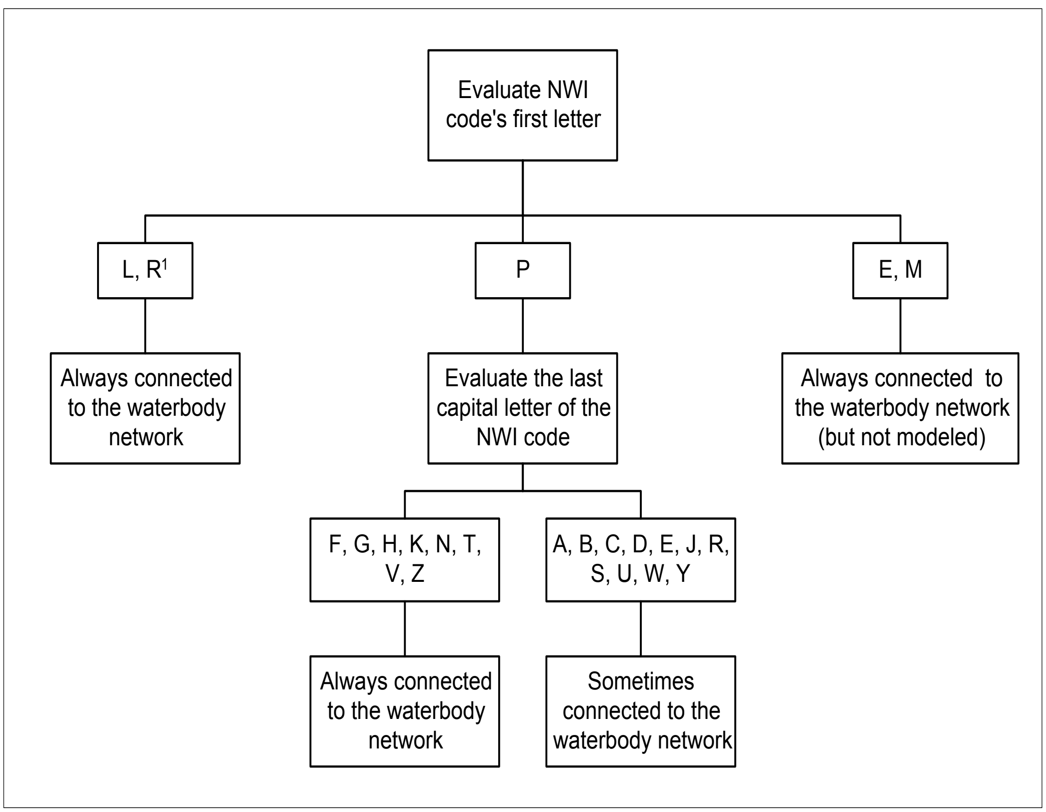
Figure 5-7. DEM stream generation.

(7) *Flow Accumulation and Flow Direction Grids*—Using the reconditioned elevation grid, a flow accumulation grid and a flow direction grid were created in ARC/INFO Grid. These grids, which provide information on elevation-based flow direction, were used to create the stream order grid that was subsequently used to create the DEM stream coverage. Also, the flow direction grid was further used in fractioning the runoff from the watershed subbasins.

(8) *National Wetlands Inventory*—To create the NWI coverage for the site, the available NWI quadrangles were identified for a particular site by overlaying a status map with a 3-km-radius circle around the WMU allowing a 1-km buffer around the AOI to avoid truncation of

1-km buffer (see Appendix 5-A for a list). For sites with an NWI feature, the 1-km buffer of the AOI was clipped out of each quad to create one coverage of the NWI for the site. Features that extended beyond the 1-km circular buffer of the AOI were truncated, leaving only the portion within the buffer in the coverage.

The NWI feature codes were examined to determine whether, based on the code, the feature was always hydraulically connected to the waterbody, sometimes connected, or never connected. The basic decision tree used in the GIS can be seen in Figure 5-8. In order to redefine the attributes, a new field, CONNECT, was created. All lake features were coded with a CONNECT attribute of ‘l’ (lakes) and wetlands that are always connected (open water, permanently flooded) are coded with a ‘y’. The features that were coded with an ‘n’ in the CONNECT field included features such as nonpermanently flooded wetlands. Rivers and riverine wetlands (‘r’ features) were connected implicitly by connecting the corresponding RF3 or DEM features (i.e., the ‘r’ NWI features were not directly used in the analysis). Estuaries were connected to the network, given reach numbers, and passed to the waterbody model as a bay/estuary waterbody type; however, they are not modeled by the 3MRA modeling system. Nonpermanently flooded wetlands were included in the model later in the process if they were located along an RF3-Alpha stream reach. Section 5.5.8.2 and Appendix 5B provide additional details on NWI codes; Section 12.0 of the data collection report discusses which connected features were considered as aquatic habitats.



[1] Connected RF3 or DEM rivers and streams corresponding to NWI "R" features (NWI rivers/streams not used)

Figure 5-8. NWI decision tree.

(9) *GIRAS Lakes and Wetlands Coverage*—To create the GIRAS lakes and wetlands coverage for the site, the 1-km circular buffer around the AOI was used to determine the specific GIRAS quadrangles that were needed for the site. Quadrangles that touched the 3-km circle were combined to create one GIRAS coverage and then the circular buffer was used to clip out the area around the site. Similar to NWI processing, only the portion of the GIRAS feature within the circular buffer was kept. From this GIRAS coverage that documented all land use for the site, only land use features that pertained to water were extracted. This extraction was performed by examining the LUCODE attribute in the GIRAS polygon attribute table. The LUCODE contains the two-digit Anderson land use classification code. The first digit is the Anderson level 1 value, and the second digit is the level 2 value (U.S. EPA, 1994a). Table 5-5 contains a brief description of the Anderson level 2 codes that pertain to waterbodies. An LUCODE between 50 and 59 represents open-water land uses such as lakes, rivers, and reservoirs. An LUCODE between 60 and 69 represents wetlands land use types. If no lake and wetland features exist at the site, a GIRAS land use and wetlands coverage would not be created for the site. Of the 201 sites, 135 sites had at least one GIRAS feature within the 1-km buffer (see Appendix 5-A).

Table 5-5. GIRAS Water and Wetland Land Use Codes

LUCODE	Description
51	Streams and canals
52	Lakes
53	Reservoirs
54	Bays and estuaries
61	Forested wetlands
62	Nonforested wetlands

Source: U.S. EPA (1994a).

(10) *RF3-Alpha Lakes and Wetlands*—To create the RF3-Alpha lakes and wetlands coverage for the site, all features with a REACHTYPE of A, C, G, H, I, L, O, Q, and W (Table 5-6) were extracted from the RF3 coverage. REACHTYPE is a field in the arc attribute table of RF3-Alpha Reach Files. It contains a one-character code used by the USGS to determine what type of feature the line represents (U.S. EPA, 1994b). A total of 161 of the 201 sites had at least one RF3-Alpha lake or wetlands in the buffered area (see Appendix 5A).[8]

[8] Note that PNW Reach Files were processed differently from the Reach Files for the rest of the country. Because no REACHTYPE attribute existed in the PNW data, all lake and wetlands features were assigned a REACHTYPE of L (see Section 5.7.7).

Table 5-6. RF3-Alpha REACHTYPE Descriptions

REACHTYPE	Brief description	REACHTYPE	Brief description
A	Artificial lake	L	Lake shoreline reach
C	Continental coastline reach	O	DLG marsh or wetland
G	Great lakes shoreline reach	Q	Questionable shoreline reach
H	Headwater lake reach	W	Wide river reach
I	Island shoreline reach		

Source: U.S. EPA (1994b).

5.4.3 Step 3: Method Determination Step

Goal: To determine whether the site can be processed using the semiautomated DEM process or whether it must be hand-delineated.

5.4.3.1 Procedures. Step 3 was a semiautomated step that allowed each site to be reviewed in order to check its location and make a preliminary decision concerning the appropriate delineation method, a DEM delineation or a manual delineation. Coverages created in the previous step were examined visually in ArcView during this review.

First each site was checked to see if its location was appropriate based on the coverages prepared. If a more appropriate location could be found, then the site was moved to that location and Step 2 was repeated. Appendix 2B of Section 2.0 provides details of this relocation effort.

Once the site location was finalized, each site was visually checked using the following general criteria to determine whether the semiautomated DEM process could be used to delineate the site:

- *Does the DEM stream network closely resembled the RF3-Alpha network?* If the DEM streams showed significant differences with or were too complex compared to the RF3-Alpha streams, then the watersheds were delineated manually. One common problem encountered at relatively flat sites was where DEM streams were represented with several parallel arcs, resulting in bowling alley-shaped watersheds one-grid-cell wide. Most sites of this type were manually delineated (see Section 5.7.2).

- *Can the lakes and wetlands be modeled using the DEM streams?* Because the DEM stream network does not model lakes and wetlands (polygon features), lakes and wetlands had to be accounted for by manually placing the features in the hydrography network (see step 5). As a practical issue, sites with many lakes and wetlands from NWI, GIRAS, or RF3-Alpha sources were manually delineated. Using the DEM method to delineate the sites would have required many manual fixes (altering watershed boundaries to account for the lakes and wetlands) to bring the lakes and wetlands into the stream network (see Section 5.7.4).

DEM watershed delineations were performed for 132 sites while 69 sites were delineated manually. Figure 5-9 shows the locations of the 201 sites in the study and the delineation method used for each site. A list of the sites and method used can be found in Appendix 5A.

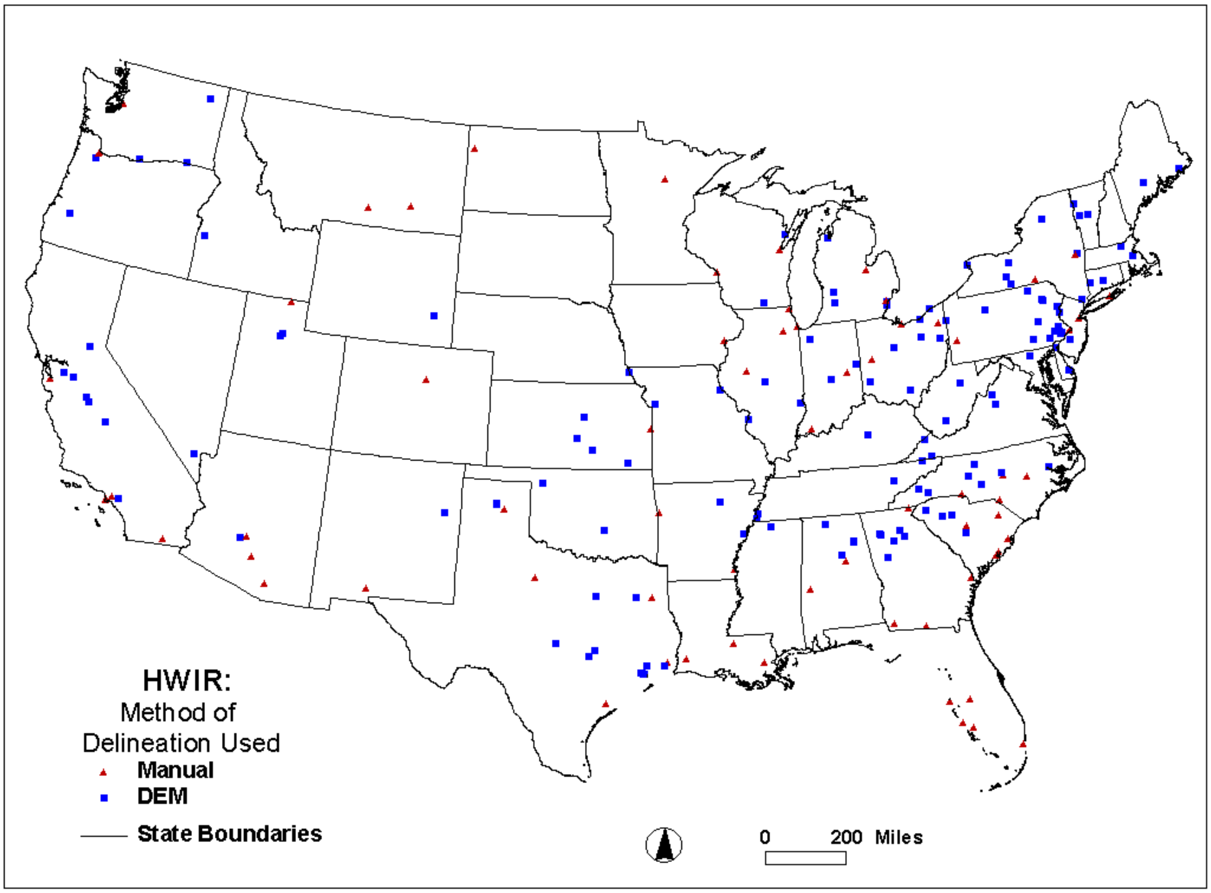


Figure 5-9. Map of 201 representative national data set sites by watershed delineation method.

5.4.4 Step 4: Delineate Watershed Subbasins

Goals: To create watershed delineation files and to number and attribute these files for later processing.

