

**Forest Service Handbook
National Headquarters – Washington Office
Washington, DC**

**Forest Service Handbook 7709.56b – Transportation Structures Handbook
Chapter 50 - Hydrology and Geomorphology**

Amendment: 7709.56b-2014-1

Effective date: November 24, 2014

Duration: This amendment is effective until superseded or removed.

Superseded Directive: 7709.56b,contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b, 0 Code Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b, 0 Code, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b, 1 Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b,1 Amendment, 7709.56b-94-1, July 27, 1994; 7709.56b, 2 Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b,2, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b, 3 Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b,3, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b, 4 Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b,4, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b, 5 Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b,5, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b, 6 Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b,6, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b_7, Amendment 7709.56b-2005-1, August 26, 2005; 7709.56b_8, Amendment 7709.56b-2005-2, August 26, 2005; 7709.56b, 9 Contents, Amendment 7709.56b-94-1, July 27, 1994; 7709.56b,9, Amendment 7709.56b-94-1, July 27, 1994

Approved by: Gregory Smith, Acting Associate Deputy Chief, NFS

Date approved: November 18, 2014

Responsible Staff:

Explanation of changes: Following is an explanation of the changes throughout the directive by section.

7709.56b: The entire Handbook has been revised; refer to the digest for a summary of the revisions.

Zero Code: Makes minor technical and editorial changes, removes obsolete direction and terminology, and updates the coding system by changing from the one-digit to the two-digit coding system.

10: Recodes, reorganizes, and updates direction throughout the chapter. Makes minor technical and editorial changes, removes obsolete directions, and updates the coding system by changing from the one-digit to the two-digit coding system.

11: Recodes, reorganizes, and updates this section in its entirety. Replaces discussion of forest plans, ecosystem management, and least total cost method decisions with subsections on travel analysis and travel management decisions. Updates direction on road management to include direction on Trail Management Objectives and recodes the direction to section 11.3. Reduces scope of direction on alternatives to stay within limits of travel management decisions and the Road and Trail Management Objectives and recodes the direction to section 11.4. Recodes the remainder of the section to new section 11.5 entitled, “Project Development Process.”

13: Sets forth new direction on inspection reports for existing structures and evaluation of load-carrying capacity of existing structures to listing of required design information.

20: Makes minor technical and editorial changes, removes obsolete direction, adds direction to meet Road and Trail Management Objectives, and updates the coding system by changing from the one-digit to the two-digit coding system throughout the chapter.

23: Adds direction to consider roadway widening needed to accommodate off-tracking of large trucks when curves are constructed close to bridges, to consider construction access to both sides of a stream, and to consider measures needed to maintain existing road traffic when replacing existing bridges.

30: Makes minor technical and editorial changes, removes obsolete direction, and updates the coding system by changing from the one-digit to the two-digit coding throughout the chapter.

34: Revises direction to conform to stream simulation requirements and to reference chapter 60.

35.4: Adds direction for identification of construction staging areas.

40: Makes minor technical and editorial changes and updates the coding system by changing from the one-digit to the two-digit coding throughout the chapter. Removes obsolete direction referencing economic analysis methods and flood insurance.

43.5: Updates direction to allow previously used materials only when they have been inspected, determined to be structurally adequate, economical and approved by the Regional Director of Engineering.

50: Changes chapter caption from “Hydrology” to “Hydrology and Geomorphology” and adds direction to require stream simulation and aquatic organism passage. Makes minor technical

and editorial changes and updates the coding system by changing from the one-digit to the two-digit coding system.

60: Changes chapter caption from “Hydraulics” to “Hydraulics and Watershed Protection” and adds direction to require stream simulation and aquatic organism passage. Makes minor technical and editorial changes and updates the coding system by changing from the one-digit to the two-digit coding system throughout the chapter. Removes obsolete direction.

70: Changes chapter caption from “Structural Design” to “Road Bridge Design” and updates the coding system by changing from the one-digit to the two-digit coding system throughout the chapter. Adds new direction and revises, reorganizes, and recodes direction throughout the entire chapter. Changes various section captions to be applicable for road bridge designs and sets forth new direction throughout the chapter. Removes obsolete direction.

80: Changes chapter caption from “Operations” to “Trail Bridge Design” and updates the coding system by changing from the one-digit to the two-digit coding system throughout the chapter. Sets forth direction for planning, design, and construction of trail bridges and other engineered trail structures.

