Map MODERNIZATION

Federal Emergency Management Agency

FEMA's Flood Hazard Mapping Program

Guidelines and Specifications *for* Flood Hazard Mapping Partners

Appendix C: Guidance for Riverine Flooding Analyses and Mapping

FEDERAL EMERGENCY MANAGEMENT AGENCY

www.fema.gov/mit/tsd/dl_cgs.htm

FINAL

February 2002

APPENDIX C

GUIDANCE FOR RIVERINE FLOODING ANALYSES AND MAPPING

This Appendix documents the study methods and review procedures that assigned Mapping Partners shall use in performing detailed and approximate hydrologic and hydraulic analyses for riverine flooding sources, preparing floodplain mapping to reflect the results of those analyses, and performing hydrologic analyses of closed-basin lakes.

C.1 Detailed Hydrologic Analyses

As part of the initial scope of work defined by the Federal Emergency Management Agency (FEMA) Regional Project Officer (RPO) and other members of the Flood Map Project Management Team (detailed in Volume I, Section 1.3 of these Guidelines), the flooding sources for which detailed hydrologic analyses must be conducted will be identified. This section addresses methods and assumptions to be used in performing detailed hydrologic analyses for riverine flooding sources.

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C.1.1 General Guidance

For detailed hydrologic analyses, the exceedance probability of flood events to be studied must be determined. At a minimum, the Mapping Partner that is performing the hydrologic analysis shall analyze the 1-percent-annual-chance (100-year) event; however, determinations of the 10-percent-annual-chance (10-year), 2-percent-annual-chance (50-year), and 0.2-percent-annual-chance (500-year) flood discharges will often be requested as well. Where appropriate, the Mapping Partner that is performing the hydrologic analysis shall use all available flood flow-frequency information and shall not duplicate previous work by Federal, State, or local agencies, or work performed as part of a new or revised Flood Insurance Study (FIS) for FEMA. Where such data are not available, where conditions have changed invalidating the published information, or where the methodologies or data used in the previous FIS(s) are not appropriate, a new hydrologic analysis will be required.

The Mapping Partner that is performing the hydrologic analysis shall estimate the flood discharges for existing land-use conditions. However, FEMA and the Mapping Partner may also consult with community officials to determine whether they want to consider developing hydrology based on future land-use conditions for local floodplain management purposes. If a community decides to include future-conditions hydrology within the scope of work for a Flood Map Project, the technical information shall be developed by the community and provided to FEMA and the Mapping Partner that is performing the hydrologic and hydraulic analyses for the Flood Map Project in accordance with the requirements in Section C.8.

The Mapping Partner that is performing the hydrologic analysis shall consider gaged versus ungaged streams and the appropriateness of developing a rainfall-runoff model. Each of these approaches is briefly discussed later in this section. When an expected probability adjustment (Interagency Advisory Committee on Water Data, 1982) has been included in published flood discharge determinations, the Mapping Partner shall contact the RPO for approval before proceeding.

Prior to performing a hydrologic analysis, the Mapping Partner that is performing the hydrologic analysis shall work with the RPO to identify which, if any, of the hydraulic structures are to be included in the analysis (such as a large impoundment) and to identify appropriate methodologies for analyzing their impacts on peak flows and volumes. If effective FIS flood discharge data are to be used, the Mapping Partner shall verify that the data are current before proceeding.

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C.1.1.1 Floodplain Storage Considerations

Large storage areas that exist in a floodplain will significantly attenuate flooding within a community. The Mapping Partner that is performing the hydrologic analysis shall evaluate attenuation using a standard flood routing technique. Storage in the floodplain may be uncontrolled, such as in detention ponds, isolated small natural depressions, and in wide floodplains of large rivers, or controlled with reservoirs. The requirements for performing hydrologic analyses of uncontrolled flood storage and controlled flood storage are presented below.

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Uncontrolled Flood Storage

Uncontrolled detention ponds and natural depressions both provide uncontrolled flood storage. Detention ponds typically are used in developed areas for onsite storage, and these ponds limit post-development peak flow rates from a design storm to those of the pre-development stage. The ponds also are used for regional detention based on a master plan for the watershed area of interest. Depending on climate characteristics and local design standards that vary across the nation, detention ponds may be able to attenuate peak flow rates for a 1-percent-annual-chance storm for arid areas; however, in more humid areas, most ponds are designed for storms with 20- to 50-percent-annual-chance storms.

Usually, an ungated spillway and a low-level, ungated conduit comprise the detention pond outflow structure. The effectiveness of a detention pond in attenuating peak flow rates in the downstream reach depends on the pond's location in the watershed and its storage and release characteristics. While an onsite detention pond may be effective for a single development site, it may not be as effective for a large urban watershed that has many onsite detention facilities that are not located and designed systematically (Maidment, 1993). The Mapping Partner that is performing the hydrologic analysis shall analyze floodplain storage in small isolated natural depressions, where outflow is only through overflow, as uncontrolled detention ponds with appropriate outflow characteristics.