Outputs: A regional watershed subbasin coverage and associated delineation files.

5.4.4.1 Procedures. Step 4 created the delineation files for the regional watershed subbasins. It was a semiautomated step that required manual input. Watershed subbasins were either delineated using GIS (semiautomated watershed delineation) or manually delineated (manual watershed delineation), based on the decision in step 3. After subbasin delineation was complete using either method, the watershed subbasins were numbered and attributed. This step produced a regional watershed coverage that defined the areas of each subbasin within each regional watershed. Each subbasin was numbered sequentially and attributed according to a set of predefined watershed types (see Table 5-7 and (3) below). The resulting coverage was used as input to the next steps in the process.

Table 5-7. Watershed Code Descriptions

Watershed Code	Brief Description
A	A watershed that drains into the headwaters of a first-order stream whose pour point is within the AOI
B2	A regular drainage subbasin (DEM-generated stream only)
R	A regular drainage subbasin (hand-delineated sites)
U	Waterbody outside the AOI
B1	A watershed subbasin that contains flow from ridge line to waterbody

(1) *Semiautomated Watershed Delineation*—For 132 of the 201 sites, the DEM elevation grid was used to determine watershed subbasin boundaries. This process was semiautomated and required manually choosing pour points along a DEM-generated stream. A pour point was defined as a selected drainage point through which all upstream drainage must flow with the point represented by a single grid cell. The software generates a subbasin by determining, based on elevation difference, which cells flow into the pour point cell, then which cells flow into those cells, etc.

Guidelines for picking pour points aided subbasin delineation. The decision guidelines were designed to enable the model to have a higher degree of detail for the area within 1 km of the WMU than for the area between 1 and 2 km from the site, and to include only necessary parts of subbasins outside of the AOI. This was necessary because of the tradeoff between the potential for averaging away high soil concentrations with larger watershed subbasins versus the additional data and model runtime requirements for smaller, more numerous watersheds. The guidelines were developed to give higher resolution (i.e., smaller watershed subbasins) within the 1-km radius, where areal soil concentration gradients are likely to be steepest.

In general watershed subbasins were defined at junctions of streams and the intersections of the stream with the 1- and 2-km-radius circles. Basins for first-order streams were only delineated within the 1-km area around the site, unless a subbasin delineation was necessary to ensure coverage of the entire 2-km AOI. When possible, individual basins were delineated for lakes and permanently flooded wetlands by picking pour points upstream and downstream of the waterbody feature. Following is a list of the specific guidelines that were used to delineate watershed subbasins. To illustrate, pour points at an example site are shown in Figure 5-10.

- For streams within the 1-km-radius circle around the WMU, the pour point guidelines were

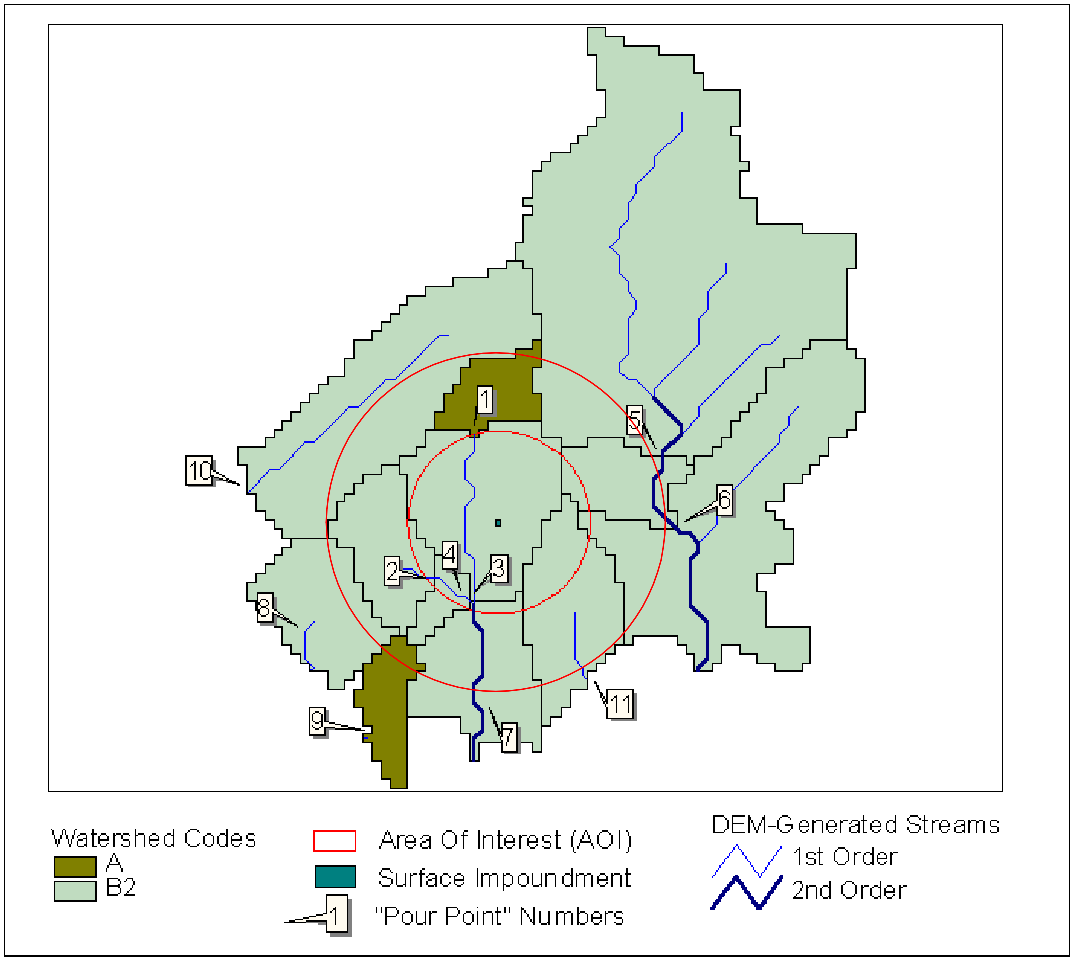


Figure 5-10. Map of DEM-generated watershed subbasins showing pour points.

- at the beginning node of a first-order stream
- where any DEM stream enters or exits the 1-km area (see pour points 1 and 2 in Figure 5-10)
- just upstream of any stream junction so that each stream had its own watershed (see pour points 3 and 4 in Figure 5-10).

■ For streams within the 2-km-radius circle around the site, the pour point guidelines were

- just upstream of any stream junction except for stream order 1
- where any DEM stream with a stream order greater than 1 entered or exited the 2-km area. For streams whose headwaters drained into the site,

a pour point was picked so that the subbasin would start within the AOI and a part of the stream reach for that subbasin was within the AOI (see pour points 5,6, and 7 in Figure 5-10).

- For lakes and wetlands, pour points were picked downstream and upstream of any lake or wetland found in NWI, RF3, or GIRAS. If a waterbody was represented by multiple coverages, NWI features were used as the waterbody. If no NWI existed, then either GIRAS or the Reach Files were used.

- Pour points were selected along any stream inside or outside the AOI as necessary to create full subbasin coverage within the AOI (see pour points 8, 9,10, and 11 in Figure 5-10).

Site-to-site variability in coverages and site characteristics required delineation staff to use judgement when applying these guidelines to ensure as much consistency and accuracy as possible in the delineation process (see Section 5.7.4).

Following pour-point selection and automated subbasin delineation, individual subbasins were merged to create a single regional watershed coverage. Then subbasin boundaries could be altered to adjust for large waterbodies and problems in the software's delineation of subbasins. When a large lake or wide river was the subbasin boundary, GIS staff would use lines from one of the lakes and wetlands base files: NWI, GIRAS, or RF3. Any DEM-delineated lines located within the large lake or river were deleted. In some cases, DEM-generated subbasin boundaries had to be extended or altered in some way in order to account for a large waterbody feature. Portions of subbasins outside of the AOI whose waterbody was not being modeled were deleted. Figure 5-10 shows a completed regional watershed coverage for a site. The boundaries are squared because the watershed boundaries were done in ARC/INFO GRID, a raster based GIS module, and then converted into vector lines.

Figure 5-11 is an example of a site with a wide river. The GIRAS feature representing the wide river was substituted in the waterbody network for the seventh-order stream that was identified in the DEM stream network. Pour points were chosen along the seventh-order stream, and watershed boundaries were generated based on those pour points. The GIRAS feature was then inserted into the regional watershed coverage, and all of the arcs located within the river were deleted. The result was a regional watershed coverage with several pseudo or one-sided (B1) subbasins representing drainage into the river.

(2) *Manual Watershed Delineation*—A total of 69 sites were determined in step 3 to be inappropriate for DEM watershed delineation and were manually delineated. Hand-delineations were drawn for each of these sites using many of the same coverages as the DEM delineations: RF3-Alpha, GIRAS, NWI, and DEMs. The DEMs were used to create 2-m contour lines for the site. The entire GIRAS land use coverage, not just the lakes and wetlands coverage, was used in delineating these sites. This expanded GIRAS coverage was helpful for sites in urban and industrial areas, where drainage occurs through underground culverts.

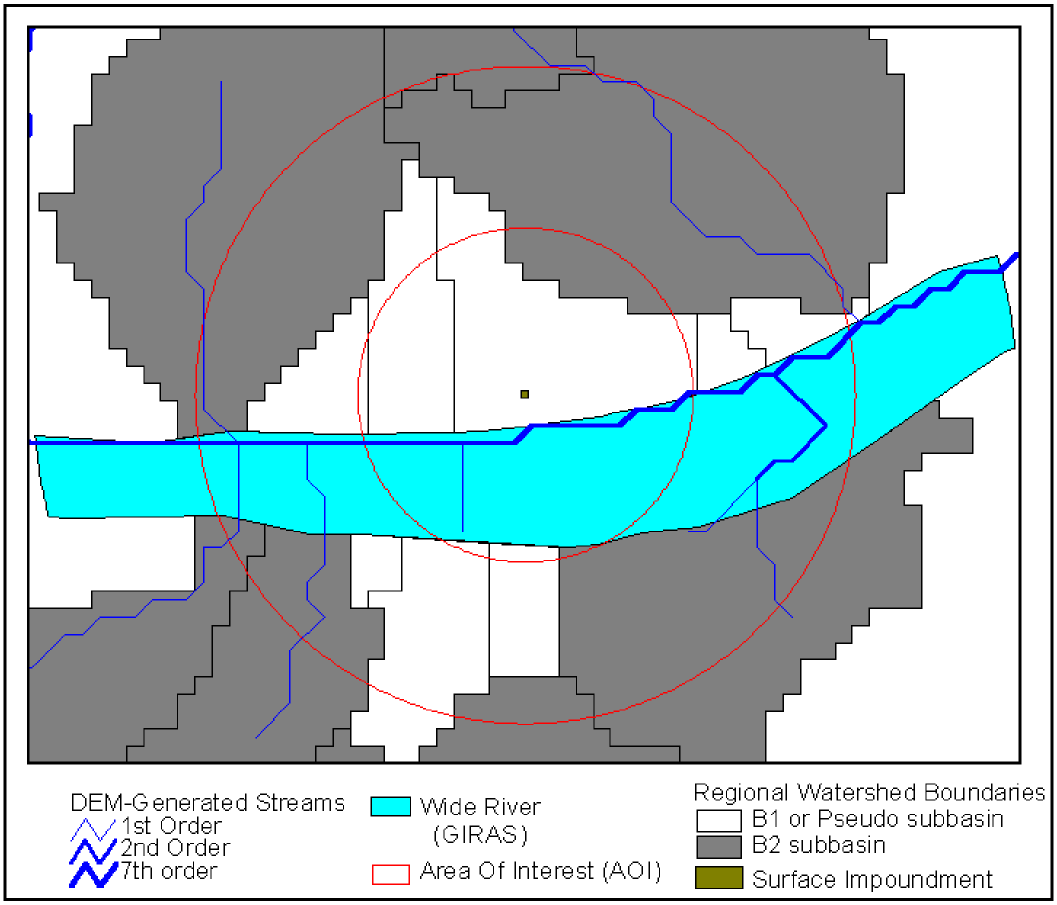


Figure 5-11. Map of regional watershed with a large waterbody.

Once the hand-delineations were completed, the maps were screen-digitized in ArcView 3.1 and stored as ArcView shapefiles. Boundaries of large rivers, lakes, and wetlands were brought into the subbasin shapefile where necessary.

Once the boundaries were digitized, the created ArcView shapefiles were converted into ARC/INFO coverages. Only minor alterations of the coverages took place after the conversion from shapefiles to ARC/INFO coverages. In most cases, this alteration consisted of correcting minor digitizing errors such as sliver polygons.

Figure 5-12 represents a manually delineated regional watershed coverage. GIRAS features (in blue and green) and RF3-Alpha streams (in dark blue) were used to delineate the watersheds. Subbasins 3, 5, 6, 7, 9, 10, and 11 are one-sided B1 subbasins that flow into the GIRAS river, which was designated as a single reach. Subbasins 1, 2, 4, and 8 flow into RF3-Alpha stream reaches 1, 2, 3, and 4.

