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# Introduction to Stream Reaches

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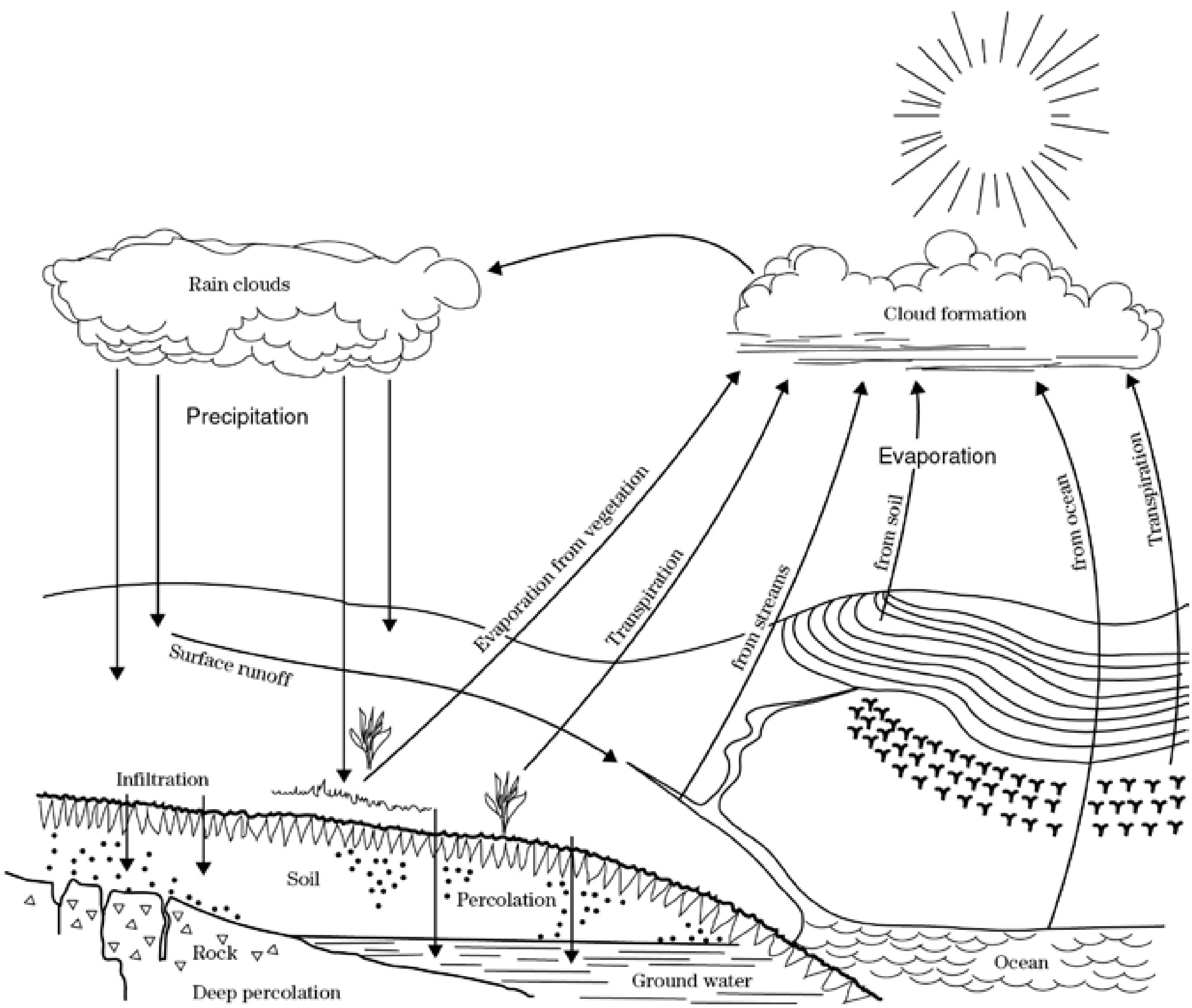
# Chapter 6 Stream Reaches and Hydrologic Units