The Mapping Partner that is performing the hydrologic analysis may use both hydrologic and hydraulic routing methods to route the flow through ponds. Hydrologic routing methods are to be used when the outflow from the pond is not dependent on tailwater. Most of the single-event hydrologic models (e.g., HEC-HMS, HEC-1, TR-20) use hydrologic routing methods. The Mapping Partner that is performing the hydrologic analysis shall use hydraulic routing methods when outflow from the pond is dependent on tailwater conditions. For example, tailwater condition is a control factor where a series of interconnected detention ponds are used for flood attenuation in a relatively flat watershed. The hydraulic routing for ponds is often performed with an unsteady-flow model. A list of models accepted by FEMA for this purpose may be found on FEMA's Flood Hazard Mapping website at http://www.fema.gov/mit/tsd/en_modl.htm.

Wide floodplains with significant storage areas often exist along large rivers in relatively flat watersheds. The Mapping Partner that is performing the hydrologic analysis may use the unsteady-flow models, both one-dimensional models with quasi-two-dimensional capabilities and two-dimensional models that appear on FEMA's accepted models list to simulate flood attenuation due to this type of storage.

Controlled Flood Storage

Most large reservoirs on large river systems are operated with outflow controls. In these reservoirs, gates are used for regulating flow through outlet structures. The gates are operated according to established rules that determine the relationship between inflow, outflow, storage, and water demand.

The Mapping Partner that is performing the hydrologic analysis normally shall not consider storage capability below the Normal Pool Elevation of reservoirs operated primarily for purposes other than flood control because the availability of such storage is uncertain. The exception is when all of the following conditions have been met:

- Operation of the project in accordance with its documented water control plan could affect the 1-percent-annual-chance flood elevations in a community by 1 foot or more.
- The storage capability to be considered is totally dedicated to flood control. Where different amounts of storage can be totally dedicated during different parts of the year, the Mapping Partner shall obtain flood discharges from the joint probability combination of frequency curves established for each part of the year that the different storage levels are dedicated. Joint use storage based on forecasted inflow is not acceptable for NFIP purposes.
- A project water control plan providing explicit details of operation during flooding conditions is in effect and has been reviewed and approved by FEMA or another Federal agency responsible for Federal flood-control activities. The

Mapping Partner that is performing the hydrologic analysis shall contact the RPO to discuss the review and approval process.

- A written commitment to dedication of the flood-storage capacity and to the approved reservoir operation plan is assured through a mandatory condition of Federal or State licensing or through a direct agreement between the project operator and FEMA for non-Federal projects.

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C.1.1.2 Gaged Streams

Flood discharges may be determined directly from gage data in areas where river gages are located, or may be estimated based on data from gages in nearby areas having similar characteristics.

At a Gaging Station

The Mapping Partner that is performing the hydrologic analysis shall perform floodflow-frequency analyses in accordance with the guidelines for determining floodflow frequency presented in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) and subsequent modifications. To use analysis techniques other than those outlined in Bulletin 17B, the Mapping Partner that is performing the hydrologic analysis shall obtain approval by the RPO and provide written justification for their use. The basic floodflow-frequency curve for gaged sites on unregulated streams may be obtained from the U.S. Geological Survey (USGS), Water Resources Division; from published reports of the USGS; or derived using methods described in Bulletin 17B. The annual maximum peak flows used in floodflow-frequency analyses are available on the USGS web page at http://water.usgs.gov/nwis/sw. Computer programs for performing Bulletin 17B analyses are available from the U.S. Army Corps of Engineers (USACE) *HEC-FFA Frequency Analysis* (USACE, 1992) and the USGS *PEAKFQ, Annual Flood Frequency Analysis Using Bulletin 17B Guidelines* (USGS, 1998).

The Mapping Partner that is performing the hydrologic analysis shall use the floodflow-frequency curve and adjust it, if necessary, to provide reliable flood discharge estimates for the site under consideration. The Mapping Partner that is performing the hydrologic analysis also may use the methodologies outlined in the USACE Engineering Manual No. 1110-2-1415 (USACE, 1993) to develop frequency curves for gaged streams. The Mapping Partner that is performing the hydrologic analysis shall document reasons for the modification and procedures that were used to modify the published USGS floodflow-frequency curves. When modeling mixed populations of hydrologic events, the Mapping Partner shall refer to Engineering Manual No. 1110-2-1415 (USACE, 1993) or Appendix F of these Guidelines.

Near a Gaging Station

Generally, for peak flood discharges for ungaged sites on a gaged stream, both the gaged site information and information from an appropriate regional estimate, where available, are to be considered. The Mapping Partner that is performing the hydrologic analysis shall select an appropriate transfer technique for establishing flood discharges at the ungaged location. The selected transfer technique shall consider the difference in the drainage areas at the gaged and ungaged sites. The procedures prescribed in most regional floodflow-frequency reports published by the USGS are recommended for this purpose. These transfer procedures usually use information from the gaged site and the regional estimate when the ungaged site is within 50 to 200 percent of the drainage area at the gaging station. In cases where a more specialized local study of a watershed may be more appropriate than one prepared by the USGS, the Mapping Partner shall consult with the RPO before proceeding.

For gaged streams with regulated flows, the Mapping Partner that is performing the hydrologic analysis may obtain peak flood discharges from the agency responsible for regulation. If the effects of regulation on floodflow frequency have not been established, the Mapping Partner that is performing the hydrologic analysis shall determine the most appropriate analysis technique and obtain approval from the RPO before proceeding. Guidance on regulated frequency analysis can be found in USACE Engineering Manual No. 1110-2-1415 (USACE, 1993)

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C.1.1.3 Ungaged Streams

Acceptable hydrologic analysis methods that the Mapping Partner that is performing the hydrologic analysis may use for ungaged streams include regional regression analyses and the rainfall-runoff model. These methods are discussed below.