90: Changes chapter caption from “Construction” to “Road Bridge Operation” and updates the coding system by changing from the one-digit to the two-digit coding system throughout the chapter. Revises, reorganizes, and recodes entire chapter. Major changes are: 1) removes the distinction and inspection requirements between bridges formerly known as NBIS and non-NBIS (National Bridge Inspection Standards), 2) removes all trail bridge references and guidance and 3) incorporates culvert guidance.

100: Establishes code, chapter “Trail Bridge Operation”, and sets forth direction for maintenance, inventorying, and operation of trail bridges and other engineered trail structures.

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50.2 - Objectives

To develop watershed and project specific geomorphology and hydrology data in order to:

1. Design and construct stable drainage structures that maximize structure life and minimize risks to the watershed, aquatic resources, road users, and the road investments.
2. Design and construct watershed improvement/restoration projects that improve watershed condition and function.

50.3 - Policy

Use an interdisciplinary process to develop watershed characteristics data, geomorphic stream variables, design discharges, and aquatic species needs and risks that are necessary to design stream crossing structures and watershed restoration projects.

50.6 - References

1. American Association of State Highway and Transportation Officials (AASHTO). Highway Drainage Guidelines, Volume II, Hydrology. Current edition.
https://bookstore.transportation.org/browse_bookstore.aspx.
2. AASHTO. Model Drainage Manual. Current edition.
https://bookstore.transportation.org/browse_bookstore.aspx.
3. Federal Interagency Stream Restoration Working Group. 1988. Stream Corridor Restoration: Principles, Processes, and Practices. ISBN-0-934213-59-3.
4. Harrelson, C., Rawlins, C., & Potyondy, J. 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. USDA Forest Service General Technical Report RM-245. Fort Collins, CO. 61p.
5. Knighton, D. Fluvial Forms and Processes. New York: John Wiley and Sons. 383p.
6. Montgomery, D. R., & Buffington, J. M. 1997. Channel-Reach Morphology in Mountain Drainage Basins. Geological Society of America Bulletin. 109p. 596-611.
7. Montgomery, D. R., & MacDonald, L. H. 2002. Diagnostic Approach to Stream Channel Assessment and Monitoring. Journal of the American Water Resources Association. 38p. 1-16.
8. Ritter, D. F., Kochel, R. C., & Miller, J. R. 1995. Process Geomorphology. Dubuque, IA: Brown Publishers. 535p.
9. Rosgen, D. 1996. Applied River Morphology. Pagosa Springs, CO. Wildland Hydrology.

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11. HEC-HMS, Hydrologic Engineering Center – Hydrologic Modeling System, US Army Corps of Engineers, Institute of Water Resources, Hydrologic Engineering Center, 609 Second Street, Davis, CA 95616-4687.
12. U.S. Department of Agriculture, National Resources Conservation Service (USDA-NRCS). *Engineering Field Manual*. Chapter 2. Estimating Runoff. Current edition. U.S. Government Printing Office, Washington, DC 20402.
13. USDA-NRCS. *National Engineering Handbook*. Section 4. Hydrology. Current edition. U.S. Government Printing Office, Washington, DC 20402.
14. USDA, Forest Service (USDA-FS). 1995 and 2003. *Guides for Field Identification of Bankfull Stage in the Eastern and Western United States*. Stream Systems Technology Center. VHS videotapes. 31 and 46 minutes.
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16. USDA-FS. 2008. *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*. San Dimas Technology and Development Center.
17. Handbook and Manuals. <http://directives.sc.egov.usda.gov/21422.wba>.
18. Hydraulics and Hydrology. Tools and Models. http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/tool_mod.html.
19. National Engineering Handbook. Part 630. Hydrology. <http://directives.sc.egov.usda.gov/viewerFS.aspx?hid=21422>.
20. EFH2 Computer Program. Estimating Runoff and Peak Discharge Training. http://www.wsi.nrcs.usda.gov/products/w2q/H&H/Training/trng_ser.html.
21. The Hydrologic Engineering Center. <http://www.hec.usace.army.mil/>.
22. Hydrologic Modeling System. <http://www.hec.usace.army.mil/software/hec-hms/>.
23. Hydrologic Engineering Centers River Analysis System. <http://www.hec.usace.army.mil/software/hec-ras/>.
24. Hydraulics Engineering. <http://www.fhwa.dot.gov/engineering/hydraulics/hydrology/index.cfm>.
25. Highway Hydrology. Second edition. http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=2&id=6.