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Additional reviews and comments were provided by **Ruth Book**, state conservation engineer, NRCS, Champaign, IL; **Thomas Bourdon**, (retired); **Scott Gong**, design engineer, NRCS, Jackson, MS; **Annette Humpal**, hydraulic engineer, NRCS, Appleton, WI; **William Merkel**, hydraulic engineer, NRCS, Beltsville, MD; **Helen Fox Moody**, hydraulic engineer, NRCS, Beltsville, MD; **Quan D. Quan**, hydraulic engineer, NRCS, Beltsville, MD; **Arlis Plummer**, hydraulic engineer, NRCS, Lincoln, NE: **Ed Radatz**, hydraulic engineer, Salina, KS; **Nick Reynolds**, design engineer, NRCS, Bismarck, ND; **Tim Ridley**, hydraulic engineer, NRCS, Morgantown, WV; **Chris Ritz**, hydraulic engineer, NRCS, Indianapolis, IN; **Jacob Robison**, civil engineer, NRCS, Lincoln, NE; **Terri Ruch**; state conservation engineer, NRCS, Raleigh, NC; **Barry Rankin** (retired); **Jim Stafford**, hydraulic engineer, NRCS, Bowling Green, OH; and **Barry Southerland**, fluvial geomorphologist, NRCS, Portland, OR.

The Technical Publications Team, **Wendy Pierce**, illustrator, and **Suzi Self,** editorial assistant, NRCS, Fort Worth, TX, prepared the document for publication.

# Chapter 6 Stream Reaches and Hydrologic Units

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## 630.0600 Introduction

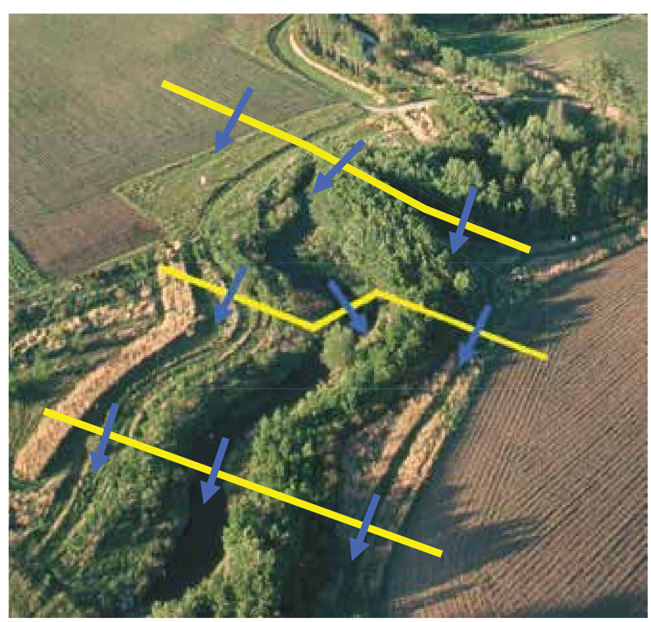
The stream system of a watershed is divided into reaches, and the watershed into hydrologic units (HU), for the convenience of work as a part of a hydrologic or hydraulic study. This chapter provides some details on the selection of reaches for hydrologic or economic studies, presents alternative means for studies of alluvial fans, and briefly describes a hydrologic unit and its use in a study.

## 630.0601 Reaches

A reach is a length of stream or valley used as a unit of study. It contains a specified feature that is either fairly uniform throughout, such as hydraulic/geomorphic characteristics or flood damages, or that requires special attention in the study, such as a bridge. Reaches are generally shorter for hydraulic studies than for other types of studies, so it is best to consider hydraulic needs first when selecting reaches and then combine the hydraulic reaches into longer ones for the other studies.