Regional Regression Analysis

The Mapping Partner that is performing the hydrologic analysis shall make use of any valid existing floodflow-frequency analysis conducted by a Federal, State, or local agency that have authoritatively established and officially adopted the flood discharges for the ungaged stream under consideration, or the Mapping Partner shall make use of flood discharges from published FISs. In the absence of such an analysis or in cases in which the analysis is outdated, the Mapping Partner that is performing the hydrologic analysis shall use, where appropriate, the most recently published USGS report for estimating flood magnitude and frequency that is applicable to the Flood Map Project area. Such reports are generally available on a statewide basis. The Mapping Partner that is performing the hydrologic analysis shall exercise caution to ensure that these reports are used only for conditions and locations for which they are recommended.

USGS has published regression equations for estimating flood discharges for urban watersheds in several states including Alabama, Florida, Georgia, Missouri, North Carolina, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Virginia, Washington, and Wisconsin. Where the statewide reports do not contain procedures to account for urbanized conditions, or the statewide equations do not apply to the watershed conditions, the Mapping Partner that is performing the hydrologic analysis shall adjust the flood discharges determined for the rural condition. The Mapping Partner that is performing the hydrologic analysis shall use the techniques described in *Flood Characteristics of Urban Watersheds in the United States* (USGS, 1983) to adjust the flood discharges.

The Mapping Partner that is performing the hydrologic analysis may use the USGS "National Flood Frequency" program (USGS, 1994) to determine flood discharges of different frequencies for the continental United States, Alaska, Hawaii, and Puerto Rico for both rural and urbanized conditions. When a regression equation other than those published by the USGS is proposed, the Mapping Partner that is performing the hydrologic analysis shall obtain the approval of the RPO and shall justify the use of this equation.

USGS also has developed the region-of-influence method to estimate flood discharges, and computer programs have been published for Arkansas, Louisiana, and North Carolina. In the region-of-influence method, regression equations are computed for an ungaged site by selecting from a statewide database of gaging stations a predetermined number of stations having characteristics similar to the ungaged site. This method does not involve published regression equations. The Mapping Partner that is performing the hydrologic analysis may use the region-of-influence method; however, the Mapping Partner shall obtain the approval of the RPO and shall justify the use of this method.

Rainfall-Runoff Model

Where USGS regional regression equations are not applicable due to flow regulation, storage, watershed development, or other unique basin characteristics, the Mapping Partner that is performing the hydrologic analysis may obtain RPO approval to develop a rainfall-runoff model using a computer program such as HEC-HMS, HEC-1 or TR-20. A list of models accepted by FEMA for this purpose may be found on FEMA's Flood Hazard Mapping website at http://www.fema.gov/mit/tsd/en_modl.htm.

A wide variety of automation tools have been developed to facilitate hydrologic modeling. These products range from simple graphical user interfaces that help input model parameters to highly advanced GIS-based tools that contain state-of-the-art software and modeling approaches with fully integrated data processing, graphics, and visualization capabilities. The tools have been organized into three categories based on their relationship to accepted FEMA models. The following is the policy for their acceptance for use in FEMA's flood hazard mapping program.

- Category 1 Tools: These simple tools can be either pre-processing or post-processing independent modules. They function in conjunction with, but separately from, the executable file of a computer model that is on FEMA's accepted models list. These tools are considered acceptable for use in the flood hazard mapping program because they are not computer models themselves.

- Category 2 Tools: These software tools are computer models that perform modeling routines that emulate a model on FEMA's accepted model list; however, their source code has been rewritten to perform these tasks, instead of using the accepted model's source code. Category 2 software tools must be reviewed and placed on the list of accepted models.

- Category 3 Tools: These software tools use new hydrologic modeling methods and/or models not currently on the FEMA-accepted models list. They may add pre- or post-processing functions similar to the other categories of tools as well. Because these are new computer models, Category 3 software tools must be reviewed and placed on the list of accepted models.

In developing a rainfall-runoff model, the Mapping Partner that is performing the hydrologic analysis shall consider the following factors:

- The unit hydrograph method is preferred when developing hydrographs. However, subwatershed drainage areas shall be appropriately defined within the limit that the unit hydrograph is able to reflect watershed response to changing conditions.

- Loss rates must be varied when computing different frequency floods. Urbanization effects must be reflected in the loss rates.

- Time of concentration or lag computations must reflect effects of increases in velocities due to channel modifications and urbanization.

- Rainfall duration, at a minimum, must exceed the time of concentration for the watershed and must be large enough to capture all excess rainfall as well as provide reasonable runoff and sediment volumes when performing storage analyses. The Mapping Partner that is performing the hydrologic analysis may use the critical storm concept to determine the storm duration, or use the duration specified in guidelines developed by state agencies responsible for flood control or floodplain regulation. The critical storm is a design storm (total amount, duration, temporal distribution) which provides the highest flood discharge/water-surface elevation for the flooding source. The Mapping Partner that is performing the hydrologic analysis shall determine the critical storm through a sensitivity analysis of various storm durations to determine which storm duration produces the highest flood discharge/water-surface elevation (e.g., 6-hour vs. 24-hour). Note that for communities that only get short duration storms, the storm durations to be evaluated must be longer than the time of concentration of the watershed, and not the duration of the rainfall.