26. Precipitation Frequency Data Server. <http://hdsc.nws.noaa.gov/hdsc/pfds/>.
27. Current NWS Precipitation Frequency Documents and Related Studies. http://www.weather.gov/oh/hdsc/currentpf.htm#PF_documents_by_title.
28. Stream Systems Technology Center. <http://www.stream.fs.fed.us/publications/index.html>.
29. NSS. <http://water.usgs.gov/software/NSS/>.
30. Regression Equations. <http://water.usgs.gov/osw/programs/nss/pubs.html>.
31. National Streamflow Statistics Program. <http://water.usgs.gov/software/NSS/>.
32. National Streamflow Statistics Program. Regional Regression Equations. <http://water.usgs.gov/osw/programs/nss/pubs.html#tx>.
33. Identification of Bankfull Stage. <http://www.stream.fs.fed.us/publications/videos.html>.
34. Rosgen, D. Stream Classification Training. http://www.epa.gov/watertrain/stream_class/.
35. National Water Information Systems (NWIS). <http://water.usgs.gov/nwis/>.

51 - General Procedures

Use an interdisciplinary approach to identify design criteria for the road or trail stream crossing and impacts and risks to the watershed and aquatic life caused by the crossing. Collect data to develop design criteria including:

1. Passing ice, woody debris, water, sediment, and aquatic species.
2. Minimizing risk to resource values.
3. Minimizing forest health impacts such as wildfire and/or insects.
4. Flow data from stream gauges.
5. Data developed with U.S. Geological Survey or Department of Transportation regression equations.
6. Data developed with adjacent State regression equations.

Identify watershed risks that could affect the structure, watershed, or stream stability. Consider moving the structure to a more stable location before deciding to replace a structure in its current location. Identify the limits of vertical and horizontal channel movement potential (scour) and the design considerations necessitated by that potential movement. Identify watershed and travel

route consequences of road or trail overtopping. Identify risks associated with culvert alignment relative to stream flow (skew angle).

Identify the bankfull flow and stream dimensions. In many streams, the bankfull width is defined by the stage associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow the floodplain. In certain stream types, floodplains can be small and inconspicuous. Streams that are entrenched do not exhibit significant changes in channel width as flood flows increase. In these streams, the width can be determined by using a series of common stage indicators that are generally located along the boundary of the active channel. Structures that span less than the bankfull width generally exhibit higher failure rates as they impede normal functions of stream discharge, wood and debris flow, and sediment transport. On average, bankfull discharge moves the most sediment, thus forming or removing bars and changing bends and meanders, and generally does the most work over time to form the average morphologic stream characteristics. For most areas, the bankfull discharge occurs on average every 1-3 years.

Identify watershed, soil, and geologic risks that would affect structure material choices such as: soil PH, abrasive sediment transport, debris potential, rain on snow event potential, and ice jam potential. Compare the life of the proposed material choices to the actual structure replacement cycle on the Forest.

Compare deterministic or statistical flood flow data with physical, geomorphic evidence of stream flow and capacity, for example, bankfull physical characteristics should generally match a 2 year flood frequency determined by deterministic or statistical methods. Also, compare any recent structure failures at or near the site for evidence of flood and debris flow potential. Physical evidence and bankfull discharges (at the crossing) and actual flood data should be used for the design where possible, then supplemented and reinforced by deterministic or statistically derived flood flow data.

Use FHWA-HEC-19 “Hydrology” (sec. 50.6) to estimate flood discharges and frequencies using either the Deterministic or Statistical Method.

1. The Deterministic Methods attempt to model rainfall and the resulting runoff that is controlled by the watershed characteristics. These methods include watershed computer models, Soil Conservation Service hydrology procedures, and the Rational Formula method (sec. 54.3).
2. The Statistical Methods apply analysis to actual or synthetic data to develop flood frequency distributions. Examples are the U.S. Geological Survey and the Federal Highway Administration regression equations.

