Chapter 3
Flood Studies

3-1. Overview

a. Development of work plan. The hydrologic engineer must develop a work plan appropriate to the flood problem being studied and the type of flood damage reduction alternatives under investigation. The flood hazard must be defined to determine the tangible damage resulting, both for present conditions in the watershed and for a future time period, if significant changes in the watershed may occur. A level of detail commensurate with the type of analysis must be determined, a method of formulation and evaluation of the proposed flood damage reduction alternatives adopted, and the consequences (both positive and negative) addressed.

b. Hydrologic engineering. This chapter describes, in general terms, the hydrologic work necessary for a flood study. Interested readers may review ER 1110-2-1460 for additional information on hydrologic engineering management and for hydrologic engineering required for feasibility studies, respectively. Additional information on hydrologic engineering and other engineering disciplines in the feasibility and PED phases is referenced in ER 1110-2-1150.

3-2. Definition of the Flood Hazard

The study process and how the plan formulation and evaluation evolve must be defined to provide the hydrologic data needed by other disciplines. The method of analysis, level of detail, time requirements, and format of the hydrologic information must be commensurate with the needs of the study team, including the cost-sharing partner.

a. General. Most flood studies require the definition of a stage-frequency relationship at key locations in the watershed, and how these relationships change in time, both with and without various flood damage reduction projects. Flood frequencies ranging from a 50-percent chance exceedance event through the Standard Project Flood or a 0.2-percent chance exceedance frequency event[1] are selected to define a full range of frequency events. Existing, or base (start-of-project operation), conditions form one "snapshot" of land use conditions to evaluate. At least one additional time period, usually 20-50 years in the future, based on available land use planning information, is chosen to form a second time period. If land use differences between the two times are great, additional periods may be interpolated. Similarly, additional periods could be extrapolated. The same two times are also used to evaluate the changes in the watershed's flood hydrology caused by the various flood reduction measures evaluated. Figure 3-1 illustrates frequency curves at a location undergoing continuous urbanization, resulting in changes to the relationship.

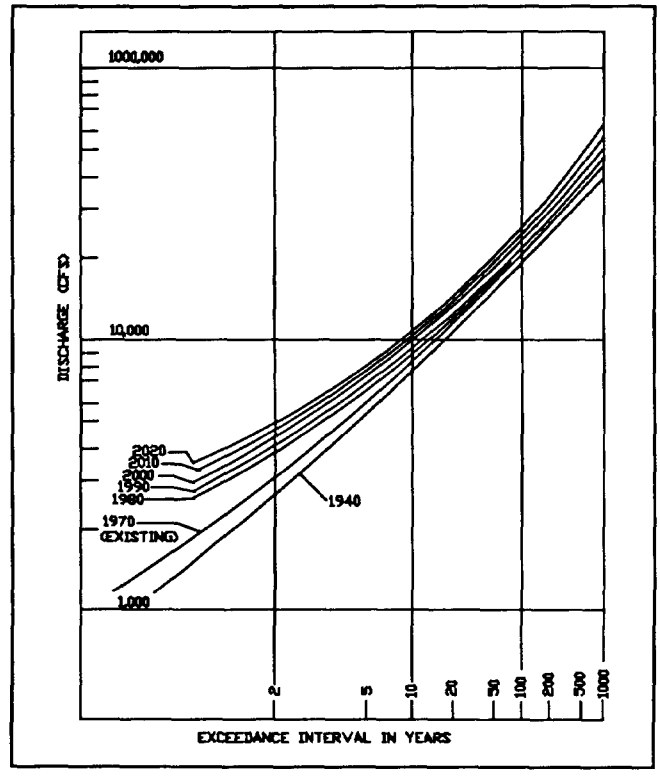

Figure 3-1. Frequency curves developed for an urbanizing area

b. Hydrologic information. The hydrologic engineering information needed could include the following:

(1) Discharge hydrographs.
(2) Peak discharge frequency.
(3) Runoff volume frequency.
(4) Water surface profiles.
(5) Flood inundation boundaries.
(6) Flow velocities.
(7) Warning times.

[1] Exceedance frequency is percent chance an event may occur in any given year. An event with a 0.2-percent chance exceedance frequency will occur once every 500 years, on the average, but can occur in any given year.

(8) Duration of flooding.
(9) Sediment deposition and erosion quantities.
(10) Operational performance of projects (amount of flood reduction).