(3) *Numbering and Attribution of the Regional Watershed* created for both manually delineated and DEM-delineated watershed subbasins, the process of numbering and coding the watersheds; was the same. First the watershed subbasins were numbered sequentially beginning with 1. This numbering was done by declaring a cursor on the polygon attribute table and

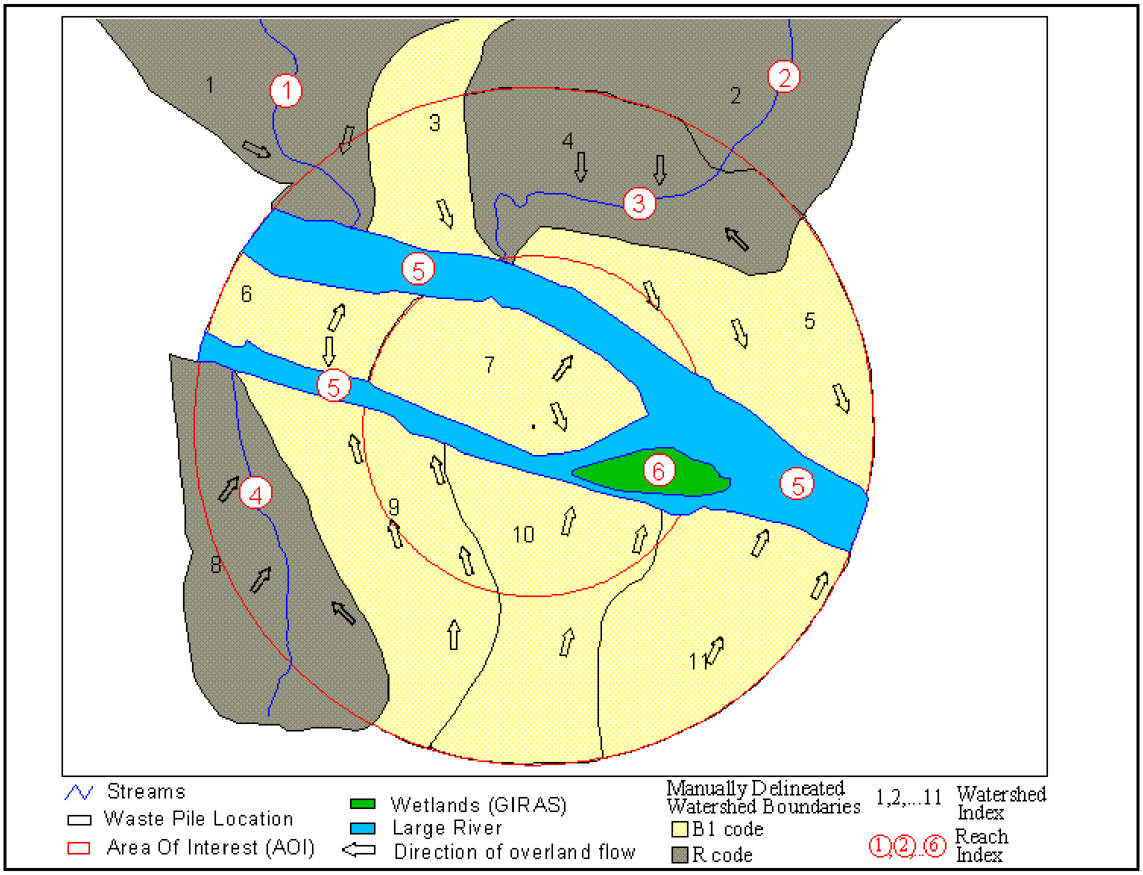


Figure 5-12. Map of manually delineated regional subbasins.

calculating the watershed number equal to a counter. The counter was incremented each time a new record was processed by the cursor.

GIS staff then coded the subbasins with a watershed code (see Table 5-7). These codes were used throughout much of the later GIS processing to determine what stream model (RF3-Alpha or DEM streams) was used in the subbasin and whether to calculate a stream length in the subbasin. DEM-delineated sites had three codes: A, B2, and B1. Manually delineated sites could have a potential of five codes: A, B1, B2, R, and U.

An ***A** watershed code* described a headwater subbasin as delineated by the DEM model. A watershed code of A meant that within the basin all drainage was to the head of a first-order stream. This code also could be used to describe a subbasin that flowed into a headwater lake or wetland (see Figure 5-10 for an example of an A subbasin).

A *watershed code of **B2*** described a subbasin that drained from both sides to a single DEM-generated stream arc. Overland flow in this type of subbasin flowed to both sides of the

DEM stream. It also was used when drainage in the subbasin was flowing into a lake or wetland feature (see Figures 5-10 and 5-11 for an example of B2 subbasins).

The ***R** watershed code* was used in subbasins that drained into an RF3-Alpha stream, lake, or wetland. This code was used only in manually delineated sites. Using this code differentiated whether the stream arc used in modeling was a DEM-generated stream arc or a RF3-Alpha stream arc (see Figure 5-12 for an example of a R subbasin).

A ***U** code* was used only in manually delineated sites and to describe a subbasin that did not have any surface drainage feature located within the AOI.

A ***B1** watershed code* described a subbasin that drained into only one side of a stream, lake, or wetland. B1-coded subbasins could be of two types: those that drained into a single stream arc and those that drained into a large lake, river, or wetland. When the flow was to a single stream arc, the DEM stream arc or RF3-Alpha stream arc was brought into the subbasin coverage to serve as the boundary of the subbasin, thus cutting the actual subbasin in half. This type of B1 subbasin was used to create a smaller subbasin within the 1-km radius of the site where the model hoped to get greater resolution. Using the B1 code with a single stream arc also allowed for a flow length to be calculated so that overland flow could be distributed to a lake or wetland waterbody that also resided in the subbasin but not along the stream arc. It also was used in DEM-delineated sites when a subbasin drained into a stream arc that was located completely outside of the AOI.

The B1 code also was used to describe a subbasin that drained into a large waterbody. For DEM modeled sites, an attempt was made to use the subbasin boundaries generated from the DEM representation of the large waterbody. GIS staff tried to used the DEM-generated ridge lines as boundaries to make subbasins smaller and more defined (see Figure 5-11 and 5-12 for examples of B1 subbasins).

5.4.5 Step 5: Delineation of Waterbodies

Goals: To identify and define lakes and wetlands that should be modeled, to identify streams that should be modeled, and to attribute lake, wetland, and stream reaches for later processing.

Inputs:
(1) Lakes and wetlands coverages (NWI, GIRAS, and RF3-Alpha)
(2) DEM streams and/or RF3-Alpha streams.

Outputs:
(1) A lakes and wetlands coverage
(2) A reach-to-reach connectivity table
(3) A reach-to-subbasins connectivity table
(4) A table describing each lake and wetland feature, including subbasin connectivity and reach connectivity.

5.4.5.1 <u>Procedures.</u> Step 5 was a semiautomated step that was performed using two AML macros: one that created a lakes and wetlands coverage, attributed it, and created a data table describing the coverage; and another that created two data tables that were used to define the reach connectivity in the regional watershed.

(1) *Creating the Lakes and Wetlands Coverage*—After the subbasins had been delineated, GIS staff created a lakes and wetlands coverage for the site using NWI, GIRAS, and RF3-Alpha as inputs. If NWI existed for the site, the site's NWI coverage was copied into the new coverage (LK_WET). If no NWI existed, then the GIRAS lakes and wetlands coverage was copied into the LK_WET coverage. If neither GIRAS nor NWI existed for the site, then a blank LK_WET coverage was created. Once the coverage existed, lake and wetland features included in other coverages could be added to the features already in the LK_WET coverage.

The first step in the editing process was to delete all features completely outside the AOI. Next, when only a portion of the feature was located inside the AOI, a determination was made whether that feature would stay in the coverage (see Section 5.7.4).

The next step was to move lake and wetland features that crossed subbasin boundaries so that the feature was contained by a single subbasin. This was only done for features that are determined by the preprocessing decision rules and the visual check of the delineation to be part of the stream network. Moves were restricted to cases where it was impossible to create a DEM subbasin that could contain the wetland. Wetlands were not moved to accommodate subbasin boundaries in manually delineated sites because these were created using the wetlands as a guide.

Some wetlands also were moved from their original location in an attempt to simplify wetlands (NWI sites only). This happened only if wetland features were deemed part of the stream network. The NWI ATTRIBUTE code of the predominant feature in the group of wetlands to be combined was applied to the entire group (see Section 5.7.4).

Wide rivers and lakes also could be combined from any of the lake and wetland sources. If the subbasin coverage used one source type as the boundary of the subbasin, then that data source was used as the feature source in the lakes and wetlands file. GIRAS was often favored as boundaries of large lakes due to the ease with which it could be inserted into both the subbasin coverage and the lakes and wetlands coverage.

The features were numbered sequentially using CURSOR in ARC/INFO. Wide rivers were assigned a RF3RCHID code. An RF3-Alpha reach that was part of the river was selected and used to label the river feature in the lake wetland coverage with the RF3RCHID.

(2) *Creating the Reach Connectivity Tables*—All lakes, rivers, and streams received reach numbers. Wetlands were included if they were determined to be connected to the waterbody network. Stream reaches received only one reach number per watershed subbasin. Large rivers and lakes received only one reach number but could have multiple one-sided (B1) subbasins that flowed directly into them.

Two data tables were created: one that defined reach-to-reach connectivity and one that defined reach-to-subbasin connectivity. Each reach was manually referenced to a watershed subbasin, any directly upstream tributaries, and any lake feature that the reach represented.

All GIRAS and RF3-Alpha wetland features were included (connected) in the waterbody network. For NWI features, all features coded in step 2 with a y in the CONNECT field were included in the network. These connected wetlands were further broken down based on whether they could be the only reach in a subbasin. If the feature's ATTRIBUTE code contained the letter combination of either RB, UB, AB, US, ML, or OW, then it could be the only reach in the subbasin. Else, the stream segment would receive a reach number as well. NWI features coded with an n in the CONNECT field were only connected to the stream network if they were located on a Reach File stream. These features could not be the only reach in a subbasin.

In Figure 5-13, reach numbers 5 and 8 represent a waterbody type of Lake based on the NWI code. These features were labeled with a CONNECT code of l and had to be included in the waterbody network. Reach number 9, which is a wetland located along a river, was labeled with a CONNECT code of n. It was only included in the waterbody network because it was located along a third-order RF3-Alpha stream. Had it not touched the stream, it would not have been connected. It was included as a tributary feature to the stream arc in the subbasin, reach number 6.

5.4.6 Step 6: Delineation of Local Watershed

<u>Goals:</u> To create a local watershed sheet flow runoff-only mode for each WMU type.

<u>Outputs:</u> A local watershed coverage for each WMU type at the site location.

5.4.6.1 <u>Procedures</u>. A local watershed is a drainage basin that contains the WMU, or portions thereof, and is subject to direct runoff and erosional processes from the WMU. A local watershed is composed of up to three subareas: the WMU, any land area upslope of the WMU extending to the drainage divide, and the downslope buffer zone between the WMU and the first waterbody encountered. If the WMU overlapped a drainage divide, then multiple local watersheds could result. For modeling the local watershed, the coverage was represented as a rectangle that extended from the upslope drainage divide downslope to the first defined drainage channel, lake, or pond. Figure 5-14 shows a completed local watershed coverage.

(1) *Delineate All Subbasins (Including Those for Order 1 Streams) in the Vicinity of the WMU*—This step was done often in conjunction with the delineation of the regional watershed coverage (see Section 5.4.4). Watersheds were created by picking pour points along the DEM-generated stream network and then generating a subbasin based on that pour point.