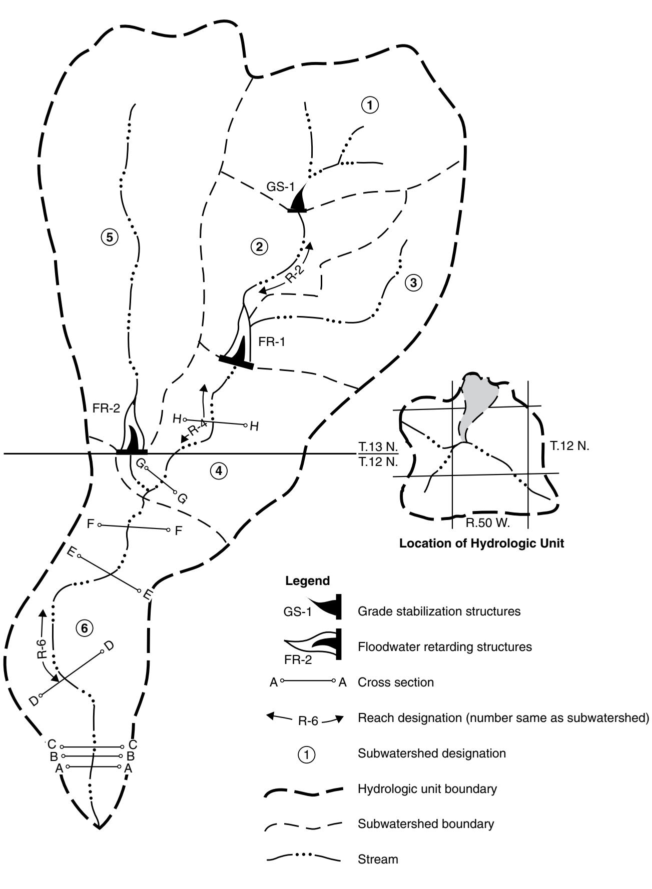
Reaches are physically defined throughout their length and at each end by cross sections that usually extend across the valley and include the channel section as well as a significant portion of the flood plain. The section should include enough of the flood plain to extend beyond whatever flood limits the engineer expects to impact the study. A cross section is both straight and perpendicular to the major path of flow in the valley, or it is a connected series of segments each of which are perpendicular to the flows in their vicinity. An example is shown in figure 6–1.

**Figure 6–1** Example cross sections oriented perpendicular to flow direction



The head and foot of a reach are the upstream and downstream ends respectively. In some studies, the head is referred to as the top and the foot is referred to as the bottom of the reach. Right bank and left bank are generally designated looking downstream. For reference, reaches and cross sections are identified numerically or alphabetically in a simple and consistent way, such as the example shown in figure 6–2 and table 6–1. If a computer program is used, the numbering follows the system specified in the program. For example, the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center—River Analysis System (HEC–RAS) computer program numbers the river stations starting at the downstream end so that river stations increase in the upstream direction.

**Figure 6–2** Hydrologic unit sample watershed having detail for use as a sample watershed




The use of geographical information system (GIS) packages can greatly facilitate watershed visualization and assessment. Figure 6–3 provides an example of an initial watershed evaluation. This figure was generated using Esri® ArcGIS, ArcInfo, and ArcScene. Hydrologic characteristics were generated using the USACE's HEC-Geographical Hydrologic Modeling System (HEC-GeoHMS). The watershed illustrated in this figure is based on real topography. The grade stabilization structure and floodwater retarding structures are not actual structures, but are used in this hypothetical example to illustrate cross-sectional and reach placement. In an actual study, as the study progresses, the illustration would be modified to show subareas terminating at the structures.

Global positioning systems (GPS) are both highly useful and commonly used tools for identifying specific reach locations and applying attributes. Systems vary significantly from engineering grade systems, such as real time kinematic (RTK) surveying units, to basic units designed to navigate within several meters of a reference or a desired way-point (a reference point in physical space). GPS use and applications combined with AutoCAD, GIS and other software tools can provide robust utility and analyses.

