CECW-EH-Y Regulation No. 1110-2-1464	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	ER 1110-2-1464 30 June 1994
	Engineering and Design HYDROLOGIC ANALYSIS OF WATERSHED RUNOFF	
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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

CECW-EH-Y

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Engineering and Design
HYDROLOGIC ANALYSIS OF WATERSHED RUNOFF

1. Purpose

This regulation defines the scope, authorities, and analysis and reporting requirements for performing watershed-runoff analyses associated with U.S. Army Corps of Engineers studies. Detailed guidance on study methods and procedures is given in EM 1110-2-1417.

2. Applicability

This regulation applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works planning, engineering, and design responsibilities.

3. References

ER 1110-2-1150
Engineering and Design for Civil Works Projects

ER 1110-2-1460
Hydrologic Engineering Management

ER 1110-8-2(FR)
Inflow Design Floods for Dams and Reservoirs

ER 1130-2-417
Major Rehabilitation Program and Dam Safety Assurance Program

EM 1110-2-1411
Standard Project Flood Determination

EM 1110-2-1413
Hydrologic Analysis of Interior Areas

EM 1110-2-1415
Hydrologic Frequency Analysis

EM 1110-2-1417
Flood Runoff Analysis

U.S. Geological Survey 1983
U.S. Geological Survey. 1983. "Flood Characteristics for Urban Watersheds in the United States," Water Supply Paper 2207, Department of the Interior, Washington, DC.

4. Scope of Watershed-Runoff Studies

Watershed-runoff analyses are an essential component of most riverine projects, and the results from these analyses are often critical to project formulation, design, construction, and operation throughout the life of the project. Watershed-runoff studies include the analysis of runoff from rainfall and/or snowmelt and the subsequent flow in streams and rivers. Watershed and river changes due to natural or man-made conditions are also included. This regulation addresses the development of a study plan, the conduct of the study, and the reporting of significant technical assumptions and results in support of riverine projects.

5. Study Design

A study plan is required for watershed-runoff studies, an integral part of the project management plan for each phase of project development. Developing the plan takes time and should be undertaken as an essential first step of a study. The study plan consists of a detailed outline of the objectives, scope, level of detail, procedures, work products, potential problems, data requirements, personnel and expertise requirements, and schedule of specific tasks and resources necessary to complete the study. The plan will establish essential milestones or checkpoints required to ensure that each aspect of the study is coordinated, reviewed, and provided to others without causing delays in the overall study. The plan is prepared in sufficient detail to form a basis for time and cost estimates and is used frequently to monitor study progress. Coordination, review, and approval of the study plan, by the immediate supervisor, is required. Coordination with the study manager will occur during the formulation of the study plan. ER 1110-2-1150 defines the engineering requirements in support of project management.

6. Study Design Process

The successful execution of a watershed-runoff study requires a clear understanding of the study purposes and objectives, an assessment of the data resources, and an understanding of the controlling physical features and processes. Accurate problem identification and establishment of clear project objectives may require specialized expertise and, therefore, early coordination among all members of the study team.

a. Identification of study purposes. A written statement of why the study is being performed and what information is needed will be prepared. How the requested information will be used in the project analysis will be identified. The level of detail for the desired results will be described. These statements will be coordinated among study participants so that a complete understanding of the problem, information needs, solution techniques, and expected results are well understood by all.

b. Assessment of available data. The availability of data to meet information needs and to support the desired analysis techniques must be determined. Data availability often influences which methods are used. Meteorologic, hydrologic, geographic, and other data can be obtained from electronic databases and from reports by the Corps, other Federal agencies, and state, local, and private organizations. The level of detail desired in the results will also affect the data needs (see paragraph 6*e*. All data must be critically reviewed to validate its accuracy and applicability to study purposes. If existing data are inadequate to meet study needs, recommendations for new data collection should be made to the study manager. Such recommendations will be consistent with level of detail. Data limitations which will restrict the desired study effort should be coordinated with other affected parties as soon as possible.