(2) *Create an Intermediate Local Watershed Coverage*—This intermediate coverage was called the L2 coverage and consisted of one or two polygons, depending on the number of local watersheds at the site. An L2 polygon (shown outlined in green in Figure 5-13) could contain all or a portion of the regional watershed subbasin, but it could not extend into two regional subbasins. The regional watershed subbasin containing the WMU was determined. If the WMU was located in two watershed subbasins then there were two polygons in the L2 coverage, one for each watershed subbasin. To simplify the process, if less than 30 percent of the WMU

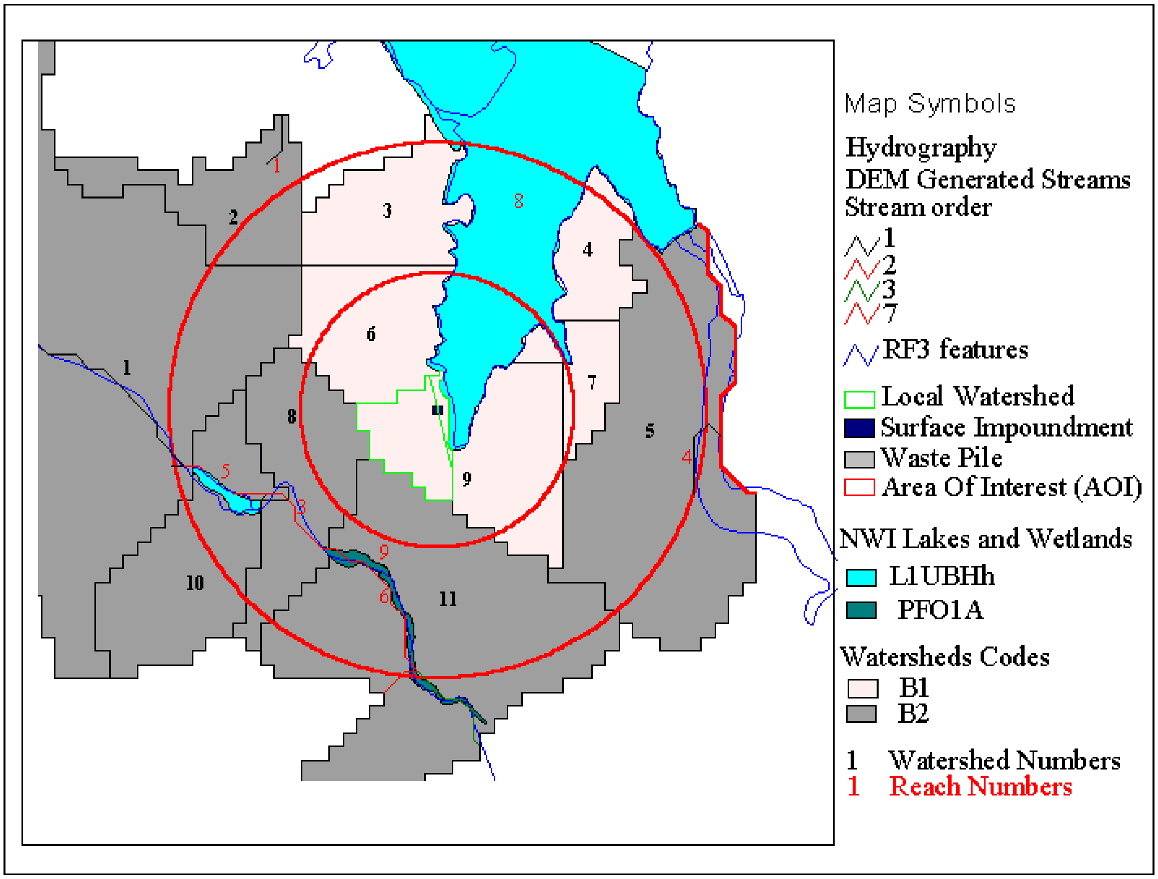


Figure 5-13. Map of watershed and waterbody delineation showing local watershed.

resided in a watershed subbasin, it was not considered to be located in that watershed subbasin. For manually delineated regional watersheds, the L2 coverage also was manually delineated.

(3) *Divide L2 Coverage into Upstream and Downstream Portions*—To get the approximate upstream and downstream flow length, the local watershed was divided in half by bisecting the center of the circular WMU with a line oriented parallel to the stream or waterbody into which the local watershed drains. In this way, the arcs of the L2 coverage were coded based on whether it was an upstream, downstream, or stream arc. The values were then summed and divided in half to derive the upstream and downstream values.

(4) *Create a Local Watershed Sheet Flow-Only Model*—The model contained up to three subareas. Subarea 1 was always the upstream subarea, subarea 2 was the WMU site itself, and subarea 3 was the area from the WMU to the closest waterbody within the local watershed. It was created by first copying the square WMU model into the new coverage and then adding a rectangle with two sides equal to the upstream flow and another rectangle with two sides equal to the downstream flow. The resulting rectangle resembled the rectangle shown in Figure 5-14. If there were two local watersheds, the square WMU used to create the subareas for each local watershed had an area equal to the area of the WMU in each local watershed.

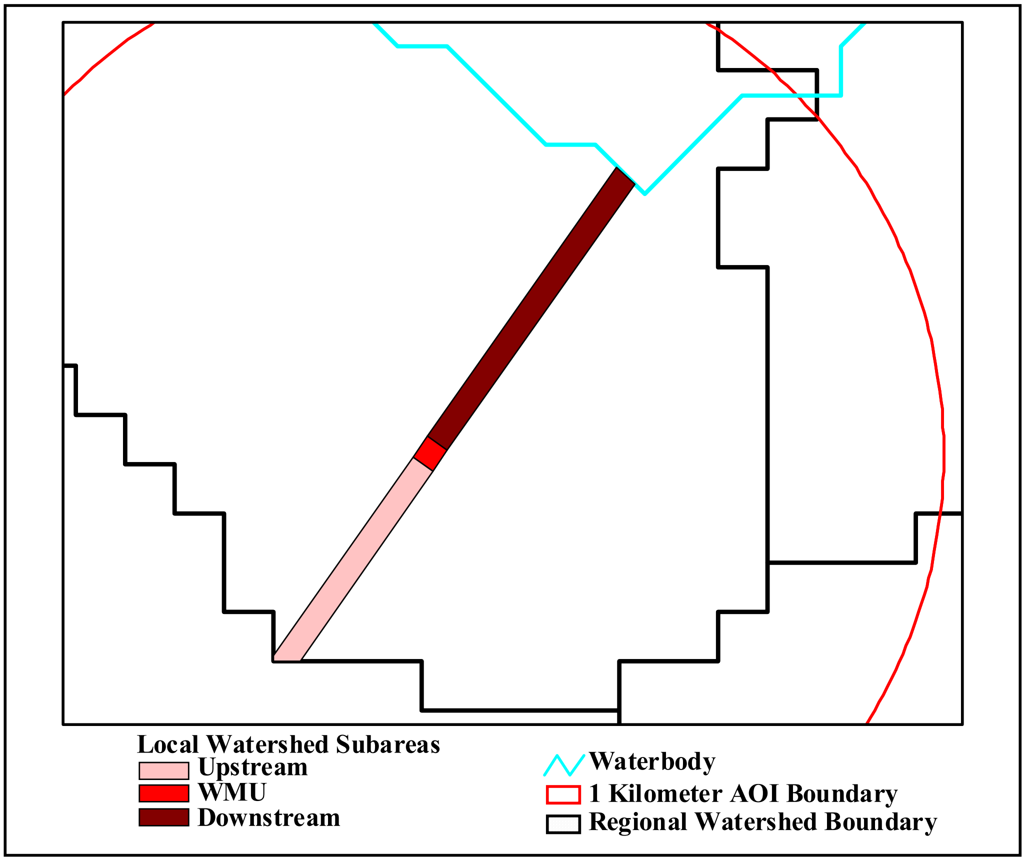


Figure 5-14. Map of a local watershed.

(5) *Rotate the Local Watershed to the Average Aspect in the L2 Coverage*—Using the elevation grid and the L2 coverage, an average aspect was determined. This value was used to rotate the sheet flow model so that it was oriented properly within the watershed. This was an interactive step and required manually rotating the local watershed toward the waterbody if autorotating based on the aspect was not successful.

(6) *Clip to the Boundary of the L2 Coverage*—The resulting local watershed coverage was clipped to the boundary of the L2 coverage to ensure that the local watershed remained in the correct regional watershed.

5.4.7 Step 7: Create the UTM Reference Grid

Goals: To create a UTM reference grid to be used to determine x,y locations for waterbodies and watershed data coverages.

Output: UTM reference grid.

5.4.7.1 Procedure. In an earlier step, a UTM reference grid for the example data set was created based on the largest WMU area for the entire project (see Section 2.0 for procedures on creating the UTM reference grid for the 3MRA modeling system). This grid was copied to the site location and centered on the x,y coordinates of the site using the UTM coordinates for each site, created in step 2 (Section 5.4.2). The x,y coordinates for each grid cell were attributed with the ADDXY command in ARC/INFO and referenced to the cell address number of the grid.

5.5 Database Compilation and Processing

After the delineations were complete, the data were postprocessed to produce the GIS database tables shown in Figure 5-15. These tables were read by the Input Data Integrator and Processor (IDIP) to extract the necessary data, do any necessary calculations and manipulations, and create two final databases to be sent as input for the 3MRA modeling system: an input parameter database, containing model inputs and a grid database, containing *x,y* coordinates for the features of interest, including watersheds and waterbodies. This section describes the processes necessary to create the 3MRA modeling system input data set from the delineations.

The various delineations described in Section 5.4 resulted in multiple GIS coverages and hand-entered data tables. In order to provide the necessary data in a convenient format for further automated processing, data from the coverages were processed by GIS software to obtain spatial statistics such as areas or lengths. All data went through processing to compile a comprehensive set of tables with parameters related to the coverages that defined them. For example, the watershed area was put in a table by site number and watershed number.

The resulting GIS database tables were linked into the IDIP, which was used to produce the final model-ready input databases (one file with grid data only and one with all nongrid input variables). Queries and Visual Basic for application code were created to extract the data for each variable, manipulate it, perform any necessary calculations and format it for the 3MRA modeling system. The queries were grouped by topic into individual SQL (structured query language) text files used by the Windows Scripting Engine in conjunction with databases containing the data to be processed. The individual SQL files made it possible to run only certain sections of the data, making it easier to test and develop the SQL code. A master script was used with the Windows Scripting Engine to fully automate the generation of 3MRA modeling system input files from the GIS data.

5.5.1 Number of Waterbody Networks and Number of Reaches in Waterbody Network

The waterbody networks for a given site were constructed using the reach connectivity table (r_all, Figure 5-15) generated during the delineation of the waterbodies and a reach coverage clipped to the AOI (q_all, Figure 5-15). Each reach at the site was associated with a waterbody network. The number of waterbody networks (NumWBN) at each site was a count of the constructed networks. The number of reaches in each waterbody network (WBNNumRch) was a count of reaches by waterbody network.

5.5.1.1 Database Compilation for NumWBN and WBNNumRch. The reach connectivity table (r_all) lists the reach number (RCH_NUM) and then an upstream reach (RCH_UP). All reaches are represented in the table. If they do not have an upstream reach, the RCH_UP is zero, the default. If a reach does have an upstream reach, the reach number of the upstream reach was entered in the RCH_UP field. If two or more reaches existed in a watershed, only one reach was assigned a RCH_UP and a zero was entered for the others in the RCH_UP field.

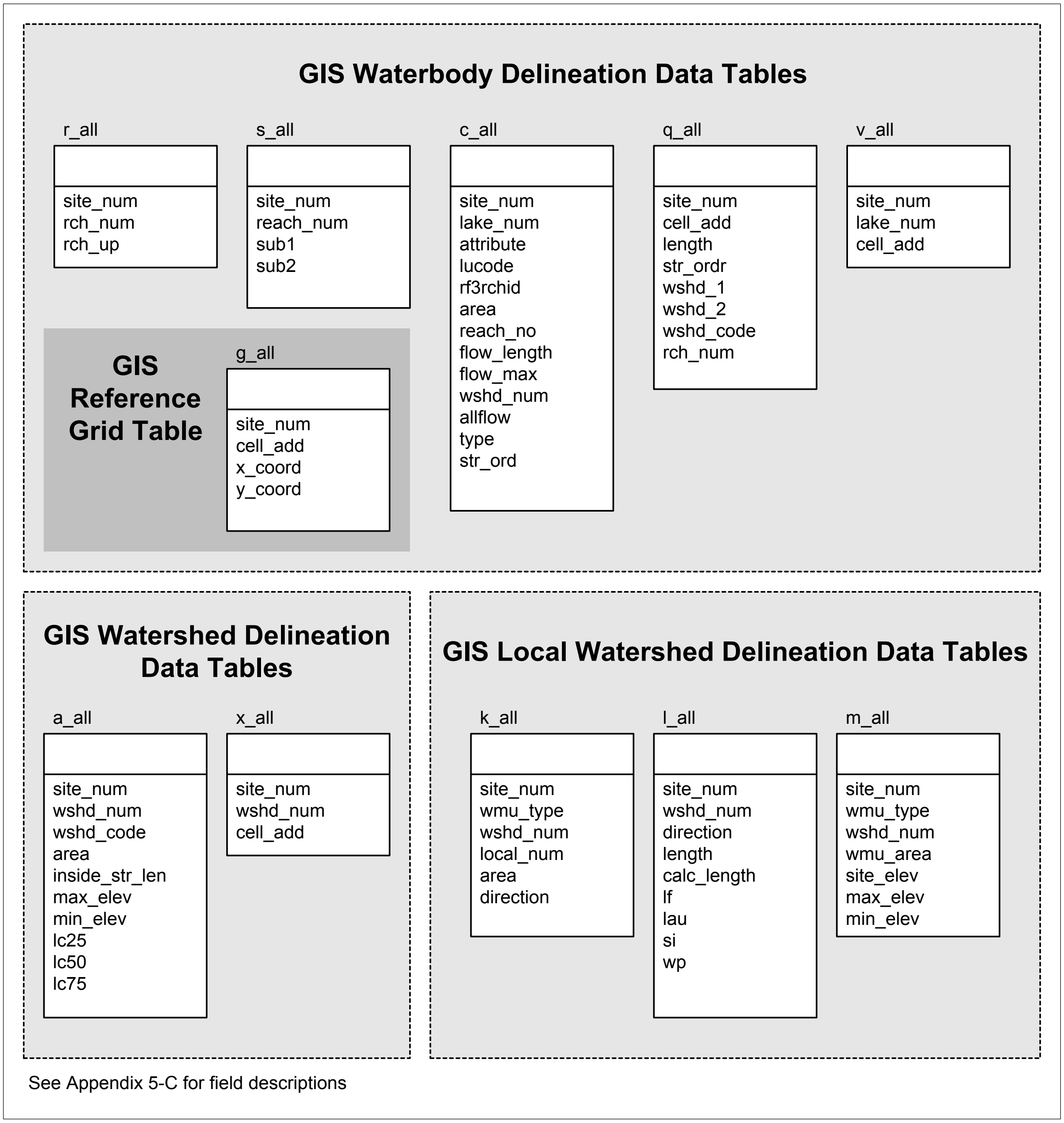


Figure 5-15. GIS database tables exported for further data processing.