Of the above information, accurate flood inundation determinations have the most impact on project evaluation. The extent and depth of flooding for with- and without-project conditions result in the estimate of flood damage reduction benefits, which are the basis for determining the economic feasibility of flood reduction projects. For agricultural flood studies, duration and time of year of flooding are important. The quality of the hydrologic work, as well as the survey and mapping information, can significantly affect the determination of project feasibility.

c. Field presence. The hydrologic engineer must spend time in the field throughout all phases of the analysis, from the reconnaissance through the actual construction. A field presence is required to gather data needed for the various phases of the study and to maintain continuous contact with local interests involved with the proposed project. Credibility is quickly lost when the engineers involved in the project recommendations have spent little or no time in the study area. Field visits should in many cases include other members of the study team and the local sponsor. The hydrologic engineer's field presence is needed for:

(1) Determination of topographic and survey needs.

(2) Determination of high-water marks and times of flood peaks by interviewing local residents and researching newspaper files.

(3) Obtaining the characteristics of flood events, including debris and sediment problems, flood dates, velocity patterns, and changes to the stream and watershed since historic floods have occurred.

(4) Estimation of friction values (Manning's n) for the channel and floodplain.

(5) Identification of obstructions to flood flow (bridges, dams, logjams, levees, road embankments, etc.), and historical floods which caused overtopping of these obstructions, including how often they occurred and whether debris or ice was a factor.

(6) Operation procedures for existing structures (dams, pumping plants, drains, frequency of channel dredging, etc.).

(7) Identification of the type and location of potential flood loss reduction measures, and any constraints on these measures (relocations, environmental damage, etc.).

d. Level of detail. Most of the hydrologic engineering effort is concentrated in the reconnaissance-phase and feasibility-phase studies.

e. Reconnaissance-phase study. The effort in the reconnaissance phase emphasizes the use of existing data, primarily due to the short duration of the study. Much information is obtained from local residents and officials, existing studies of the watershed, from measured and readily available data, and from field reviews and engineering judgement. If time and funding are available, it is desirable to establish the existing condition hydrology and flood profiles to avoid major changes in the feasibility phase. The reconnaissance-phase study evaluates several potential alternatives to determine if at least one is economically justified. If economic justification exists and there is a local sponsor willing to cost share, the study continues into the feasibility phase.

f. Feasibility-phase study. The majority of hydrologic engineering work is performed in this phase. The analysis must be sufficiently rigorous so that the project recommended in the feasibility report is essentially what is constructed, after detailed PED is completed. The hydrologic engineer, working closely with the study manager, economist, cost engineer, and other members of the Interdisciplinary Planning Team (IPT), completes the with- and without-project evaluations so a plan that maximizes net benefits is identified at completion of feasibility planning. This end result requires a continuous exchange of technical information among the various disciplines as follows:

(1) Technical data to the hydrologic engineer:

(a) Survey and mapping information.

(b) Maps showing land use, soil types, vegetation, storm sewer layouts, bridge plans, and other information from local agencies.

(c) Rainfall information from the NWS or other agencies.

(d) Stage, discharge, and sediment information from the U.S. Geological Survey (USGS) or other agencies.

(e) Potential alternatives to analyze, in conjunction with the study team and the local sponsor.

(2) Hydrologic data to the study team:

(a) Specification of topographic data needed by surveyors.

(b) Stage-frequency relations for without-project (base conditions), future without-project, and with-project conditions.

(c) Effects (reduced flooding) of each flood mitigation component to the study manager.

(d) Component capacities or dimensions to the designer and cost engineer.

(e) Velocity, sediment, duration, depth, and other information to the environmental specialist and permit specialist.

(f) Flood inundation boundaries with and without a project to mapping and to the real estate specialist.

(3) The information is furnished via an iterative process, leading to the refinement of the recommended project.

g. Design memoranda.

(1) Detailed hydraulic design. The emphasis in this phase is on the detailed hydraulic design aspects, because no additional plan formulation, economics, etc. should be necessary. The hydrologic engineer is more involved in refining the detailed design of the project components. The overall component capacities, general design, etc. are held relatively constant from that recommended in the feasibility report. For instance, the feasibility report may have recommended 5 miles of channel modifications having specified channel dimensions. The design memoranda would refine these dimensions to fit the channel through existing building and bridge constraints; perform detailed hydraulic design of tributary junctions, bridge transitions, drop structures, and channel protection; and conduct detailed sediment transport studies to identify operation and maintenance requirements, and other hydraulic design aspects.