The purpose of the study or analysis under consideration determines which relationships of the reach must be developed from cross section information. For a hydrologic study, the required relationships include those of stage and discharge, Title 210, National Engineering Handbook (NEH), Part 630, Chapter 14, stage and end-area (210–NEH, Part 630, Chapter 17). If the work is environmental restoration, habitat or fluvial geomorphic characteristics should be utilized (210–NEH, Part 654). For an economic study, the relationships are stage and discharge, stage and area-inundated (210–NEH, Part 630, Chapter 13), and stage and damage, National Resource Economics Handbook (NREH), Part 611, Water Resources.

## (a) Location

The head and foot of a reach are typically selected to be at or near one of the following types of locations on a stream:

- Boundary of an agricultural area having flood damages.

**Table 6–1** Reach and cross section data

(Example for a portion of the sample watershed shown in figure 6–2)

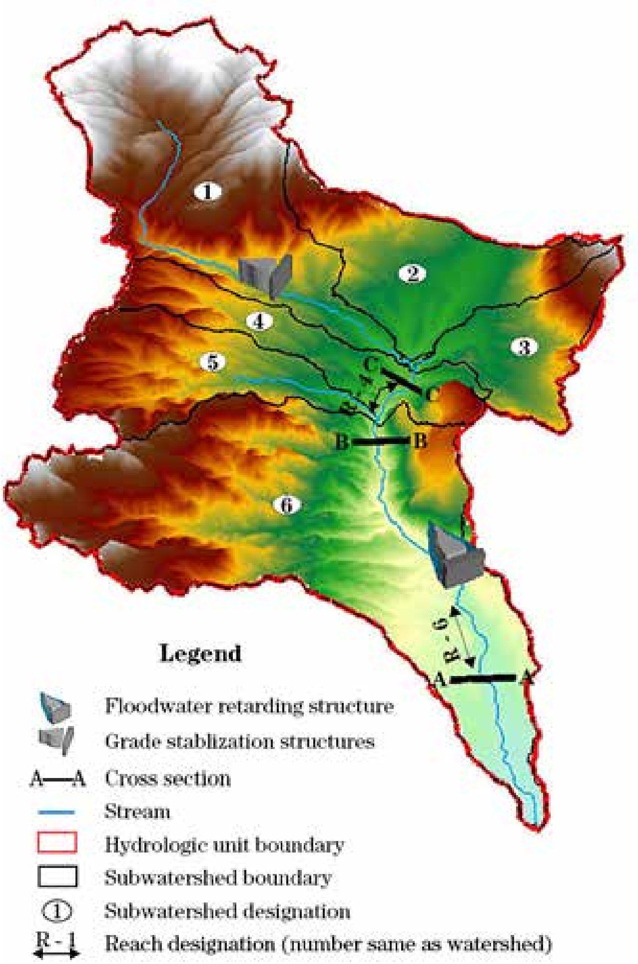
| Reach number [1] | Cross section number [2] | Cross section stationing | Length of reach [3] (ft) | Travel time [4] (h) | Accumulated drainage area ($mi^2$) | Runoff curve number [5] | |
|---|---|---|---|---|---|---|---|
| | | | | | | Present | Future |
| 4 | | | 7,500 | 0.6 | | 80 | 78 |
| | FR–1 | 2231+00 | | | 3.6 [6] | | |
| | HH | 2192+00 | | | 4.0 [7] | | |
| | GG | 2160+00 | | | 4.4 [8] | | |
| 6 | | | 15,600 | 1.5 | | 80 | 78 |
| | FF | 2138+00 | | | 7.5 | | |
| | EE | 2100+00 | | | 8.0 | | |
| | DD | 2054+00 | | | 8.4 | | |
| | CC | 2016+00 | | | 8.8 | | |
| | BB | 2014+00 | | | 8.8 | | |
| | AA | 2012+00 | | | 8.9[8] | | |

**Notes:**

1. For this example, reach number is same as subwatershed number. However, in many studies, the reach number and subwatershed number do not correspond
2. Designation on mapping. May be based on previous studies.
3. Channel length of reach.
4. Travel time of a 2-year frequency flow through the reach.
5. Runoff curve numbers for the total area above the foot of the reach. They were obtained by weighting (210–NEH Part 630 chapter 10).
6. Drainage area at the head of the reach.
7. The drainage area at this cross section was estimated.
8. Use drainage area at the foot of the reach if the cross section is located at or near the lower boundary crossing of the stream.