c. Study-area inspection. Field reconnaissance of the study area is required. The field trip will be well planned and have specific objectives. The reconnaissance will include tributary areas upstream and downstream from the project. This reconnaissance ensures that controlling features in the area (that could affect the project, or vice versa) are known prior to the selection of appropriate analytical procedures. Photographs and a trip log will be used to document observations and can be utilized throughout the study.

d. Assessment of controlling physical phenomena. The available data and field review described above provide the basic information to determine the physical processes and critical aspects of the project. The information is used to evaluate the problem under investigation, the potential project features to minimize the problem, and the required methods for proper evaluation. The study boundary for this evaluation will encompass the significant hydrologic processes that affect the project under current and future conditions. Downstream areas that may be affected by the project should also be included. The critical processes and watershed features (e.g., infiltration, channel flow, urbanization, flow constrictions, etc.) that will most influence the project performance must be identified. Assumptions concerning future conditions, such as urbanization, will be carefully reviewed and documented. Possible future changes to these controlling physical features and their effect on the proposed project will be evaluated and documented.

e. Level of detail. The information needs, physical processes, data availability, and time and resource requirements should be analyzed to determine whether the study objectives can be met. The technical accuracy and confidence in potential results will be conveyed to the study manager as soon as possible. If conflicts between expected and desired results arise, they must be resolved within the framework of issue-resolution conferences, when first identified, not when the analysis is complete.

f. Selecting methods of analysis.

(1) Basis. Considering the project purposes, availability of data, controlling physical phenomena, level of detail, and resource requirements, the watershed analysis methods should be structured to meet study goals and objectives. The user's experience and knowledge of the theory and limitations of the methods are also critical to successful analysis. Technical approaches may range from use of existing regional statistics (e.g., U.S. Geological Survey (USGS) studies) to detailed precipitation-runoff simulation for a period of record. In some cases, more than one approach may be desirable for validation purposes or to enable development of a composite results. For example, a flood frequency study may use annual peak flow frequency analysis of local streamflow gages (EM 1110-2-1415), USGS regional equations (e.g., USGS 1983) of flood frequency, and a rainfall-runoff simulation model with frequency-based storms from a National Oceanic and Atmospheric Administration (NOAA) precipitation statistics atlas.

(2) Justification. Clear written support must be provided for the selected study methodology and the analytical methods to be used. The statement will show how the methods selected will meet the information needs of the study. The use of available data and/or procedures for obtaining new data will be documented relative to the selected methodology. The justification will show how the overall cost of the runoff investigation can be within budget and provide an acceptable level of detail. Tradeoffs between study effort (cost) and level of detail should be itemized. This is particularly useful if a small additional cost will bring about a significant increase in detail and in confidence of the study results.

g. Calibration/verification. Whatever level of analysis method is used (from empirical equations to detailed physical-process simulation), calibration and verification are required. Calibration is the process by which the method's parameters are estimated from historical data and watershed characteristics. The estimation is made so that computed results agree as well as possible with observed data and in accordance with expected physical performance. Calibration may require adjusting several parameters; consistency between parameters and consistency within parameters for similar geographic areas will be maintained. Parameter values will be kept within reasonable physical limits. Calibration will concentrate on those events most pertinent to the study purposes. Verification is the process by which the method is checked against data not used in the calibration process. Criteria for testing the method should be developed knowing the method's limitations compared with the phenomena being analyzed. If there are inadequate local data for a method, then regional data must be used. Regionalization is the process by which data from hydrologically similar areas are transferred to the area of interest. It is important to verify the form of estimation equations for a range of values, including extremes. If the method's predictions are erroneous in the extremes, then other values may also be wrong.