An appended stream reach coverage (q_all, Figure 5-15) was created for each site using a semiautomated macro. To determine from which data source to extract the stream segment, a stream coverage was constructed using the watershed code (see Section 5.4.4, Table 5-7): for A and B2 watersheds, the DEM-generated stream model was used; for R watersheds, RF3-Alpha was used; and for B1 watersheds, a manually delineated shoreline was used. To create q_all, the resulting stream coverage was clipped at the AOI, projected to the proper UTM coordinates for the site, and overlaid with the reference UTM grid for the site.

5.5.1.2 Database Processing for NumWBN and WBNNumRch. The watershed delineation procedure resulted in stream reaches that were not in the AOI being passed in the reach connectivity table. Because stream reaches not inside the AOI were not modeled, these reaches needed to be clipped out of the reach connectivity table before using it to construct the waterbody networks at the site. The stream coverage table clipped at the AOI (q_all) was used to automatically remove the reaches outside the AOI from the reach connectivity table (r_all).

The clipped connectivity table was then used to determine which reaches were waterbody network roots. There are three main types of network roots: (1) reaches with upstream reaches but that are not an upstream reach for any other reach, (2) any lake or wetland with no connectivity with any other reach, and (3) stream reaches with a stream order greater than 1 that do not connect with any other reach and are longer than 1,000 m within the AOI.

The connectivity table was then used to walk up each waterbody network, starting with the network root. Network roots not connected to other reaches resulted in a waterbody network with only one reach. A waterbody network table was constructed including the original GIS reach number identifier, a waterbody network number identifier, and waterbody network reach number identifier. These identifiers were used to identify which reaches belonged to which networks as well as serving as the indices for all waterbody parameters. The number of waterbody networks at the site was simply a count of the unique waterbody network identifiers. The number of reaches for each waterbody network was the count of the reach identifiers by the waterbody network identifier. In subsequent steps, this waterbody network table was used as a crosswalk between the old GIS-assigned reach identifiers and the new network identifiers to get the correct indices for all of the parameters associated with the waterbody network.

5.5.2 Number and Index of Reach that Impacts a Reach and Fraction of Reach Impacted by Another Reach

The number of reaches that impact a reach (WBNRchNumRch), the index of a reach that impacts a reach (WBNRchRchIndex), and the fraction of a reach impacted by another reach (WBNRchRchFrac) were all obtained using the same clipped reach connectivity table (r_all, Figure 5-15) used to construct the waterbody network.

5.5.2.1 <u>Database Compilation for WBNRchNumRch, WBNRchRchIndex, and WBNRchRchFrac</u>. The reach connectivity table (r_all) was used for all of the reach-to-reach connectivity parameters.

5.5.2.2 <u>Database Processing for WBNRchNumRch, WBNRchRchIndex, and WBNRchRchFrac</u>. The AOI-clipped reach connectivity table used in constructing the waterbody network also was used to obtain all other reach connectivity parameters. The number of reaches that impact a reach was obtained by counting the upstream reaches for each reach. The indices of those reaches were extracted directly from the reach connectivity table using the waterbody network table as the crosswalk between GIS and network identifiers. If a reach had an upstream reach the fraction of the upstream reach impacting the reach was always set to 1. If a reach did not have an upstream reach, the fraction was set to zero.

5.5.3 Reach Length

The stream reach length (WBNRchLength) was calculated using the stream reach coverage clipped at the AOI (q_all, Figure 5-15) used to clip the reach connectivity table. Lengths of large rivers were manually measured using ArcView.

5.5.3.1 <u>Database Compilation for Reach Length</u>. The stream reach coverage clipped at the AOI (q_all) contained the length of each stream segment by reach number, stream order, and reference cell address. Because the stream reach coverage contains only the lengths of reaches represented by a single line, wide rivers, represented by polygons, were measured using ArcView. A line was drawn down the center of the river and then the total length of the line was entered into a table by site and GIS reach number.

5.5.3.2 <u>Database Processing for Reach Length</u>. Using the stream reach coverage (q_all), the total length for each reach at each site was taken as the sum of the lengths of each segment by rch_num across all stream orders and cell addresses. The only exception occurred when an order 1 stream segment was identified with the same reach number as a higher order stream. Then only the lengths of segments with an order greater than 1 were summed, omitting the order 1 segments from the total length. The manually measured river lengths were simply extracted from the table in the database. Null length values were passed for nonstream reaches (i.e., lakes and wetlands).

5.5.4 Reach Surface Area

The reach area (WBNRchArea) for lakes and wetlands was extracted directly from a GIS-generated table of areas by reach number (c_all, Figure 5-15). Areas for stream reaches were passed as nulls.

5.5.4.1 <u>Database Compilation for Reach Surface Area</u>. The reach surface area was based on the polygon areas of the features in the lakes and wetlands coverage (for GIS delineation methods for lakes and wetlands, see Section 5.4.5). Specifically, the AREA attribute was used. This field was summed by lake number using the FREQUENCY command in ARC/INFO.

5.5.4.2 <u>Database Processing for Reach Surface Area</u>. The reach areas were extracted from the GIS-generated table (c_all) by the SiteID and reach number.

5.5.4.3 <u>Assumptions and Uncertainty for Reach Surface Area</u>. The lake surface area was calculated using a coverage that had been clipped or truncated by a 3-km radius circular area around the site. Any large lake or wetland within the AOI that extended beyond the 3-km limit was clipped at this limit.

5.5.5 Stream Order

Stream orders (WBNRchOrder) were obtained from a variety of sources. For sites delineated using the DEM-generated stream coverage, the orders were determined using GIS. For sites that were manually delineated, stream orders were either assigned using the RF3-Alpha and Pacific Northwest Reach Files or, for higher order streams, obtained using the RF3RCHID to look up the orders (see Section 6.0 for a discussion of how these were obtained). When stream orders were not available by RF3RCHID the stream orders were obtained using the river name and *The Water Encyclopedia* (van der Leeden et al., 1990) to look up the flow rate and then infer an order based on the flow rate.

5.5.5.1 <u>Database Compilation for Stream Order</u>.

- For sites based on the DEM-generated stream network, stream orders were generated in ARC/INFO using the Strahler (1957) method (i.e., stream order increases at the confluence of two streams of the same order).

- Stream orders for large rivers were manually assigned to the polygon feature in the lakes and wetlands coverage. Stream order was inferred from the DEM-generated stream coverage. The highest stream order that most likely represented a feature was used as the stream order. For instance, in Figure 5-11, the stream order for the wide river is a 7 because a seventh-order DEM-generated stream is the highest order stream along its general path.

- For manually delineated sites, stream orders were based on RF3-Alpha and Pacific Northwest Reach Files. Using the Strahler (1957) method, stream orders were manually assigned to each reach number in the stream coverage for the site.

- For manually delineated sites with higher order streams that were difficult to derive using the Strahler (1957) method, the RF3RCHIDs were used to obtain the order from a table of stream order by RF3RCHID (see Section 6.0). When the RF3RCHID was not in the table, *The Water Encyclopedia* (van der Leeden et al., 1990) was used to obtain the flow rate using the waterbody name. The flow rate was then used to obtain an approximate stream order based on the flow rate from a table of flow rates by order in Leopold (1962).

Most stream order information was passed using the stream reach coverage table used to clip the reach connectivity table and calculate reach length (q_all, Figure 5-15). This table contains the reach order by reach number and cell address for each site. Stream orders for wide rivers, lakes, and wetlands were passed in the lakes and wetlands information table (c_all, Figure 5-15). Rivers were included in this table when they were represented as polygons in the reach coverage (i.e., had a measurable width).

5.5.5.2 <u>Database Processing for Stream Order</u>. For DEM stream reaches the maximum stream order in the stream reach coverage table for each reach was passed as the stream order for that reach. Lakes with an associated stream segment flowing into and out of them were given the same stream order as the stream that flowed through them. Other lakes and wetlands were given a default stream order of 1. Rivers represented by polygons received their stream order from the lakes and wetlands information table (c_all).

5.5.5.3 <u>Assumptions and Uncertainty for Stream Order</u>. The evaluation of stream orders for manually delineated sites had various uncertainties. Manual stream order evaluation was difficult in large complex stream systems and anthropogenically altered stream systems. Also, for the rivers that did not have an available stream order by RF3RCHID, the flowrate-based stream order only provided a general estimate based on national data from Leopold (1962). Additional uncertainties associated with the RF3-Alpha Pacific Northwest Reach Files and DEM-generated streams are discussed in Section 5.7.1.

5.5.6 Number and Index of Fishable Reaches

Fishable reaches were identified using the stream order and the waterbody type (stream, lake, or wetland). This included the number of fishable reaches (WBNNumFishableRch) and the index of reaches that are fishable (WBNFishableRchIndex).

5.5.6.1 Database Compilation for WBNNumFishableRch and WBNFishableRchIndex. Fishable reaches were identified using the stream reach coverage table (q_all, Figure 5-15) and the lakes and wetlands information table (c_all, Figure 5-15).

5.5.6.2 Database Processing for WBNNumFishableRch and WBNFishableRchIndex. All lake or wetland reaches were identified as fishable along with order 3 or higher stream reaches. Reaches designated as bay/estuary were not designated as fishable because they were not modeled. The number of fishable reaches was simply the count of all reaches identified as fishable by the waterbody network. The indices for the fishable reaches were extracted from the waterbody network table using the GIS reach number.

5.5.6.3 Assumptions and Uncertainty for WBNNumFishableRch and WBNFishableRchIndex. Any uncertainty associated with the steam order could affect the identification of fishable reaches. In addition, reach order can only provide a rough estimate of whether a reach can be fished or not, which varies regionally and by type of fish present.

5.5.7 Reach Type

For reach type (WBNRchType), reaches were identified as headwater, exiting, or other using the AOI-clipped reach connectivity table (r_all, Figure 5-15).

5.5.7.1 Database Compilation for Reach Type. The AOI-clipped reach connectivity table (r_all) used to construct the waterbody networks for each site also was used to determine which reaches were headwater reaches, exiting reaches, or other.

5.5.7.2 Database Processing for Reach Type. A reach with no upstream reach but that flows downstream into another reach was identified as a headwater reach. A reach with upstream reaches that flows out of the AOI was identified as exiting. All other reaches were identified as "other."

5.5.8 Waterbody Type

The type of waterbody (WBNRchBodyType) for each reach (stream, lake, wetland, or bay/estuary) was determined using the lakes and wetlands information table (c_all, Figure 5-15) which contained information on connected reaches derived from three GIS data sources: NWI, GIRAS, and RF3.

5.5.8.1 Database Compilation for Waterbody Type. The lakes and wetlands information table (c_all) was created using the lakes and wetlands coverage resulting from the waterbody delineation. The lakes and wetlands information table had an attribute column that contained either an NWI code or a descriptor (lake, wetland, bay/estuary, stream/river) derived from GIRAS or RF3 data.

5.5.8.2 Database Processing for Waterbody Type. Any reach not contained in the lakes and wetlands information table (c_all) was designated as a stream. Reaches with NWI codes in c_all were processed through a decision tree to assign waterbody type based on the hierarchical structure defined by Cowardin et al (1979). The following rules were developed to identify streams, lakes, wetlands and estuaries from NWI attribute code:

- If the code began with P, the waterbody is palustrine and the following designation was used to decide whether it was a wetland or a lake:
  - If P was followed by EM, SS, ML, or FO, then it is a wetland because there is emergent vegetation, shrub/scrub, or forest.
  - If P was followed by RB, UB, AB, US, or OW, then it is a lake.
- If the code began with L (lacustrine) the following applied:
  - If a 1 followed the L, then it is lacustrine-limnetic and a lake
  - If a 2 followed the L, then it is lacustrine-littoral and the following applied:
    - L2EM is a wetland (EM is for emergent vegetation)
    - L2 followed by any other code is a lake.
- If the attribute code began with an R (riverine) then it is a stream.
- If the attribute code began with an E (estuarine) then it is a bay/estuary.

Because site-based data were not available to differentiate ponds and lakes, and this distinction is not standardized region-to-region, the lake/pond designation was made within the 3MRA modeling system based on the area of the lake/pond feature.

For reaches in the wetland and lake information table that did not have an NWI code, the descriptor from GIRAS or RF3 was used to assign a waterbody type. All reaches attributed as stream/river became streams. All of the other attributes (lake, wetland, and bay/estuary) were passed on directly as the designation.