- Boundary where agricultural damages change significantly.
- Boundary of an urban area or any other area of high potential flood damage for which levees or other local protective works may be proposed.
- Junction of a major tributary and the main stream.
- Station where streamflow is gaged.
- Hydraulic control feature, such as a bridge, weir, culvert, low-flow stream crossing, or natural features such as bedrock or large boulder control.
- Existing or proposed site for a floodwater-retarding or other structure.
- Section where shape or hydraulic characteristics of the channel or valley change greatly.
- Section where channel control creates large storage upstream.
- Major political boundaries.
- Point of diversion.
- Change in geomorphic channel type.
- Change in channel evolution stage.
- Change in aquatic or riparian habitat.
- Change in ecosystem classification (such as perfect functioning condition (PFC) or stream visual assessment protocol (SVAP) reach designations).

**Figure 6–3** Hydrologic map developed using ArcGIS software




In selecting reaches, the method of computing water surface profiles may specify a maximum or a minimum length of reach. Some hydraulic models, such as HEC–RAS have a user defined capability to interpolate sections as specified intervals between specified sections or along an entire reach. However, even these programs have limitations that must be observed.

Reach locations are selected by the engineer and others on the evaluation or planning team. Tentative locations are selected during the preliminary watershed investigation (NEH, Part 630, Chapter 3) and shown on a base map, aerial photograph or identified on a GIS data layer. Low altitude aerial reconnaissance may be necessary for locating reaches in watersheds without access roads or where timber, brush, or cultivated crops obstruct vision at the ground level. If flood damage studies will be made, floodplain areas with potentially high damage are also located and shown. If environmental restoration studies are the objective, critical habitat or representative reference conditions may be identified. A map or georeferenced photographs may also be later used for identifying the reaches that need most attention in the studies.

Once the relative importance of the reaches is known, the engineer selects the locations of cross sections and determines whether the information requires field surveys or can be obtained from remotely-sensed data such as Light Detection and Ranging (LiDAR) and other available digital elevation models (DEM).

## (b) Measurement

In selecting cross section locations for hydraulic modeling, it is important to understand how the model applies the cross section information. Whether the cross section represents the upstream reach, downstream reach, or average reach condition can effect cross section location and application of reach characteristic data.

Each cross section should define the changes in ground elevation along a line perpendicular to the channel flow path. The cross section itself should include the channel and floodplain shape with distance and elevation measurements along a line perpendicular to the channel (and approximate floodplain) flow paths. Manning's $n$ must be estimated for hydraulic computations for each reach and must represent roughness conditions for the portion of the reach between two adjacent cross sections. If a cross section is divided into segments, the $n$ for each segment applies to a strip through the portion of the reach between the adjacent cross sections.

## (c) Length

The length of a reach is the distance between cross sections at the head and foot. In general, the minimum length of a reach is typically 10 times the approximate bankfull width, but it can be much larger. The measurement is taken between the approximate centroid of the cross sectional flow area at the target flow in the cross section. It can follow along the sinuous path of flow in the channel if in-channel flows are being modeled or straighter at higher flows. The channel is nearly always longer than the valley so in some cases two or more lengths may be applied in a study. For example:

- Low flow length—the channel length represents the flow length when the flow is relatively low (within the channel banks).
- High flow length—the valley length represents the shortened flow length over the floodplain.

The reach length often becomes shorter when flow spills into the overbank floodplain. This effect is taken into account when computing water-surface profiles (210–NEH, Part 630, Chapter 14) and flood damages (210–NEH, Part 630 Chapter 13). Because flow paths are often complex and not easily determined in the field, reach lengths are generally determined using aerial photography, a detailed topographic map, or GIS. The left and right overbank floodplain lengths between cross sections can be adjusted after initial computer analysis delineates flood boundaries either by hand or on a GIS terrain model.