h. Application. The application of a method to obtain information for the study team will follow the general study plan. That plan may need to be updated per results of the calibration/verification. The application of the method will include both direct analysis of the project features and sensitivity analyses of important parameters. The sensitivity of the parameters to controlling physical phenomena, uncertainties in data, and important socioeconomic considerations will be analyzed. This sensitivity information will be considered in making decisions about study methods. The results will be checked against other data whenever possible. Comparison of the results with similar studies will check for consistency, and differences will be explained. The results will also be checked against regional information, e.g., peak-flow envelope curves and flow statistics of the USGS and other Federal, state, or local agencies. Finally, the results will be physically reasonable. Travel times will be checked with flow-velocity estimates (e.g., Manning's equation). Hydraulic controls will be recognized and routing results checked for continuity and upstream-downstream consistency. Volumes of runoff and interception/infiltration losses will be balanced against precipitation.

i. Uncertainly analysis. It is important to understand and quantify the consequences of possible errors in the data, errors in the method, and errors in the results. Flood damage reduction studies will require discharge frequency curves with the uncertainty in discharge explicitly quantified. If statistical information is available or can be computed from the data and results, then confidence limits, standard errors of estimate, etc. (statistical measures), should be directly determined. Sometimes sensitivity analysis, using engineering judgment to determine a range of possible results, with associated likelihood is necessary when statistical information is not available. When input data to a method are obtained from regional data, error statistics from the regional data, and error statistics from the regional relationship, will be used in the uncertainty analysis. Project sizing and feature design will be approached within the context of risk-based analysis wherein uncertainty and performance tradeoffs are explicitly considered.

7. Documentation and Reporting

Guidelines for documentation of hydrologic engineering investigations are given in ER 1110-2-1150 and EM 1110-2-1417. These documents also identify reporting requirements. In general, each of the above aspects of the study will be documented in a hydrology appendix and summarized in the main report. Data and analysis procedures/models will be archived for future review/reanalysis. Electronic input data, output, and models (executables) should be properly documented in the appendix and labeled. Tapes and diskettes can be stored with project papers, or in designated computer media storage areas. The primary intent of the study documentation is to communicate the problem, data, assumptions, methods, and results to the study team, higher authority, and future investigators. Details of the investigation are contained in an appendix. Any of the study results will be able to be reproduced from the information in the appendix and the backup papers and electromagnetic media.

a. General report content. The documentation will describe the project location, features, and function. The watershed and river system are described, including storm and flow characteristics and geography for with- and without-project conditions. The use of tables, figures, charts, and maps will be maximized in order to present data. Locations discussed in the text will be clearly indicated on accompanying maps and will be appropriately referenced. A description of the source and reliability of the data and how it was used will be included. Consistent labelling of geographic features (e.g., river miles) will be used throughout the report.

b. Analytical methods. Methods of analysis investigated, supporting reasons for adopting selected methods, and associated relationship to project formulation will be described. Methods development, calibration, verification, and application will be presented in sufficient detail to substantiate study findings. Computer file names for data, models, and output should be included, and these files will be available on diskette for higher authority if requested.

c. Methods application. The report will address the credibility of the watershed-runoff analysis and the related impact on project performance. The analysis will cover the life of the project and show how the project is expected to perform physically over a full range of potential floods and droughts. The significance of assumptions in terms of required operation and maintenance, and future conditions, must be clearly stated. Local cooperative agreements, and other legal and institutional arrangements required to ensure the intended project performance, will be clearly described.

d. Uncertainties. The uncertainties in a watershed-runoff study will be evaluated and documented. The impact of uncertainties in the data and analysis methods on the study results will be addressed. The results of statistical and sensitivity analyses will be presented so that decisions can be made concerning more analysis or increased contingencies to account for the uncertainty in the study results.

e. Interpretation of results. The existing watershed condition and the performance of a proposed project are the essential results of most watershed-runoff studies. While infiltration, peakflow rates, and other parameters may be featured in the study report, these data only serve to support conclusions concerning the physical performance of the project. Watershed-runoff study results require engineering interpretation to present the information in descriptive terms. In addition to descriptions of project performance for design conditions, topics such as safety issues (warning time, potential hazards, and emergency operations associated with flows exceeding design) will be addressed. The description should give a clear picture of what will happen and how the project will perform during various possible scenarios. Any unusual and/or life-threatening residual flood situations will be carefully documented. The goal is to plan, design, construct, and maintain sound, functional, cost-effective projects. The study report will present the project in a comprehensive, balanced, open manner to support that goal.