(2) Additional activities. Additional topographic site surveys and subsurface information are normally obtained in this phase so that structural design, geotechnical analysis, cost engineering, and other activities can be finalized. The hydraulic design is often updated to reflect changes in analysis parameters prior to completion of detailed design. Additional information on the design memoranda phase is referenced in ER 1110-2-1150.

h. Construction and operation. Unforeseen problems during construction frequently involve further modification and adaptation of the hydraulic design for onsite conditions. Similarly, most projects require detailed operation and maintenance manuals and hydrologic engineering information can be a critical part of these manuals. The operation of reservoirs, pumping stations, and other flood mitigation measures can require considerable hydrologic operation studies to determine the best operating procedures. Post-construction studies are necessary for most projects. These studies monitor sediment deposition and scour caused by the project, ensure that adequate hydrologic design capacity is maintained, monitor the correctness of the data used in analyzing the project, and estimate the remaining useful life of the project.

3-3. Formulation and Evaluation of Solutions

a. Methods of solution. Appropriate application methods of solution are required to provide the necessary information to the study team and to evaluate both positive and negative aspects of the project. Simple versus complex methods and a frequency approach versus a period-of-record approach are considered, depending on the phase of the study and the type of flood damage reduction measures being evaluated. A simple regression equation giving peak discharge, knowing drainage area and slope, may be acceptable for a reconnaissance-phase effort to size a channel, but is inadequate for determining adverse effects downstream.

b. Investigation sites. Locations where hydrologic information is needed must be identified. This process must include the study team's requirements as envisioned at the time of the determination. In general, these points include:

(1) Locations of tributary junctions with the main channel, to evaluate significant flood flow changes.

(2) Stream gages, to calibrate model output to actual data.

(3) Points along reaches where flood damage reduction measures are to be evaluated.

(4) Locations in the watershed where land use, soil type, etc. change significantly.

(5) Damage centers, to compute damage with and without a project.

Figure 3-2 illustrates how a watershed could be subdivided to determine where hydrologic information is necessary.

3-4. Impact Assessment

Analysis results are given by the impact of the flood damage reduction measures on flooding. These impacts are quantified through evaluation of with- and without-project comparisons of flooding represented by flooded area, depth, and frequency curves.

a. Project formulation. Evaluations are conducted to determine the performance characteristics of multiple sizes and configurations of measures. A range of flood events is analyzed for each measure. Each measure is analyzed to determine attributable flood damage reduction, costs, and benefits. The analysis will determine the project that maximizes the net benefits or NED plan. The project identified as the NED plan is that typically recommended for project design and construction. The risk of exceedance is also displayed for the selected design event to better illustrate the likelihood of design exceedance.

b. Design exceedance. The project design is exceeded when top of protection is exceeded or structural failure occurs. Every project can and eventually will be exceeded if it remains in place over a long period of time. When a flood overtops the protection, significant damage, possibly more than the damage prior to the project, could be experienced. Part of the analysis is to evaluate the consequences of design exceedance, and to design the project to minimize damage to both the project and the protected area.