5.5.9 Number, Indices, and Fraction of Watershed Subbasins that Impact a Reach

The waterbody connectivity to the watershed subbasins was manually entered during the waterbody delineation and conveyed to the IDIP for further processing in two GIS-generated tables, c_all and s_all (Figure 5-15). Watershed/waterbody connectivity parameters include the number and indices of watershed subbasins that impact a reach (WBNRchNumWSSub, WBNRchWSSubIndex). The fraction of each watershed subbasin draining into its associated reach (WBNRchWSSubFrac) was calculated using the lake types assigned during delineation. If only one reach in the watershed existed, then the entire subbasin area was assumed to be impacting the reach (i.e., WBNRchWSSubFrac = 1). For watershed subbasins with multiple reaches, it was necessary to fractionate the overland flow from the subbasin to the individual reaches. In these cases, the fraction of the watershed subbasin impacting a reach was calculated from several GIS-processed data fields on a conditional basis based on the lake type field in the lakes and wetlands information table (c_all).

5.5.9.1 <u>Database Compilation for WBNRchNumWSSub, WBNRchWSSubIndex, and WBNRchWSSubFrac</u>. The watershed-to-waterbody connectivity table (s_all) matched the reach identifier to the watershed subbasin identifier of the watershed(s) that drains to the reach. The lakes and wetlands information table (c_all) matches any nonstream reaches not in the first table to their appropriate watershed identifier. The lakes and wetlands information table also contained the lake type assigned during GIS processing. Lake type was used as a conditional parameter to determine the appropriate fractioning calculation. It was manually entered after the delineation of the waterbodies (see Section 5.4.5). Only reaches included in the waterbody network received a lake type. The six lake types are described below and illustrated in Figure 5-16:

Type 1—Lake or an open water, permanently flooded wetland extending the length of a watershed subbasin. The watershed subbasin that drains into a type 1 lake or wetland was delineated (see Section 5.4.4) so that all overland flow from the subbasin flows into the feature.

Type 2—Nonpermanently flooded wetland extending the length of an entire stream reach in a watershed subbasin. A type 2 feature is associated with another lake or stream reach in the same watershed subbasin. It receives all the overland flow from the subbasin and flows into the associated lake or stream reach (which receives no direct overland flow from the subbasin). If the feature does not extend the entire length of the other reach in the watershed, then it is a type 5 wetland (see below). A type 2 feature could be an NWI-derived waterbody connected to the stream network because it is located along an RF3-Alpha stream (see Section 5.4.5) or could be an RF3 or GIRAS wetland feature.

Type 3—Lakes or permanently flooded wetlands located in a one-sided (B1) watershed subbasin. In this case, a portion of the subbasin's overland flow flows directly into the stream or large waterbody (see Type 4) and a portion flows into the type 3 lake or wetland. This type of watershed subbasin was often created in DEM delineations when

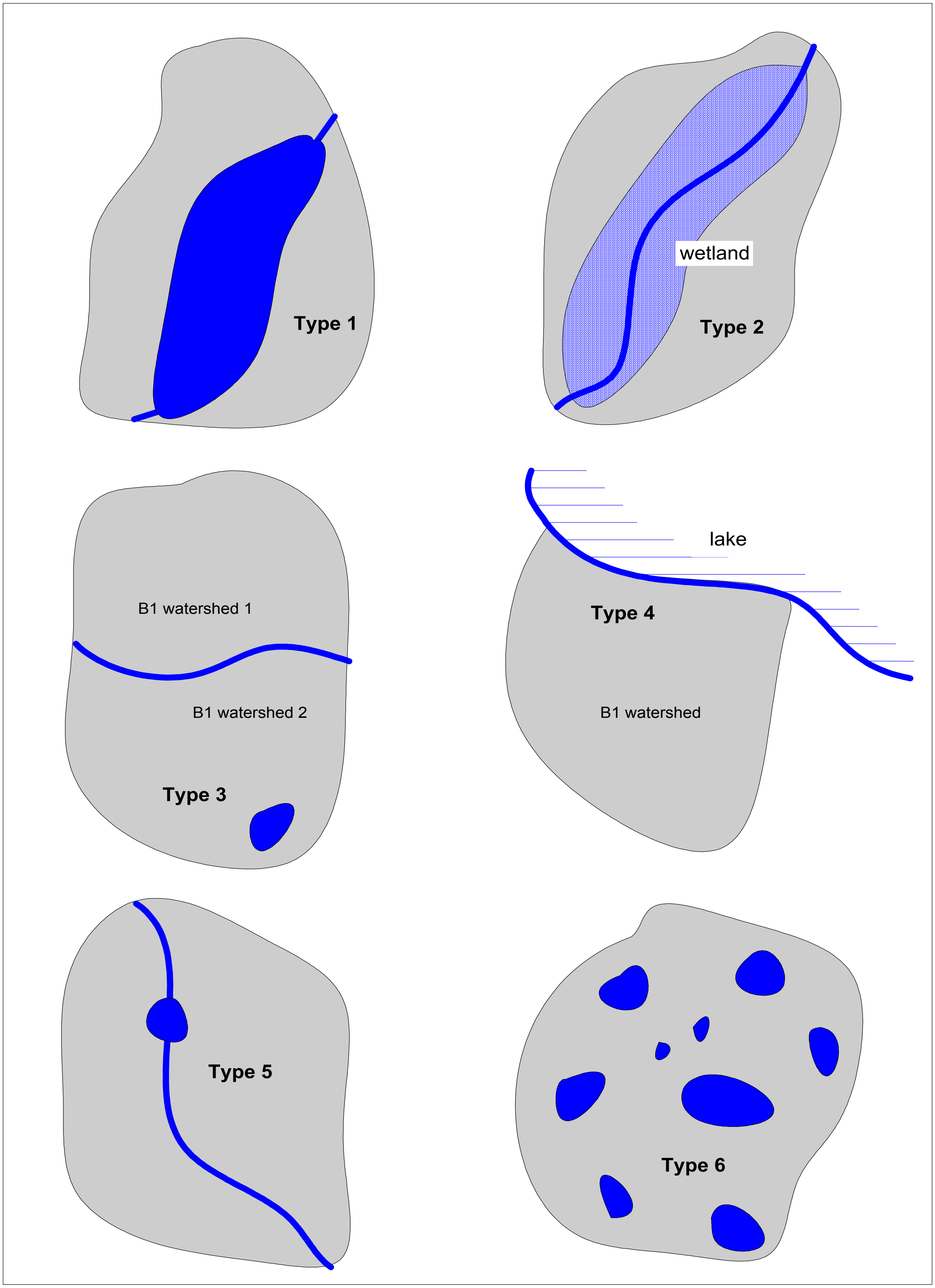


Figure 5-16. Example lake types used to fractionate watershed flows.

an individual subbasin could not be delineated for the type 3 feature. Flow was apportioned based on flow lengths.[9]

Type 4—Large waterbodies. These are features (large rivers, lakes, wetlands, bays, or estuaries) that have one-sided (B1) watersheds delineated. Usually the waterbody extends outside the AOI and is not modeled in its entirety.

Type 5—Small lakes or wetlands not extending the entire length of a stream reach in a watershed subbasin. In these cases, the flow from the subbasin is fractioned between the lake/wetland and stream reach based on their relative lengths parallel to flow.

Type 6—Multiple, unconnected lakes or wetlands occupying a single watershed subbasin. In this case, each lake or wetland was designated as a separate waterbody network. Overland flow was fractionated to each type 6 feature based on the ratio of its area to the total area of the type 6 features in the subbasin. Type 6 was only used where a waterbody network and individual watersheds could not be delineated because of an apparent lack of surface drainage between waterbodies (e.g., karst terrain).

5.5.9.2 Database Processing for WBNRchNumWSSub, WBNRchWSSubIndex, and WBNRchWSSubFrac. Using the watershed-to-reach connectivity table (s_all) and the watershed connectivity information contained in the lakes and wetlands information table (c_all), a table of all watershed-to-reach connectivity was assembled. From this table the number and indices of watershed subbasins that impact a reach was determined and exported to the system. In the few cases when reaches were located inside larger reaches (such as a river running through a large wetland area) and therefore were not associated with a watershed subbasin, the number of watersheds was passed as zero and the watershed index was left null.

The fraction of each watershed subbasin impacting a reach was calculated based on the lake types passed in the lakes and wetlands information table (see Section 5.5.9 and Figure 5-16). For stream reaches not found in this table or not occupying the same watershed as a reach in the table, the fraction was passed as 1. Fractions for the various lake types were determined as follows:

Type 1—Reaches received a fraction of 1 because they were the only reaches associated with the watershed.

Type 2—The wetland surrounding the stream was given a fraction of 1 (it receives all of the watershed runoff) and the stream received a fraction of zero (it receives no runoff directly off the watershed).

Type 3—The fraction impacting the lake or wetland in the watershed was calculated by dividing the flow length to the lake (FLOW_LENGTH) by the maximum flow length for

[9] Additional GIS data included maximum subbasin flow length (FLOW_MAX) and mean flow length to the lake (FLOW_LENGTH; watershed divide to lake center), calculated in ARC/INFO Grid using the site flow direction grid (see Section 5.4.2).

entire watershed (FLOW_MAX). The fraction received by the stream, large lake, or large wetland was then calculated as follows:

$$\text{fraction} = 1 - (\text{FLOW\_LENGTH}/\text{FLOW\_MAX}) \tag{5-1}$$

Type 4—If no other reaches occupied the same watershed, then the fraction was passed as 1. If another reach (type 3) occupied the same watershed, then the fraction was calculated as described under type 3.

Type 5—The fraction of the watershed impacting each reach was calculated using the area of the lake or wetland and the length of the stream in the watershed. A *length* of the lake along the stream was calculated from the *area*, assuming that the lake was a rectangle with the width equal to one half the length, using the following equation:

$$length = \sqrt{2 \times area} \tag{5-2}$$

The fraction of the watershed subbasin impacting the lake was then calculated by dividing the lake length by the total stream reach length. The corresponding fraction impacting the stream was calculated by subtracting the lake length from the total stream reach length, then dividing by the total stream reach length.

Type 6—The fraction of the watershed impacting each lake or wetland reach inside it was calculated by taking each individual waterbody area and dividing it by the total area of all waterbodies inside the watershed subbasin.

5.5.9.3 Assumptions and Uncertainty for WBNRchNumWSSub, WBNRchWSSubIndex, and WBNRchWSSubFrac. Various assumptions were made on the runoff flow from the watershed subbasins into the reaches. Many of these assumptions needed to be made due to data and processing constraints. The scale of the DEMs often did not permit detailed drainage (i.e., separate watersheds for every waterbody) at sites with NWI features present, requiring the fractionation schemes described earlier to apportion watershed flows to multiple waterbodies. In addition specifying data matching the more complex drainage situations (i.e., more watersheds, more reaches) would have slowed data processing and increased data storage requirements.

5.5.10 Index of Local Watershed that Impacts a Reach and Fraction of Local Watershed Impacting a Reach

The local watershed connectivity to the waterbody network reaches was determined using the watershed subbasin to reach connectivity tables (s_all and c_all, Figure 5-15) and a local watershed to WMU connectivity table (m_all, Figure 5-15) created during the delineation of the local watershed. These parameters included the index of the local watershed impacting a reach (WBNRchSrcLWSIndex) and the fraction of the local watershed impacting a reach (WBNRchSrcLWSFrac).

5.5.10.1 <u>Database Compilation for WBNRchSrcLWSIndex and WBNRchSrcLWSFrac</u>. In addition to the watershed to waterbody connectivity table (s_all) and lakes and wetlands information table (c_all) used in the previous section, a local watershed-to-WMU connectivity table (m_all) was used to determine which waterbody network reaches were impacted by the local watershed and the fraction of the local watershed impacting the reach.

5.5.10.2 <u>Database Processing for WBNRchSrcLWSIndex and WBNRchSrcLWSFrac</u>. The local watershed to WMU connectivity table gives the watershed subbasin identifier for the watershed in which the local watershed is located. In some cases, there were two local watersheds and, thus, two watershed subbasins with which they are identified. Knowing the watershed subbasin identifier for the local watershed allowed the reaches located in the same watershed subbasin to be identified using the same tables generated for the watershed connectivity to the reaches. Thus, those reaches in the same watershed as the local watershed will be impacted by the local watershed.

Due to the data structure required by the 3MRA modeling system, an array of all reaches was passed in these data. For those reaches impacted by the local watershed, the index of the local watershed impacting it was passed. All other reaches were passed with null values in WBNRchSrcLWSIndex. Similarly, the fraction of the local watershed impacting the reach receiving loads from the local watershed was assumed to be 1; for streams and lake types 1 and 2. For other lake types, reaches were assumed to be impacted by the same fraction of the local watershed as the regional watershed. Those reaches not impacted by the local watershed received a null value.

5.5.10.3 <u>Assumptions and Uncertainty for WBNRchSrcLWSIndex and WBNRchSrcLWSFrac</u>. Two assumptions were made for those reaches impacted by the local watershed. The first assumption was that all reaches in the same watershed subbasin as the local watershed were impacted by the local watershed. The second assumption was that these reaches were impacted by the same fraction of the local watershed as the regional watershed. When only one reach was in the watershed, the assumptions were always valid. If there was more than one reach in the watershed, then the assumptions may not have always been correct. For a few sites, one of the reaches may have been located to one side of the local watershed and not impacted at all by the local watershed or only partially impacted, but not by the same fraction as the watershed subbasin.