52 - Probability and Frequency

Use the concepts of probability and frequency for designing transportation structures and performing hydrologic and economic analyses. Hydrology estimates are continuous variables, and it is impossible to predict the probability of a single annual peak flow occurring in any year

or number of years. However, it is possible to calculate the probability that the annual peak flow for any year is within a given range of possible flood flows.

53 - Types of Flow Data

When available, use annual peak flow data from stream gauges to develop flood discharge and frequency relationships for economic analyses and designing transportation structures. Show the flood discharge and frequency relationship as a flood magnitude versus return period curve.

Use hydrographs when there is a need to know the length of time a travel route is overtopped or the upstream storage effect when determining the upstream water surface elevation for a bridge or culvert.

Use USDA, Forest Service, Stream Simulation: An Ecological Approach to Providing Passage For Aquatic Organisms at Road-Stream Crossings, when designing culverts for Aquatic Organism Passage.

Consult with hydrologists or watershed specialists in locating sources of stream flow data.

Where possible, validate computed flow data with existing channel features. For example, if the Q2 flood recurrence interval is similar to the bankfull discharge for a given site, then stage elevations should be similar.

54 - Estimating Peak Flows

There are several methods for estimating peak flows and their return periods at any given site. Use the methods that are most appropriate. Base selection of the method on the geographical, geological, hydrologic and geomorphic data available for the sites, the validity of the methods for the sites, and on the designer's experience using specific methods.

54.1 - Gauge Data

Data collected for several years from stream gauges located near the site are best for estimating peak flows. However, Forest Service transportation structures are not commonly near established stream gauges. Where gauges are not present, use methods with basin derived from U.S. Geological Survey regression equations and flows from gauge data normalized by drainage area.

54.2 - U.S. Geological Survey Regression Equations

Use the Federal Highway Administration (FHWA) regression equations for each State developed by the U.S. Geological Survey (USGS) to estimate peak flow for return periods ranging from 2 to 100 years. Each State is divided into regions of similar hydrologic, meteorological, and physiographic characteristics. Long-term records of peak annual flow were synthesized for all watersheds in each region.

When an ungagged watershed has characteristics similar to a nearby or adjacent gauged watershed or basin, adjust the predicted flows for the gauged basin as applicable and use them for the proposed structure site. Use the USGS regression equation for the basin location.

Collect cross-sectional data at a crossing site and then, with an appropriate hydrologic model, calculate peak flows at the site to validate predicted values. Adjustments to estimated peak flows should be made as necessary.

54.3 - Rational Formula

Use the Rational Formula to determine peak flow from small watersheds. The Rational Formula is based on the following assumptions:

1. Peak flow occurs when the entire watershed is contributing runoff.
2. The rainfall intensity is uniform over a period of time equal to or greater than the time of concentration.
3. The frequency of the peak flow equals the frequency of the peak rainfall intensity.
For example, the 10-year peak rainfall will produce the 10-year peak flood.

These assumptions are not fully valid in every case. However, if the Rational Formula is used on small watersheds, parking lots, or small developed areas, the errors will not be large. Do not use this method for drainage areas larger than 300 acres.

The most common form of the Rational Formula is:

$$Q = ciA \quad \text{where} \quad \begin{array}{l} Q = \text{peak flow in cfs.} \\ i = \text{rainfall intensity in inches per hour.} \\ A = \text{watershed area in acres.} \\ c = \text{a dimensionless coefficient that is a function of the watershed} \\ \text{characteristics.} \end{array}$$

As with all algorithms, validate predictions with existing geomorphic features and stages present at the site. Additional refinement may be necessary if expected outputs differ for appropriate discharges.

54.4 - U.S. Geological Survey Synthetic Unit Hydrographs

The U.S. Geological Survey (USGS) develops reports for some States that give hydrographs for a range of return periods. This method uses the USGS procedures for estimating peak flows (sec. 54.2) to find the hydrograph peak. The shape of the hydrograph may be affected by basin characteristics.

55 - Geomorphic Design

In most situations, use a geomorphic design approach concurrently with traditional hydrologic and hydraulic design procedures. A design based on the geomorphic approach replicates the

natural channel configuration for dimension, pattern, profile, and bedform of the stream, in addition to the channel regime, sediment size and volume, wood size and volume, and hydrology of the drainage system. Facilitating natural processes through this approach will maximize multiple project objectives, minimize maintenance, and reduce failure liability and resource damage in the future.