## (d) Profile

The profile is the elevation of the reach invert as defined by distance from a point, and defines the steepness of the reach. Profiles represent channel bottom, water surface, floodplain, top of bank, or any other consistent feature along the study reach. Profiles also provide a common datum by which to reference a computation of water-surface profiles by the standard step method, usually computed using a computer program such as HEC–RAS.

## (e) Hydraulic roughness

Estimates of hydraulic roughness (Manning's $n$) are made by the procedure given in 210–NEH Part 630, Chapter 14 or an equivalent procedure. Publications such as 210–NEH, Part 654; Barnes (1967); Arcement and Schneider (1989); and Fasken (1963) provide more information on Manning's $n$ and its variations in natural channels.

## (f) Reach data input for computer programs

Software user manuals generally describe the limitations on the input data, such as length of reach and number of elements in a cross section. Users should keep these limitations in mind when working instructions are given to the survey crew or creating cross sections from remotely-sensed data such as LIDAR.

## (g) National geospatial data for stream reaches

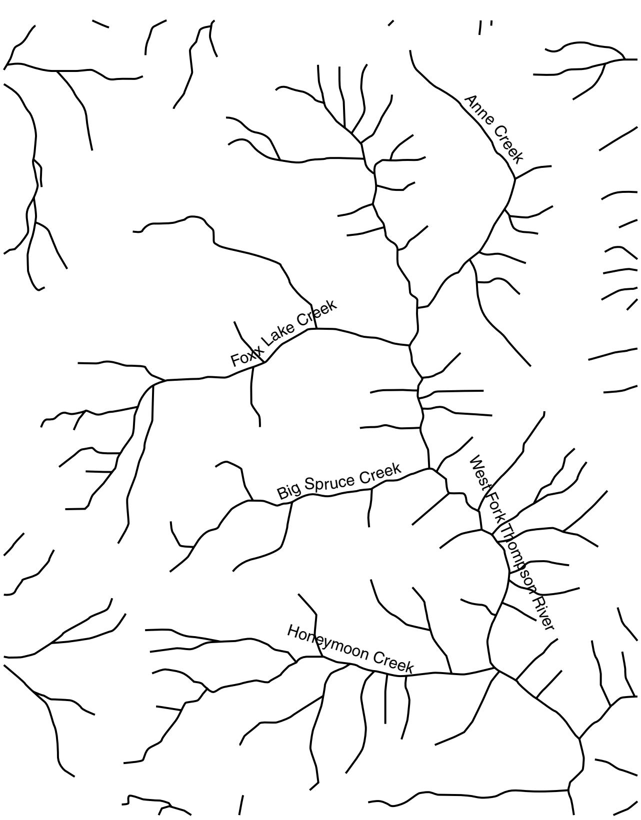
The United States Geological Survey (USGS) and other Federal agencies cooperated to develop the national hydrography dataset (NHD) of the United States and provide the data for geospatial analyses. The stream locations and associated data attributes are available at the Web site: *http://www.horizon-systems.com/*

NHDPlus. Each stream reach is assigned an identification number.

In addition to location of stream reaches, there are various tools available to organize and analyze stream reach data. A national system of organizing and numbering streams of different sizes assists with interagency coordination, data collection, and data organization. Geospatial locations of the stream reaches represent a significant amount of effort and add value to the database. Locations are official and provide for consistency among Federal, state, and local agencies and others doing water-related and land management studies and projects.

A sample map of stream locations from the NHD is shown in figure 6–4.

**Figure 6–4** Sample map with stream locations from NHD




## 630.0602 Project Benefits Estimation on Alluvial Fans

Alluvial fans, also called debris slopes or fans, are sediment depositional areas formed where the channel grade is reduced as the stream enters an area of gentler slope, such as the valley of another stream. Large fans may be inhabited or have agricultural use.