5.5.11 Number, Indices, and Fraction of Aquifers that Impact a Reach

Because site-specific data were not available for aquifers at each site, the aquifer was assumed to be similar to the local watershed, with the direction of ground water flow (AquDir) in the same direction as the overland flow away from the WMU (see Section 5.5.18). The aquifer-to-reach connectivity was, thus, assumed to be the same as the local watershed-to-reach connectivity. Related parameters included the number of aquifers impacting a reach (WBNRchNumAqu) and the index and fraction of the aquifer impacting a reach (WBNRchAquIndex, WBNRchAquFrac).

5.5.11.1 <u>Database Compilation for WBNRchNumAqu, WBNRchAquIndex, and WBNRchAquFrac</u>. The same tables (s_all, c_all, m_all) used for the local watershed connectivity were also used for the aquifer connectivity (GIS processing did not separately address aquifer data).

5.5.11.2 <u>Database Processing for WBNRchNumAqu, WBNRchAquIndex, and WBNRchAquFrac</u>. Processing similar to that used in the local watershed connectivity was used for the aquifer connectivity. Reaches located in the same watershed subbasin as the local watershed were now also impacted by the aquifer associated with the local watershed. If there were two local watersheds at a site, there were two aquifers at the site identified with the same numbers as the local watersheds. Only one aquifer and one local watershed could impact a reach, and the index of the aquifer impacting the reach is the same as that for the local watershed impacting the same reach. In the example data set, the fraction of aquifer impacting a reach was always set to one for reaches impacted by an aquifer.

5.5.11.3 <u>Assumptions and Uncertainty for WBNRchNumAqu, WBNRchAquIndex, and WBNRchAquFrac</u>. As mentioned previously, site-specific data were not readily available for aquifer flow direction, and the local watershed flow direction and the reach it impacts was used to represent the aquifer flow direction and reach connectivity at a site. This adds uncertainty to the analysis because ground water flow does not always follow topography or discharge to the nearest waterbody downslope.

5.5.12 X,Y Coordinates for Waterbodies

X,Y coordinates for the waterbodies were extracted from a GIS table of cell addresses by the GIS reach identifier, a table of cell addresses by lake number, and a GIS table of the UTM coordinates for each cell address (q_all, v_all, and g_all, Figure 5-15).

5.5.12.1 <u>Database Compilation for X,Y Coordinates for Waterbodies</u>. Two final coverages were created following the waterbody delineations representing hydrography at the site: a stream coverage and a lakes and wetlands coverage. The stream coverage was clipped at the AOI, projected to the proper UTM zone for the site, and overlaid with the site's reference UTM grid. Each stream reach was referenced by reach number and UTM reference cell address. Similarly, the lakes and wetlands coverage was projected to the UTM zone and overlaid with the reference UTM grid. The locations were passed by lake number and UTM reference grid cell address.

5.5.12.2 <u>Database Processing for X,Y Coordinates for Waterbodies</u>. The tables of cell addresses by GIS reach number and lake number were combined and indexed on the new waterbody network identifiers using the table created during construction of the network. The table was then linked to the table of UTM coordinates for each cell to make a new table of UTM coordinates by waterbody network reach. These coordinates were passed to the 3MRA modeling system in a UTM-based site coordinate system with 0,0 as the site centroid. The UTM coordinates for the site centroid were sent separately so UTM coordinates for any site feature could be calculated from the site-based data.

5.5.13 Number and Area of Watershed Subbasins

The number and area of the watershed subbasins for each site (NumWSSub, WSSubArea) were obtained from a GIS regional watershed table (a_all, Figure 5-15). The GIS table contained watershed number identifiers, the watershed code, and the area of each watershed.

5.5.13.1 <u>Database Compilation for Number and Area of Watershed Subbasins</u>. Each watershed subbasin was assigned a watershed number during delineation. The area of the subbasin was based on the total area of the polygon feature in the regional watershed coverage (see Section 5.4.4 on delineation of the regional watershed coverage). Area was based on the entire subbasin, regardless of whether a portion of the subbasin was located outside the AOI.

5.5.13.2 <u>Database Processing for Number and Area of Watershed Subbasins</u>. The number of watershed subbasins was simply a count of the number of watersheds by site from the GIS regional watershed table. The area was passed directly from the GIS table indexed on the watershed subbasin identifier.

5.5.13.3 <u>Assumptions and Uncertainty for Number and Area of Watershed Subbasins</u>.

- Areas for one-sided (B1) subbasins only contained the area within the AOI and were not intended to characterize an entire basin.
- Some watershed boundaries may have been altered to eliminate problems caused by the coarseness of the DEMs. See Section 5.7.4 for more details.

5.5.14 Watershed Subbasin Slope

The universal soil loss equation (USLE) length-slope factor (LS) accounts for the effect of sheet flow length (Section 5.5.17) and flow slope (Theta) on unit soil erosion rates. Both parameters are positively related to increased unit erosion rates. The flow length increases unit erosion rates because of the increased runoff water as flow length increases. The slope increases erosion because of higher velocities. The length-slope factor is a function of both flow length and slope. Watershed subbasin slope (Theta) was calculated using a Williams and Berndt (1976) equation:

$$S = 0.25\ Z\ (LC_{25} + LC_{50} + LC_{75})\ /\ DA \qquad (5\text{-}3)$$

where Z is the watershed height, S is the average percent slope, DA is the area of the watershed and LC_{25}, LC_{50}, and LC_{75} are the lengths of the contours at 25, 50, and 75 percent of Z.

This equation was developed from the contour-length method of determining the average percent slope for a watershed. The values for all of the parameters in the equation were obtained from a GIS watershed table (a_all, Figure 5-15).

5.5.14.1 <u>Database Compilation for Watershed Subbasin Slope</u>. An elevation grid for each watershed subbasin was created from the elevation grid for the site. Using this grid, high and low elevations were calculated and contour lines were generated for the subbasin. The contour line interval was based on the following equation:

$$\text{interval} = \frac{\text{maximum elevation - minimum elevation}}{4} \qquad (5\text{-}4)$$

The lengths of the contour lines were calculated for lines that were 25 percent, 50 percent, and 75 percent of the total elevation change in the subbasin.

5.5.14.2 <u>Database Processing for Watershed Subbasin Slope</u>. In order to obtain the slope in degrees required by the model, the following equation was used in processing:

$$\text{slope} = \arctan\left[0.25 \times (\text{maxelev} - \text{minelev}) \times (LC_{25} + LC_{50} + LC_{75}) / DA\right] \qquad (5\text{-}5)$$

where maxelev and minelev are the maximum and minimum elevations. The calculated values were sent to the system indexed on watershed subbasin.

5.5.15 Number of Local Watersheds and Local Watershed Slope

The number of local watersheds (SrcNumLWS) was obtained from a GIS local watershed elevation table (m_all, Figure 5-15) resulting from the local watershed delineation process (see Section 5.4.6). This table also includes the minimum and maximum elevations for the local watershed used in calculating the local watershed slope (Theta). In addition to using the elevations, the length from the centroid of the WMU to the top of the local watershed, up length, and the length from the centroid of the WMU to the bottom of the local watershed, down length, were used in calculating the slope of the local watershed. The up and down lengths were obtained from a GIS table of up and down lengths by site, local watershed, and WMU type (l_all, Figure 5-15). The WMU type was when one WMU at the site was much larger than the other and had two local watersheds instead of one.

5.5.15.1 <u>Database Compilation for Number of Local Watersheds and Local Watershed Slope</u>. For slope calculation in the local watershed, maximum and minimum elevations were calculated in the subregional local watershed (the L2 coverage) using the elevation grid. Using ArcView, the up and down lengths were measured from the site centroid to the top of the local watershed and to the bottom of the local watershed. For sites with two local watersheds, the local watershed that did not contain the site centroid had an up length of zero and a down length measured from the top to the bottom of the local watershed.

5.5.15.2 <u>Database Processing for Number of Local Watersheds and Local Watershed Slope</u>. The number of local watersheds was simply a count of the local watershed numbers in the local watershed elevation table (m_all) sent by GIS. The local watershed identifiers used by GIS were the watershed identifiers of the regional watersheds in which the local watersheds resided. During processing, a local watershed table was created including the site identifier, WMU type, GIS local watershed identifier, and a new renumbered local watershed identifier used to index the various local watershed parameters. The slope of the local watershed was calculated using the following equation:

$$slope = \arctan [(maxelev - minelev) / (upperlength + lowerlength)] \quad (5\text{-}6)$$

where maxelev and minelev are the maximum and minimum elevations for the local watershed, and upperlength and lowerlength are the up length and down length from l_all.

5.5.15.3 <u>Assumptions and Uncertainty for Number of Local Watersheds and Local Watershed Slope</u>. The maximum and minimum elevations for the local watershed were not the maximum and minimum elevations for the local subareas but for the area within the entire L2 coverage (see Section 5.4.6). This was necessary due to the coarseness of the DEMs used as input into the elevation model (see Section 5.7.2).

5.5.16 Number and Area of Local Watershed Subareas and Index of Subarea Containing WMU

The number of subareas (SrcLWSNumSubArea), the subarea area (SrcLWSSubAreaArea), and the index of the subarea containing the WMU (SrcLWSSubAreaIndex) were all determined using the table of up and down lengths for the local watershed and the local watershed elevation table (l_all and m_all, Figure 5-15). The up and down lengths were used to calculate the number of local watershed subareas and the area of each subarea.

5.5.16.1 <u>Database Compilation for SrcLWSNumSubArea, SrcLWSSubAreaArea, and SrcLWSSubAreaIndex</u>. Measurement of the up and down lengths and local watershed elevations are described in Section 5.5.15.

5.5.16.2 <u>Database Processing for SrcLWSNumSubArea, SrcLWSSubAreaArea, and SrcLWSSubAreaIndex</u>. To calculate the number of subareas and the subarea areas, the WMU was assumed to be a square. The number of subareas in each local watershed for waste piles and LAUs only was determined using the following criteria:

up length > ½ square root of the WMU area: 3 subareas
up length < ½ square root of the WMU area: 2 subareas.

After the number of subareas for waste piles and LAUs was determined, the index of the subarea containing the WMU also was known, as follows:

3 subareas: WMU is in subarea 2
2 subareas: WMU is in subarea 1.

The area of each subarea was calculated based on the number of subareas in each local watershed using the following equations:

3 subareas

$$Area(1) = (up\ length - ½\ SQRTArea) \times SQRTArea \quad (5\text{-}7)$$

Area(2) = Area
Area(3) = (down length - ½ SQRTArea) × SQRTArea
If Area(3) ≤ 0 then Area(3) = 30.5 × SQRTArea

2 subareas

Area(1) = Area (5-8)
Area(2) = (down length - ½ SQRTArea) × SQRTArea
If Area(2) ≤ 0 then Area(2) = 30.5 × SQRTArea

where Area is the area of the WMU in each local watershed provided in the local watershed elevation table and Area(1), Area(2), and Area(3) are the areas of the local watershed subareas. If the WMU was at the bottom of the local watershed, a buffer of 100 ft (30.5 m) was created between the WMU and the waterbody into which the local watershed emptied.

Because the aerated tank, landfill, and surface impoundment WMU types were not required to have multiple subareas, the values for these parameters were independent of the up and down lengths. For these WMU types, the number of subareas for each local watershed was set at 1, the subarea area was set equal to the area of the WMU in each local watershed, and the index of the subarea containing the WMU was set at 1.

5.5.16.3 Assumptions and Uncertainty for SrcLWSNumSubArea, SrcLWSSubAreaArea, and SrcLWSSubAreaIndex. Because the shape and orientation of the actual WMU was not known and to make subarea calculations easier, the WMU was assumed to be a square oriented along the direction of overland flow.

5.5.17 Flow Length

The flow lengths (X) used for both the local watershed subareas and the regional watershed subbasin were default slope lengths developed by Lightle and Weesies (1996) based on professional experience. These default slope lengths were necessary because waterbody and watershed resolution resulted in unreasonably long sheet flow lengths (and excessive USLE length-slope factors) when flow length was calculated from watershed dimensions using the method of Williams and Berndt (1976). For each watershed or local watershed subarea, the default lengths are based on average watershed slope (Table 5-8), and appear reasonable when compared with the range of tabulated values provided in USDA (1976).

5.5.17.1 Database Compilation for Flow Length. A table of default flow length values by slope (Table 5-8) was hand-entered into the database. In order to get more variation in flow length, a uniform distribution between ± 20 percent of the default length in Table 5-8 was used. These values also were converted into m in the database.

5.5.17.2 Database Processing for Flow Length. The slopes for the local watersheds and regional watershed subbasins were used to extract the corresponding default flow lengths from the table. Because the slopes were not all integers, they were rounded to the nearest integer value. Slopes less than 0.5 percent were given the flow length for 0.5 percent and slopes of greater than 24 percent were given the flow length for 24 percent.