8. Special Study Considerations

Some studies require special consideration because of the complexity of hydrologic and hydraulic analyses and/or flood damage. Several aspects of such studies are summarized below. Detailed methods for treating these conditions are presented in ER 1110-2-1460 and other references as noted.

a. Urban watershed analysis. Urbanization alters the natural infiltration areas and runoff channels in a watershed. It is difficult to generalize the impacts because so many specific conditions may control the amount and rate of runoff. There are several important factors to consider: are the calibration data from a similar land-use condition or has the watershed undergone urbanization during the time data were collected; are impervious areas directly connected to channels; are there local drainage practices which affect runoff; do regional relationships for runoff parameters take into account the full range of land use in the basin; are there culverts, storm drains, or other features with limited capacity which will cause runoff to pond or take another flow path; are pump stations needed in relatively flat areas; are there detention ponds; and should impervious areas be treated separately from pervious areas or can they be lumped together? Any of the above runoff limiting or enhancing factors can drastically affect the apparent watershed-runoff. They should be given special attention in the data collection, method formulation, analysis, and documentation.

b. Flow-frequency analysis. Watershed-runoff simulation is often used to estimate flood-frequency curves. This is desirable where inadequate peak streamflow records exist, where urbanization has changed the runoff response during the gaging record, and where proposed project conditions will require estimation of future with-project flood-frequency curves. In these cases, the full hydrograph is necessary to analyze the impact of urbanization on the peak-flow frequency. Caution must be exercised in calibrating a runoff model's peak flow to a given storm frequency. An assumption commonly made is that the peak-flow runoff frequency is equal to the design-storm frequency. This is only true if the antecedent moisture condition is such that the design-storm peak flow is equal to the true flow frequency. A conservative wetness condition is often assumed if no frequency data are available for calibration. If calibrating to a given frequency curve, the infiltration, unit graph, and routing parameters are adjusted to produce the desired peak runoff.

c. Interior flooding. Interior flood control studies are particularly complex because the flood frequency is not only dependent upon the normal runoff conditions, but also on the state of the flow in the exterior area (i.e., on the other side of the levee). EM 1110-2-1413 prescribes interior flood analysis methods.

d. Reservoir versus channel projects. Both reservoir and channel projects require sound hydrologic analysis. Reservoir projects require that additional emphasis be placed on the volume of runoff. Thus, more attention should be paid to storm duration, infiltration, initial reservoir storage, and reservoir routing than, say, the unit hydrographs of the contributing subbasins. In contrast, channel projects are usually dependent on peak flow rates. The overall volume of the hydrograph is not as important except in flood routing where floodplain storage impacts are significant.

e. Water supply. Water supply hydrology emphasizes analysis of volumes of water over long time periods (years) as opposed to the single event orientation of flood studies. Groundwater contributions to streamflow are a major component of this analysis. Continuous simulation of streamflow requires soil moisture accounting and low-flow computations to carry the simulation through dry periods. Model calibration for water supply usually emphasizes daily flow volumes.

f. Inflow design floods for dams and reservoirs. Dam safety requires the use of design floods and impact analysis to determine top-of-dam elevation and spillway capacity (ER 1130-2-417). Watershed-runoff models are used to convert the design storms into inflow design floods (ER 1110-8-2(FR)).

g. Estimation of standard project flood. The following procedures should be applied when estimating the standard project flood (SPF) for Corps projects.

(1) For projects located west of the 105th meridian, use 50 percent of the probable maximum flood for the SPF. The SPF for projects located east of the 105th meridian will continue to be developed using procedures described in EM 1110-2-1411.

(2) Hydrometeorological studies involving storm transposition should be coordinated through CECW-EH for review by the hydrometeorological section of the National Weather Service.

FOR THE COMMANDER:

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