- Temporal distributions developed or recommended by Federal or State agencies responsible for flood control or regulating floodplains must be used.

- Streamflow routing methods must be able to analyze the attenuation and translation of hydrographs.

The Mapping Partner that is performing the hydrologic analysis shall calibrate the parameters in the models against known storms in the study area and, when available data permits, against a floodflow-frequency curve before the model is used to estimate flood discharges. The Mapping Partner that is performing the hydrologic analysis shall compare computed peak flood discharges from the hydrologic model to flood discharges from published regional studies (e.g., USGS regression equations) when they are applicable, or to flood discharges developed from gaging station data in watersheds with similar characteristics. If the discharge values are not comparable, the Mapping Partner that is performing the hydrologic analysis shall submit a Special Problem Report to the RPO to explain the differences before beginning the hydraulic analysis.

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C.1.2 Considerations for Restudies

In general, a restudy of hydrologic analyses could be initiated for any of four reasons:

1. To reflect longer periods of record or revisions in data;
2. To reflect changed physical conditions;
3. To take advantage of improved hydrologic analysis methods; or
4. To correct an error in the hydrologic analysis performed for the effective study.

Examples of changed physical conditions include the addition of a hydraulic structure or other watershed development that has affected the effective analyses. Regardless of the reason for the restudy, the Mapping Partner that is performing the hydrologic analysis shall provide detailed documentation of the changes that have been addressed in the restudy and why flood discharges developed for the restudy are more accurate than those developed for the effective FIS. If the reason for the restudy is an improved method, the Mapping Partner that is performing the hydrologic analysis shall provide documentation as to why the alternative method is superior and shall obtain RPO approval to use the improved method.

A study of a community's flood hazards may include a flooding source for which FEMA has not established BFEs. In these cases, the Mapping Partner that is performing the hydrologic analysis shall consult Subsection C.1.2.1 for necessary guidance on establishing flood discharges.

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C.1.2.1 Preliminary Hydrologic Analysis

The Mapping Partner that is performing the hydrologic analysis shall compare the proposed flood discharges to all available floodflow-frequency data that exist for the study area to ensure compatibility. The Mapping Partner that is performing the hydrologic analysis also shall inform the RPO, as well as Federal, State, and local agencies involved in water resources programs in the area, of the proposed flood discharges.

The Mapping Partner that is performing the hydrologic analysis shall resolve any discrepancies between available information and the flood discharges proposed for the Flood Map Project. That Mapping Partner shall bring such discrepancies shall to the attention of the RPO in a Special Problem Report, as flood discharge discrepancies shall not be the cause for delay in the study. In addition, the Mapping Partner that is performing the analysis shall keep the RPO informed of progress made in resolving such discrepancies.

Comparing Proposed and Effective Flood Discharges

In determining whether to grant a revision request, or to fund a detailed restudy of a community's flood hazards, revisions shall be considered only when a more recent floodflow-frequency analysis yields flood discharge values that are statistically significant from the effective flood discharges, or when flood discharges yield significant differences in base (1-percent-annual-chance) flood elevations (BFEs).

Determining Statistical Significance

The Mapping Partner that is performing the hydrologic analysis shall base the test for significance on the confidence limits of the more recent analysis. The new flood discharges shall be adopted if the previous flood discharges do not fall within the 95 and 5-percent confidence limits (90-percent confidence interval) of the recent estimates; the previous flood discharges shall be adopted if they fall within the 75 and 25-percent confidence limits (50-percent confidence interval) of the recent estimates. The Mapping Partner that is performing the hydrologic analysis shall consult Bulletin 17B for procedures on computing confidence limits for gaged streams. The computation of confidence and prediction limits for regression estimates is documented in statistical textbooks (Montgomery and Peck, 1982).

Significant Changes in Base Flood Elevations

When the effective flood discharges fall between the 50 and 90-percent confidence limits, the Mapping Partner that is performing the hydrologic analysis may use the step-backwater computation performed for the effective study to evaluate the effect of the new flood discharges on effective BFEs. If the new flood discharges yield BFEs that differ from the effective BFE obtained from the effective water-surface profile by more than 0.5 foot, a detailed hydrologic analysis shall be conducted. Otherwise, the Mapping Partner that is performing the hydrologic analysis for a selected stream shall not restudy the stream at this time, unless other substantial changes in hydraulic conditions exist, such as channelization and construction of flood-control structures; or unless there are errors in the effective study.

Where significantly different flood discharges are proposed for use, the Mapping Partner that is performing the hydrologic analysis shall contact the RPO immediately for approval. Where confidence limit tests are not applicable, the Mapping Partner that is performing the hydrologic analysis shall bring unresolved discrepancies to the attention of the RPO. The determining factor then becomes the effect on the BFE as described above.

Choice of Methodology

The hydrologic methodology shall be determined during the scoping process for the study and include input from FEMA and the Mapping Partner(s). The complexity of the study and the effective models and methodology shall be considered in making this choice.