Stream and river paths through alluvial fans are often dynamic. Braided streams can be prevalent. Single thread reaches can be prone to sudden movement (avulsions) during moderate and large storm events. Since the paths of flood flows in alluvial fans may shift from one side of a fan to another, the selection of reaches can be generally useless. In this case, a special method for project evaluation must be adopted which relates floodwater damages on alluvial fans to actual or estimated runoff volumes. These can be referenced to an upstream cross section above the fan, such as a stream gage or other control section. The evaluation of flood damages are:

*Step 1:* Obtain information about the monetary value of damages for each known flood on the fan from interviews and historical sources.

*Step 2:* Determine the volume of flood runoff for each flood from streamflow records or estimate by use of rainfall and watershed data and methods introduced in 210–NEH, Part 630, Chapter 10.

*Step 3:* Develop the relation between flood runoff and damages (200–NREH, Part 611).

*Step 4:* Estimate the frequencies of flood-runoff amounts (210–NEH, Part 630, Chapter 18).

*Step 5:* Develop a damage-frequency curve (200–NREH, Part 611).

*Step 6:* Determine the average annual damage (200–NREH, Part 611).

*Step 7:* Analyze the effects of a proposed upstream project on the runoff amounts. The runoff amounts (and therefore the flood damages) decrease when changes in land use and treatment decrease the runoff curve number (210–NEH, Part 630, Chapter 10) or when storage structures or increased upstream channel storage reduce flood flows (210–NEH, Part 630, Chapter 17).

*Step 8:* Use the runoff-damage relation of step 3 with the reduced runoffs of step 7 to estimate remaining damages.

*Step 9:* Develop a modified damage-frequency curve and plot on the graph used in step 5.

*Step 10:* Calculate the difference between the present and the future damage-frequency curves as shown in 200–NREH, Part 611, and estimate the project benefits.

## 630.0603 Hydrologic units

When a large watershed or a river basin is studied, the watershed or basin should be divided into subareas or subwatersheds (HUs). Analysis is simplified by then evaluating individual hydrologic units and routing results together in an incremental pattern as flow moves downstream.

A HU may also be used as a sample watershed, meaning project costs and benefits within a selected HU are evaluated in detail and afterward applied to other similar HUs for which no internal evaluation is made. The data in the sample evaluation reach or HU can be expressed as units per mile of reach or per square mile of HU. Transfer of evaluation to another similar reach or HU can then be accomplished by simply multiplying the unit values by stream miles or square miles for the HU of interest. The small watershed in figure 6–2 has enough detail for a sample watershed.

Each HU is the drainage area of a minor tributary flowing into the main stream or a major tributary. Areas between minor tributaries are combined and also used as HU. Cross sections and reaches are typically needed only when the HU is a sample watershed. Storms in the historical or frequency series (210–NEH, Part 630, Chapter 18) are assigned and/or developed on the HU basis, as are runoff curve numbers and hydrographs. Hydrographs for present, and with future land use and treatment conditions, are developed for an entire HU with reference to its outlet (210–NEH, Part 630, Chapter 16).

If the HU contains structural measures that affect the peak flow rate and/or timing of a hydrograph, the changes are determined by methods of routing (210–NEH, Part 630, Chapter 17) and the modified hydrograph, like the others, is referenced to the HU outlet. The watershed or basin flood routing is carried out on the major tributaries and mainstream, with the upstream HU supplying the starting and local inflow hydrographs.

It is often useful to determine the stream reaches in a watershed network having common attributes. These attributes can include common soil map units, groundwater characteristics, channel and floodplain geometries, or plant communities. Within these reaches, similar conservation practices may be appropriate that are not appropriate for reaches that have different discharges, channel sizes, or soil types. One of the most common methods for defining reaches within a single watershed network is through the use of the Strahler Stream Order system. In this system, reaches are assigned a stream order beginning with first order for headwater reaches. Stream order increases when reaches of an equal or higher order join. Stream order does not change when a lower order reach joins a higher order reach. First order streams begin at the point where surface runoff discharges are great enough to form a definable channel and associated floodplain. The watershed size required for the formation of first order reaches varies with climate, geology, and other factors. A map showing stream reaches designated by stream order can be readily developed using GIS Spatial Analyst tools if digital elevation data are available. The Strahler Stream Order system is illustrated in figure 6–5. More information on this system and stream classification in general is available in 210–NEH, Part 654.