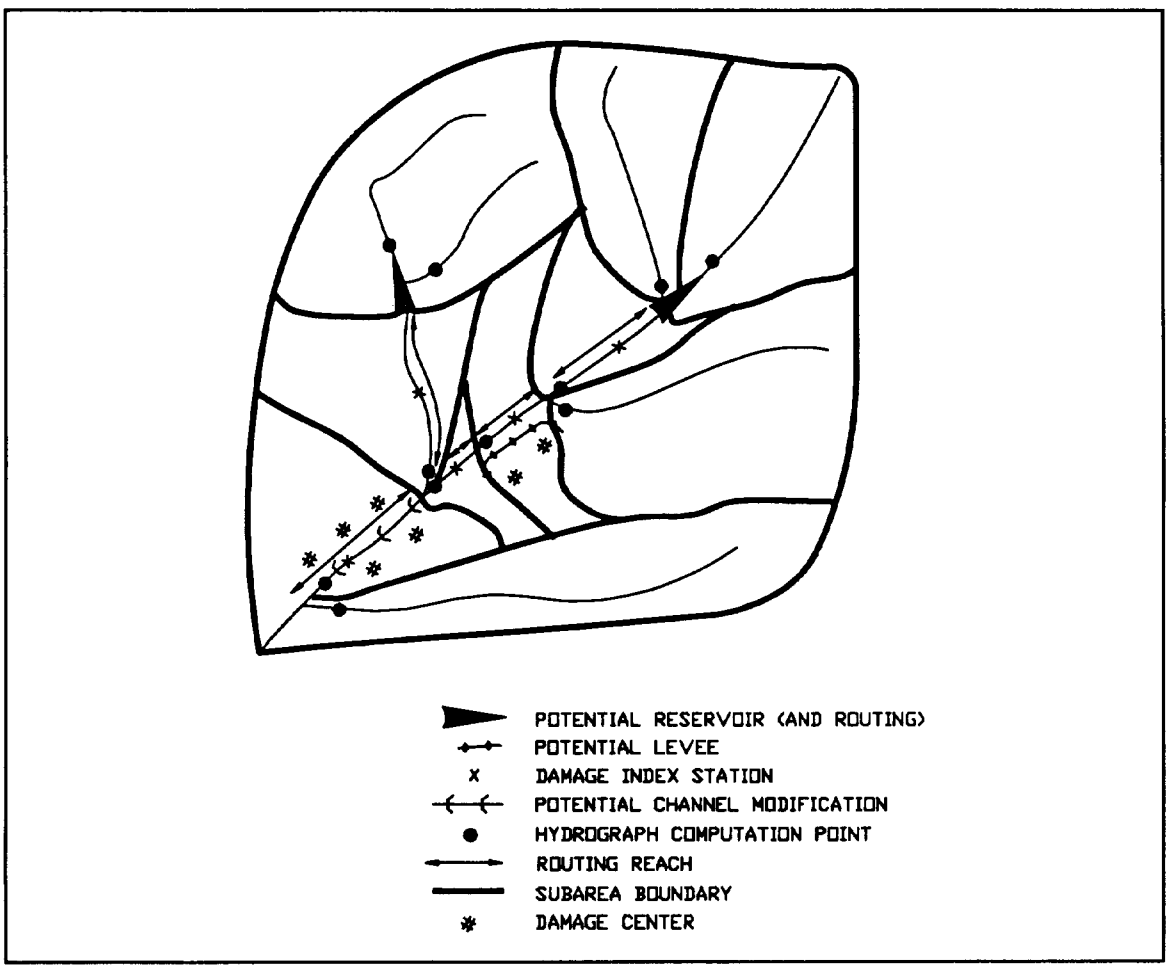

Figure 3-2. Subarea delineation

c. Positive/negative effects. Quantification of the positive effects of the project associated with its reduced flood damage is the basis for economic justification. However, the hydrologic analysis must address negative consequences as well. The consequences of the major types of flood damage reduction projects include but are not limited to the following:

(1) Reservoirs.

(a) Positive impacts.

- Flood flow and stage reduction at downstream locations.
- Downstream damage reduction.
- Source of water for multiple uses during low flow.
- Recreation usage.
- Hydropower generation.

(b) Possible negative impacts.

- Permanent inundation of reservoir lands.
- Eventual filling of reservoir with sediment.
- Changes to downstream sediment regime, usually erosion.
- Conveyance encroachment from lack of large floods.
- Changes in water quality.
- Increased losses due to evaporation.
- Elimination/reduction in fish spawning.

(2) Levees.

(a) Positive impacts.

- No flooding from exterior until design is exceeded.
- Protection to properties behind levee.

(b) Possible negative impacts.

- Induced flooding upstream and downstream of levee if extensive loss in valley storage.
- Potential for sudden large losses when levee design is exceeded.
- Interior flooding.
- Closures of openings may be required.

(3) Channelization.

(a) Positive impacts.

- Flood stage reductions even for events exceeding the design capacity.
- Local damage reduction through project reach.

(b) Possible negative impacts.

- Potential effect on fish spawning and wildlife habitat.
- Changed sediment transport characteristics.
- Increased channel maintenance requirements.
- Induced flooding downstream if extensive loss in valley storage.

(4) Diversions.

(a) Positive impacts.

- Flood stage reductions even for events exceeding the design capacity.
- Local damage reduction through project reach.

(b) Possible negative impacts.

- Changed sediment transport characteristics caused by uneven diversion of sediments.
- Induced flooding downstream of diversion reentry point.

(5) Nonstructural.

(a) Positive impacts.

- Individual structures protected.
- Essentially no change to environment.

(b) Possible negative impacts.

- High residual damage - infrastructure not protected.
- Emergency response required on event-by-event basis.