The Mapping Partner that is performing the hydrologic analysis shall apply frequency analysis of flow data at gaging stations, using procedures provided in Bulletin 17B (Interagency Committee on Water Data, 1982) wherever possible. When the systematic record at a gaging station is less than 50 years, the Mapping Partner that is performing the hydrologic analysis shall weight the results with estimates from other methods, such as USGS regression equations. The Mapping Partner that is performing the hydrologic analysis may use the method developed by Hardison, published in USGS Professional Paper 750-C, to estimate the equivalent years of record for regression equations that are needed in the weighting process (USGS, 1971). Guidance on weighting two estimates of flood discharges is also given in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982), and USGS regression equation reports.

USGS regression equations, adjusted for urbanization if appropriate, are recommended for estimating the existing-conditions base flood discharges for restudied streams if a flood hydrograph is not required and if the regression equations are applicable to the restudied streams. The regression equations are to be applied only to streams having characteristic parameter values that are within the range of values of the gages used to develop the regression equations.

For watersheds with existing hydrologic models, the Mapping Partner that is performing the hydrologic analysis may use an existing model in lieu of USGS regression equations if the model was calibrated. Such models must, however, be updated to account for any development that has occurred in the watershed since the existing model was created. The Mapping Partner that is performing the hydrologic analysis shall exercise caution when selecting a methodology for watersheds that are undergoing or are projected to undergo development. In such cases, the Mapping Partner that is performing the hydrologic analysis shall consider developing a rainfall-runoff model in lieu of a gaged analysis with non-homogeneous data or the use of regression equations.

The Mapping Partner that is performing the hydrologic analysis shall calibrate the parameters in rainfall-runoff models against major known storms that exceed 10-percent-annual-chance events for single-event analysis if the data are available. The data to calibrate the model are to include the following:

- Peak flood discharges developed at gaging stations, computed by indirect methods (e.g., computations at bridge cross sections based on high-water marks), or flood discharge hydrographs from responsible agencies;

- Rainfall distribution, reported at a minimum of hourly intervals, at rain gages within the storm area and within or near the watershed being studied;

- Total rainfall values at rain gages within the storm area or isohyetal map of the storm, indicating the duration of the storm;

- Rainfall and soil moisture conditions before the storm for single-event analysis.

Observed high-water marks may also be of value when calibrating both hydrologic and hydraulic models against historical events.

The Mapping Partner that is performing the hydrologic analysis may calibrate the rainfall-runoff model against the various flood discharges of a frequency analysis. Regardless of whether models have been calibrated against historical events, further calibration may be required to produce floodflows from the 10-percent-annual-chance, 2-percent-annual-chance, 1-percent-annual-chance, and 0.2-percent-annual-chance rainfall that are comparable to the floodflows from the frequency analysis, if records are available. If reasonable matches cannot be reached by maintaining calibration parameters within acceptable ranges, then the Mapping Partner that is performing the hydrologic analysis shall review the model methodology and its application to the watershed.

Where models are calibrated against historical events and are applied properly, and where the modeled floodflows and frequency floodflows do not agree, the Mapping Partner that is performing the hydrologic analysis shall consider adjusting the design rainfall's volume and distribution. The design rainfall distribution is typically selected from traditional distributions prepared by the Natural Resources Conservation Service (NRCS) and USACE, but recommendations from State agencies responsible for flood control or floodplain management regarding state or regional distributions also may be accepted.

Where feasible, in coordination with Federal and State agencies, the Mapping Partner that is performing the hydrologic analysis shall select a reasonable rainfall distribution for the model to best simulate floodflows corresponding to a frequency analysis in accordance with the guidance of Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). For flooding sources where the volume of flood discharge is the major concern, such as ponds in a closed basin, the Mapping Partner that is performing the hydrologic analysis may determine the rainfall duration by comparing the calculated lake stages with the stage-frequency curve.

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C.1.2.2 Preliminary Hydrologic Analysis Submittal Requirements

The Mapping Partner that is performing the hydrologic analysis shall submit the preliminary results of the analysis to the FEMA RPO or other identified FEMA regional engineer for review prior to completing and submitting the hydraulic analysis. The FEMA Lead, RPO, or other regional engineer shall forward the analysis to the appropriate PO at FEMA HQ for subsequent review by a Mapping Partner selected by FEMA to review the hydrologic analysis.

To avoid internal discontinuities in the restudy data, proposed flood discharge values must be compatible with those in the effective analyses at the limits of detailed study. Should significant discontinuities exist between the updated flood discharges and those used in the effective FIS, the Mapping Partner that is performing the hydrologic analysis shall consult with the RPO and submit a Special Problem Report.

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C.2 Hydrologic Review

A Mapping Partner selected by FEMA, identified during the initial Scoping Meeting (see Volume I, Section 1.3 of these Guidelines), shall review the proposed flood discharges prior to their being used in hydraulic analyses. The intent is to agree on the 1-percent-annual-chance flood discharges before the hydraulic analyses are conducted, and to avoid hydraulic and mapping analysis revisions necessitated by subsequent flood discharge revisions. Therefore, the Mapping Partner that is performing the hydrologic analysis shall work with FEMA to ensure that hydrology issues are identified as early as possible. This early review could reduce the level of effort during both the study and the production of the FIS Report and FIRM.