The USGS, NRCS, and other Federal agencies cooperated to develop hydrologic unit maps of the United States and provide the data for geospatial analyses. The largest hydrologic units are major river basins. These are then divided into smaller and smaller units. Hydrologic units are organized at six levels. These are represented with 2-, 4-, 6-, 8-, 10- and 12-digit numbers called hydrologic unit codes (HUC). Each 2-digit HUC is divided into a number of 4-digit HUCs. Each 4-digit HUC is divided into a number of 6-digit HUC, etc. The boundaries and database of attributes of the hydrologic units are available at the Web site: *http://water.usgs.gov/GIS/huc.html*

A national system of organizing and numbering watersheds of different sizes assists with interagency coordination, data collection, and data organization. Geospatial boundaries of the hydrologic units represent a significant amount of effort and add value to the database. Boundaries are official and provide for consistency among Federal, State, local agencies, and others doing water related and land management studies and projects. Geospatial hydrologic unit maps are also useful when developing map displays for project reports and public presentations.

Even though a watershed being studied does not precisely match a HU with a particular number of digits, the HU map could provide a part of the watershed boundary and data linked to the HUC in which the watershed is located. A sample map of 12-digit HU with respective stream locations from the NHD is shown in figure 6–6.

**Figure 6–5** Strahler Stream Order system

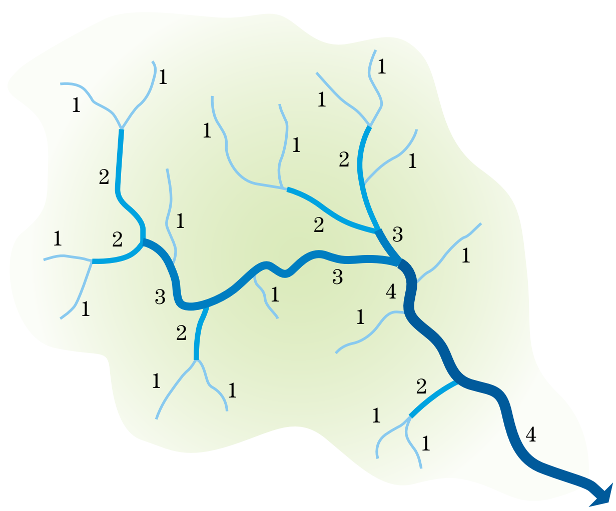
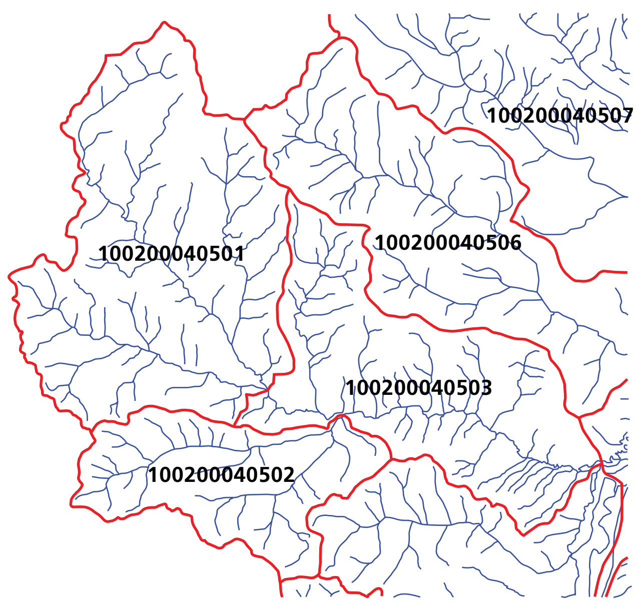


**Figure 6–6** Sample small watershed from Montana illustrating stream locations and HU from the NHD



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