5.5.17.3 <u>Assumptions and Uncertainty for Flow Length</u>. As previously mentioned, the waterbody resolution made it difficult to get a reasonable sheet flow length value based on GIS measurements, so a default value corresponding to the slope was used instead. Also, because the local watershed slope value was not available by subarea, the same flow length was sent for each subarea in the local watershed.

Table 5-8. Default Flow Lengths, by Slope (Lightle and Weesies, 1996)

Slope (percent)	Length (ft)
≤ 0.5	100
1	200
2	300
3	200
4	180
5	160
6	150
7	140
8	130
9	125
10	120
11	110
12	100
13	90
14	80
15	70
16	60
17	60
18	50
19	50
20	50
21	50
22	50
23	50
≥ 24	50

5.5.18 Ground Water Flow Direction

Because no site-based ground water flow direction (AquDir) data were available, ground water was assumed to flow in the same direction as surface water in the local watershed. The direction of the surface water drainage in the local watershed was obtained using the DEMs in the local watershed.

5.5.18.1 <u>Database Compilation for Ground Water Flow Direction</u>. Using the composite elevation grid as a base, an average aspect of the L2 coverage (see Section 5.4.6) was taken, giving a slope for the drainage in the local watershed. Because of the coarseness of the DEMs, the average aspect was checked to ensure that the direction was reasonable within the context of the other coverages available. If the direction was not reasonable, the local watershed was rotated, and a new flow direction was taken. A flow direction table (k_all, Figure 5-15) listed the flow directions by site, WMU type and local watershed.

5.5.18.2 <u>Database Processing for Ground Water Flow Direction</u>. The ground water flow direction was obtained directly from the GIS table of flow directions for each site, WMU, and local watershed and indexed on the number of local watersheds at the site. The number of aquifers at the site was assumed to be equivalent to the number of local watersheds.

5.5.18.3 <u>Assumptions and Uncertainty for Ground Water Flow Direction</u>. As mentioned previously, ground water was assumed to flow in the same direction as surface water runoff in the local watershed at every site, which is not always the case. An additional uncertainty is the coarseness of the DEMs in relation to the relatively small local watersheds, which made the flow directions difficult to obtain (see Section 5.7.2 for more detail).

5.5.19 X,Y Coordinates for Watersheds

The x,y coordinates for the regional watershed subbasins were passed using a GIS table of cell addresses by site and GIS watershed identifier and a GIS table of the UTM coordinates for each cell address (x_all and g_all, Figure 5-15).

5.5.19.1 <u>Database Compilation for X,Y Coordinates for Watersheds</u>. The regional watershed coverage was projected into UTM coordinates (see Section 5.4.2) and overlaid with the UTM reference grid for the site (see Section 5.4.7). The grid cell addresses were passed by watershed number and site.

5.5.19.2 <u>Database Processing for X,Y UTM Coordinates for Watersheds</u>. The table of cell addresses by watershed number was combined with the table of UTM coordinates for each grid cell address to produce a table of coordinates for each watershed subbasin at every site. These coordinates were passed to the 3MRA modeling system in a UTM-based site coordinate system with 0,0 as the site centroid. The UTM coordinates for the site centroid were sent separately so UTM coordinates for any site feature could be calculated from the site-based data.

5.6 Quality Assurance and Quality Control

To ensure correct data output, the watershed and waterbody data went through numerous quality control (QC) measures, both automated and manual. First, each site was checked to ensure that watersheds and waterbodies were delineated according to the general rules, as outlined in Section 5.4, and then all the output data were checked for accuracy after the database processing was complete. All QC activities were performed before any of the outputs from the watershed and waterbody delineations were used for any other data collection. Database processing of the GIS data into the 3MRA modeling system format was further checked before sending the data to be used for modeling.

5.6.1 GIS Procedures

After the manual steps were completed (through step 6, Section 5.4.6) and the stream connectivity tables were created for a site, another GIS staff member visually examined the site and ran an interactive macro to see if it was done correctly. The following was checked:

- If watersheds were correctly delineated.
- If waterbodies were correctly delineated.
- If all watershed numbers were in sequential order beginning with 1.
- If all watershed numbers were referenced in the reach-to-subbasin connectivity table.
- If all the reach numbers were referenced in the reach-to-subbasin table and in the reach-to-reach table.

- If reach connectivity was correct.
- If the lake type was correctly entered (see Section 5.5.9.1 for details of lake type).
- If RF3RCHID was assigned to wide rivers.
- If local watershed delineation was performed correctly.
- If the local watershed was referenced to the correct regional watershed in the connectivity tables.

Other procedures were performed at different times during the process to ensure data quality. The other checks included the following:

- If GIS post manual processing had been completed in the proper order.
- If all reaches in the AOI were included in the reach location table (see Section 5.5.12).
- If the reference UTM grid for the site was projected to the correct UTM coordinates for a site (see Section 5.4.2).
- If all x,y coordinates for the local watershed, regional watershed, AOI, and WMUs were in the correct locations.

5.6.2 Database Procedures

After the waterbody and watershed data were received from GIS, a combination of manual and automatic QC checks were performed. Because the waterbody layout data were highly variable by site, all data were checked before final processing. The watershed data were more straightforward and consistent and, thus, only about 10 percent of the data were checked.

The waterbody layout data were processed only enough to generate the waterbody layout data that were sent to the 3MRA modeling system. These data (all of the waterbody parameters in Table 5-1) were then manually checked, using maps generated during the delineations, to ensure that the data accurately represented what existed at the site. If delineation problems were found, the sites were returned to GIS for redelineation. If minor problems were discovered, they were corrected manually in the GIS tables and run through the database processing again to ensure that the problems had been corrected. Database-processed watershed layout data for approximately 10 percent of the sites were checked manually. The x,y coordinates for 10 percent of the sites were checked using ArcView to plot the coordinates and visually compare the results to the delineation maps.

All final database-processed data were run through a series of automatic QC queries in Microsoft Access. These queries checked that the maximum and minimum values for each parameter had not been violated, that there were no duplicate rows in the data, that the UTM coordinates were centered around the site centroid, that for each local watershed at every site there were the correct number of subareas, and that the number of indices for a parameter agreed with the number values sent for that index.

5.6.3 Quality Assurance

Quality assurance (QA) was performed to ensure that adequate QC was performed and records of all QC were kept. QA/QC records for the watershed and waterbody layout data were reviewed and are maintained in hardcopy format.

5.7 Assumptions and Uncertainties

Significant assumptions and uncertainties associated with data collection for individual variables were described by variable in Section 5.6. Some more overarching uncertainties include inconsistencies in scale for several data sources, the resolution of the DEM data with respect to the AOI, data gaps from incomplete or inconsistent coverages in NWI and RF3 data, and site-to-site methodology differences necessitated by variability in both data and site characteristics. These uncertainties are discussed in the following sections.

5.7.1 Scale of Waterbody Data Layers

One of the uncertainties in the waterbody data collection effort is the use of different scale data to delineate both watersheds and waterbodies, as follows:

- DEM-generated streams were used to model streams at most sites (132). These were created from 1:250,000 scale DEMs. In another 69 sites, however, RF3-Alpha and Pacific Northwest Reach Files were used. These files have a nominal scale of 1:100,000.

- The three different lakes and wetlands coverages (NWI, RF3, GIRAS) used in the study had different scales (1:24,000, 1:100,000, 1:250,000) but were used interchangeably in most cases.

Ramifications of these differences and remedial measures taken include the following:

- The insertion of NWI, GIRAS, and RF3-Alpha lakes and wetlands features into the DEM stream network often caused spatial mismatches because of scale and/or registration differences. Often, for instance, lakes connected to RF3-Alpha streams did not connect to corresponding DEM-generated streams. Manual manipulation (e.g., moving a lake to connect to the DEM stream) was necessary to rectify such mismatches.

- NWI, at a larger scale (1:24,000) than either GIRAS or RF3-Alpha, often had many more wetland features. Thus, sites without NWI coverage were biased low in terms of number of wetlands.

- Numerous, detailed NWI features posed challenges with respect to the overall scale and detail of the 3MRA modeling system (e.g., as reflected by the 100- x

100-m grid resolution) and required manual manipulation. For example, small, adjacent features were combined and small (less than 20,000 m^2) isolated features were not included in the waterbody coverage.

- GIRAS and RF3 wetlands do not have the detailed identifiers that NWI features have. Thus, it is possible that some GIRAS and RF3 wetlands were included in the waterbody network that would not have been included if NWI coverages and descriptors had been available.

5.7.2 Scale of the DEM

One to 250,000 scale DEM were used because 1:24,000 scale coverages are not yet available for the entire United States. This created a number of scale-related problems for the analysis that can be rectified once higher resolution data are available.

The DEM-generated stream model sometimes did not match well with the RF3-Alpha data set. Generally the more relief that existed at the site, the better the match between the DEM-generated and RF3 waterbody networks. For flatter sites, the software often did a poor job of following RF3-Alpha streams creating cases of bowling alley or parallel streams and of streams that crossed perpendicular to RF3-Alpha streams, necessitating manual delineation at many sites. The matching problem could be partially attributed to scale because 1:250,000 scale DEMs were used with a 1:100,000 RF3 stream network, which limits the detail that can be attained with a DEM, even when the DEM is conditioned to mimic the vector RF3-Alpha coverage.

All elevations represent an average elevation value in the 100-by-100-m grid cell of the DEM. Because the DEM elevations were so coarse and the features of certain local watersheds (i.e., those for small WMUs) were so small in comparison, an intermediate local watershed coverage (L2) was created using the DEMs. From this L2 coverage the actual local watershed was created geometrically using data out of the L2 coverage (see Section 5.4.6). Because the DEMs defined the L2 coverage and not the actual local watershed, the elevations for the L2 coverage were used for the local watershed.

5.7.3 Different Watershed Delineation Methods

Two different methods of delineating watershed subbasins were used to create the representative national data set; a manual and a semiautomated DEM delineation. This probably created some site-to-site variability in delineation criteria, although the number and resolution (number and size) of watersheds and waterbodies was generally similar from DEM- and hand-delineated sites.

5.7.4 Manual Processing of Data

Both the DEM and manual delineation methods involved some manual interaction, and manual data processing can be inconsistent. A watershed subbasin delineated by one person would not necessarily look exactly like another person's version. Choices such as pour point locations or what lake and wetland features to include can result in slightly different outcomes.

To minimize this variability an informal guide was developed and updated and the QC measures described in Section 5.6 were developed to limit inconsistencies; however, any duplication of the process would encounter slightly different results based on choices made in the manual process.

Some of the choices that were addressed in the guide and checked during QC include, for DEM-delineated watershed subbasins:

- Deleting overlapping areas of different watershed subbasins.
- Locating basin pour points.
- Altering DEM-generated subbasin boundaries in order to accommodate lakes and wetlands.
- Moving, deleting, or extending subbasin boundaries to solve problems such as fitting a lake in one watershed, or eliminating very small or bowling alley watersheds.

For waterbodies at both manual and DEM-delineated sites, choices included:

- Deciding which waterbodies to keep in the lakes and wetlands coverage, for instance, when wetland features along the AOI boundary can be deleted to simplify the site delineation.
- Merging wetland features to simplify delineation at a site involved moving the arcs from one feature to overlap another feature, deleting overlapping arcs, and deleting duplicate label points. Wetlands could differ in size, shape, or feature codes based on how the delineator performed this step.
- Moving waterbodies to fit within the DEM-delineated subbasins.

Although each of these actions was necessary to accommodate differences in scale and resolution for the source data sets, and was appropriate in the context of a national analysis, professional judgment was involved that could lead to some inconsistencies. However, the QC measures minimized the inconsistencies.

5.7.5 Incomplete National Wetlands Inventory

The NWI data layer used in the representative national data set is only partially complete for the United States. As available (in 1999), NWI was used as the default data layer for lakes and wetlands. Only half (100) of the 201 sites had NWI, however. Sites without NWI coverage were covered (in much less detail) by GIRAS and RF3. As NWI data become available for additional sites, this could change results of the analysis by adding additional aquatic habitats to some sites, an uncertainty that is most significant for ecological receptors.

5.7.6 Anthropogenically Altered Drainage

Anthropogenically altered stream networks were difficult to model with DEM-generated subbasins, the Surface Water Module, and the 3MRA modeling system site layout. These networks include urban drainage that has been diverted into underground culverts, and agricultural drainage by irrigation canals and ditches. For example, canals would split than rejoin as well as terminate on the GIS coverage as they enter underground drainage systems, and neither case can be modeled in the 3MRA modeling system. Most of these sites were manually delineated, with drainage networks modified as necessary to accommodate the 3MRA modeling system requirements.

5.7.7 Missing Reach Type in Pacific Northwest Reach Files

As mentioned in Section 5.4.2 the Pacific Northwest Reach Files were processed differently than the RF3-Alpha Reach Files. Notably, there was no REACHTYPE attribute in the Pacific Northwest files and a REACHTYPE of L was assigned to all lake and wetland features, making all nonstream reaches lakes. Only seven of the 201 sites are in the PNW region, so only lakes and wetlands at those sites were impacted.

5.8 References

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