The goal of the hydrologic review is to provide an assessment of the "reasonableness" of the proposed 1-percent-annual-chance flood discharges and, if necessary, to suggest alternative methods that may provide more reasonable flood discharges. The reasonableness of a flood discharge depends on the requirements of the study and its selected methodologies. The Mapping Partner that is reviewing the hydrologic analysis (hereinafter referred to as the reviewing Mapping Partner) shall check all methods for the reasonableness of their specific application and the sources of the data. A comparison of proposed flood discharges against criteria related to the regression equations is a good first screening tool; however, it does not replace the need to review the applied methodology.

In addition to comparing proposed flood discharges to those derived from gaged data and regression equations, the reviewing Mapping Partner shall compare the proposed flood discharges to the effective flood discharges, noting any significant discrepancies and possible reasons for those discrepancies. Also, the reviewing Mapping Partner shall consider the effect on BFEs as a result of different flood discharges (not just changes in flood discharges) as a check on reasonableness.

The procedures detailed below are recommended for preliminary hydrologic reviews of analyses submitted in support of studies and restudies, map revisions, and appeals. They are applicable to hydrologic analyses conducted using gaging station data, regional regression equations, and rainfall-runoff models.

[February 2002]

C.2.1 Hydrologic Analysis Based on Gaging Station Data

Proposed 1-percent-annual-chance flood discharges based on gaging station data are generally reviewed for conformance to the guidelines in Bulletin 17B (Interagency Committee on Water Data, 1982). If procedures other than those outlined in Bulletin 17B were applied, then the reviewing Mapping Partner shall determine whether these procedures are reasonable. At least 10 years of record are needed to define the 1-percent-annual-chance flood discharge; however, estimates based on shorter periods of record shall be compared to flood estimates based on precipitation data and to regional estimates for similar watersheds as described in Bulletin 17B. In more arid regions, there are often many years when the annual peak flow is zero. For these conditions, at least 10 years of nonzero flow are recommended for defining the 1-percent-annual-chance flood discharge.

Floodflow-frequency curves for gaging stations are routinely published by the USGS as part of regional floodflow-frequency studies. The reviewing Mapping Partner can compare these published flood discharges to the proposed flood discharges to judge their reasonableness. The Mapping Partner shall compare the effective flood discharges to the confidence limits of the proposed flood discharges to determine which flood discharges are more appropriate.

For regulated watersheds, floodflow-frequency curves are often developed for unregulated conditions and then converted to regulated conditions by utilizing the current reservoir operation criteria. The designated Mapping Partner shall review the regulated floodflow-frequency curve to determine whether acceptable procedures were used to convert to regulated conditions. Guidance on regulated frequency analysis can be found in USACE Engineering Manual No.1110-2-1415 (USACE, 1993).

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C.2.2 Hydrologic Analysis Based on Regional Regression Equations

The reviewing Mapping Partner shall compare the proposed 1-percent-annual-chance flood discharges computed from regional regression equations to the effective flood discharge, to flood discharges from other (published) regression equations that are applicable to the region, and to flood discharges at gaging stations in the vicinity. In general, proposed regional regression equations should be the most recent published equations developed by the USGS for the region unless justification is provided for the use of earlier equations.

The reviewing Mapping Partner shall assume the proposed regression equations are applicable if the watershed, climatic, and urbanization characteristics of the ungaged sites are within the range of those at the gaging stations used to develop the equations, and if flow is not regulated. If appropriate, the regional regression equations may be adjusted for urbanization using procedures in *Flood Characteristics of Urban Watersheds in the United States* (USGS, 1983) or, if available, urban regression equations for the applicable state or metropolitan area.

The reviewing Mapping Partner shall compare the proposed regression estimates to gaging station estimates in nearby watersheds having similar characteristics to those of the studied streams. The reviewing Mapping Partner may obtain estimates of 1-percent-annual-chance flood discharges at nearby gaging stations from published USGS regional flood reports if the frequency curves were published in the last 10 years and if no major floods have occurred in the intervening time. Otherwise, floodflow-frequency estimates for the gaging stations are to be updated in accordance with Bulletin 17B (Interagency Advisory Committee on Water Data, 1982).

The reviewing Mapping Partner shall plot the 1-percent-annual-chance flood discharge estimates from these sources against drainage area on logarithmic paper to determine whether the proposed flood discharges are reasonable. Confidence intervals of the gaging station estimates may be estimated using Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) or procedures given in *Frequency and Risk Analysis* (Kite, 1999) or in *Handbook of Hydrology* (Maidment, 1993). The reviewing Mapping Partner may use the 68-percent confidence interval, which is analogous to plus or minus one standard error for a normal distribution, to judge the reasonableness of flood discharges derived from regression equations. If the proposed flood discharges generally lie within the 68-percent confidence interval of the gaged data, then these flood discharges are accepted as reasonable for the hydraulic analysis. If not, then options for obtaining more reasonable flood discharges shall be provided.

The reviewing Mapping Partner shall use caution in reviewing 1-percent-annual-chance flood discharges derived from regression equations that are significantly different from those derived from gage data. When the regression estimates differ significantly from data from long-term gaging stations and the elevation difference is significant, the regression estimate may be adjusted based on the gaging station data.

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C.2.3 Hydrologic Analysis Based on a Rainfall-Runoff Model

The reviewing Mapping Partner shall first verify that the rainfall-runoff model used by the Mapping Partner that performed the hydrologic analysis is included on FEMA's Acceptable Models List, which is posted on the FEMA Flood Hazard Mapping website at http://www.fema.gov/mit/tsd/en_modl.htm. The reviewing Mapping Partner shall compare the proposed 1-percent-annual-chance flood discharges from the rainfall-runoff model to the flood discharges from USGS regional regression equations (if they are applicable) and to flood discharges at gaging stations in the vicinity. Procedures for developing estimates from gaging station data and regression equations are discussed in Subsections C.2.1 and C.2.2.

The reviewing Mapping Partner shall plot the flood discharge estimates from these sources against drainage area on logarithmic paper to determine if the proposed flood discharges are reasonable. Plus or minus one standard error bars (68-percent confidence intervals) shall be shown about the regression and gaging station estimates. The USGS regional flood reports typically provide the standard error of prediction or estimate. The reviewing Mapping Partner shall use the standard error of prediction, if available, because this is more indicative of the predictive accuracy of the equations.

The proposed flood discharges from the rainfall-runoff model are considered reasonable if they are generally within one standard error of the regression and gaging station estimates. If not, the reviewing Mapping Partner shall review the rainfall-runoff model in greater detail to determine why there are significant differences. Some unique characteristics of the watershed may explain these differences and justify the use of the proposed rainfall-runoff model estimates, and the reviewing Mapping Partner that performed the hydrologic analysis shall provide detailed information to explain these unique characteristics.

Even if the criteria for flood discharge reasonableness are satisfied, a review of the rainfall-runoff model is advisable to determine that the model was applied appropriately. Recommendations to use a reasonable flood discharge in the hydraulic model cannot be made if the calculation of the flood discharges was incorrect and yielded reasonable flood discharges only by chance. Such a study is subject to appeal or protest on the basis of being scientifically or technically incorrect.

In watersheds with significant storage, hydrologic routing may be needed in estimating the flood discharges. Some hydrologic routing methods require a relationship between the water-surface elevation and the cross-sectional area, or the floodplain storage area between cross sections. For those methods, a hydraulic model is required as part of the hydrologic analysis, and the hydraulic model used to generate rating curves shall be provided for review with the hydrologic model.

The reviewing Mapping Partner shall ensure that the rainfall-runoff model has been calibrated against available data as described in Subsection C.1.1.3. Where reliable gaging station data are available, the rainfall-runoff model must be calibrated against them.

In ungaged watersheds where high-water marks from major flood events are available, the reviewing Mapping Partner shall ensure that the rainfall-runoff model and the hydraulic model have been calibrated against the high-water marks. If no high-water marks from major events exist, and regression equations are determined not to be applicable, the Mapping Partner that performed the hydrologic analysis shall provide a detailed explanation of the rainfall-runoff model, and the designated Mapping Partner shall review the model in detail to determine flood discharge reasonableness.

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C.2.4 Hydrologic Review Documentation

The reviewing Mapping Partner shall document the results of the review in a memorandum or letter that will be sent to the RPO and to the Mapping Partner that performed the hydrologic analysis. The documentation shall describe the review approach and conclusions (whether flood discharges are reasonable or unreasonable) and shall provide options for resolving any concerns.

If the proposed flood discharges are determined to be unreasonable, the options may include, but are not limited to:

- Requesting further justification or documentation that the proposed 1-percent-annual-chance flood discharges shall be used;
- Suggesting an alternative study method; or
- Revising the analysis to obtain more reasonable results.

[February 2002]

C.3 Detailed Hydraulic Analyses

During the initial Scoping Meeting (Volume 1, Section 1.3 of these Guidelines), the RPO or other FEMA Lead and other members of the Flood Map Project Management Team will decide which flooding sources within the community will be studies using detailed hydraulic analyses. Guidance for performing these analyses is provided in the subsections that follow.

[February 2002]

C.3.1 General Guidance

The Mapping Partner that is performing the hydraulic analysis shall use, to the maximum extent possible, all valid existing flood elevation, survey, and other pertinent information for the study area. Whenever existing 1-percent-annual-chance flood elevations are available for the study area, the Mapping Partner that is performing the hydraulic analysis shall assess their validity without undertaking extensive computations or reanalysis. Except where significant changes in flood discharges, floodplain geometry, or flooding characteristics have occurred, or errors in the original computations have been found, such elevations shall be considered valid for use in a Flood Map Project carried out for NFIP purposes.

If an existing study that contains a valid 1-percent-annual-chance Flood Profile does not provide other profiles or a required floodway that may be required for the Flood Map Project, the Mapping Partner that is performing the hydraulic analysis shall attempt to obtain the original hydraulic model and use it to generate this information. Whenever the original model is unavailable or unusable, the RPO, through the Assistance Officer, may choose to remove the requirement for these additional elevations and floodway data or request that they be determined by a simplified analysis.

In any case, the Mapping Partner that is performing the hydraulic analysis shall obtain approval from the RPO before performing hydraulic analyses for flooding sources that have previously established 1-percent-annual-chance flood elevations. The Mapping Partner shall not study areas having a drainage area less than 1 square mile unless RPO approval has been obtained.

The Mapping Partner that is performing the hydraulic analysis shall carefully estimate the roughness coefficients for use in backwater computations. The estimates, prepared by experienced engineers, shall include the consideration that roughness may vary with flood stages, depending on such factors as the width-to-depth ratio of streams, vegetation in the channel and overbanks, and materials of the channel bed. Wherever possible, the Mapping Partner that is performing the hydraulic analysis shall calibrate hydraulic models using measured profiles, reliable high-water marks, or reliable stage information at stream gages for past floods. Models must match known high-water marks within 0.5 foot.

The Mapping Partner that is performing the hydraulic analysis shall not calibrate against data that result in roughness coefficients out of the realm of published roughness coefficients for similar observed conditions. If such data are lacking or are out of date, the Mapping Partner that is performing the hydraulic analysis shall determine the roughness coefficients using Cowan's method (Federal Highway Administration, 1984) based on a field inspection of the channel and floodplain and compare the new roughness coefficients to roughness coefficients published in Federal agencies documents and hydraulic text books.

It is extremely important that the Mapping Partner that is performing the hydraulic analysis select roughness coefficients in overbank areas to carefully represent the effective flow in those areas. There is a general tendency to overestimate the amount of flow occurring in overbank areas, particularly in broad, flat floodplains. The Mapping Partner shall document the use of roughness coefficients to define ineffective-flow areas clearly in the FIS Report.

Before preparing work maps, the Mapping Partner that is performing the hydraulic analysis shall reconcile the 1-percent-annual-chance Flood Profile proposed for the Flood Map Project with all available published or unpublished information. Any discrepancies shall be identified and resolved by the Mapping Partner that is performing the analysis in consultation with the RPO and the Mapping Partner producing the final FIS Report and FIRM (in most cases, the reviewing Mapping Partner). Except where a clearly identified change in flooding characteristics or an error in the existing data can be shown, the proposed 1-percent-annual-chance flood elevations must agree with those of other contiguous studies of the same flooding source within 0.5 foot of the contiguous elevation. However, the final 1-percent-annual-chance flood elevation or Flood Profile submitted with the FIS report must match the contiguous study exactly.

Where elevations cannot be reconciled within 0.5 foot because of changed flooding conditions or an error in the previous analysis, the Mapping Partner that is performing the hydraulic analysis shall provide a full explanation and justification for the difference to the RPO in a Special Problem Report. The Mapping Partner that is performing the hydraulic analysis shall obtain approval for the discrepancy in 1-percent-annual-chance flood elevations from the RPO before proceeding.

[February 2002]

C.3.2 Flood Insurance Studies

The detailed hydraulic analysis for a FIS will include flood elevation determination for the communities under Part 60.3(c) of the NFIP regulations, and the flood elevation determination and floodway determination for the communities under Part 60.3(d) of the NFIP regulations.

[February 2002]

C.3.2.1 Flood Elevation Determination

The Mapping Partner that is performing the hydraulic analysis normally shall determine flood elevations for the 10-, 2-, 1-, and 0.2-percent-annual-chance floods, unless otherwise instructed by the RPO. These flood elevations must be referenced to the National Geodetic Vertical Datum of 1929 (NGVD29) or the North American Vertical Datum of 1988 (NAVD88).

Flood elevations for riverine areas are normally determined by step-backwater computer models such as the USACE Hydrologic Engineering Center's HEC-RAS Computer Program (USACE, 2001) or the USGS/Federal Highway Administration (FHWA) WSPRO computer model (USGS and FHWA, 1999). Regardless of the hydraulic model used, the Mapping Partner that is performing the hydraulic analysis shall follow modeling techniques specified in the most recent version of the appropriate user's manual.

In addition, the Mapping Partner that is performing the hydraulic analysis using HEC-RAS shall provide input and output files in the HEC-RAS native file format, although the Mapping Partner may use a variety of shell programs to conduct analyses. The numerical models currently accepted by FEMA for use in the NFIP are listed on the FEMA Flood Hazard Mapping website (http://www.floodmaps.net/mit/tsd/en_modl.htm).

A wide variety of automation tools have been developed to facilitate hydraulic modeling. These products range from simple graphical user interfaces that help input model parameters to highly advanced GIS-based tools that contain state-of-the-art software and modeling approaches with fully integrated data processing, graphics, and visualization capabilities. The tools have been organized into three categories based on their relationship to accepted FEMA models. The following is the policy for their acceptance for use in FEMA's flood hazard mapping program.

- Category 1 Tools: These simple tools can be either pre-processing or post-processing independent modules. They function in conjunction with, but separately from, the executable file of a computer model that is on FEMA's accepted models list. These tools are considered acceptable for use in the flood hazard mapping program because they are not computer models themselves.

- Category 2 Tools: These software tools are computer models that perform modeling routines that emulate a model on FEMA's accepted model list; however, their source code has been rewritten to perform these tasks, instead of using the accepted model's source code. Category 2 software tools must be reviewed and placed on the list of accepted models.

- Category 3 Tools: These software tools use new hydraulic modeling methods and/or models not currently on the FEMA-accepted models list. They may add pre- or post-processing functions similar to the other categories of tools as well. Because these are new computer models, Category 3 software tools must be reviewed and placed on the list of accepted models.

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C.3.2.2 Floodway Determination

A regulatory floodway is defined as the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the 1-percent-annual-chance flood without cumulatively increasing the water-surface elevation by more than a designated height. The NFIP regulations designate a height of 1.0 foot. Regulatory floodways are developed as unobstructed waterways to convey floodwaters. The community is responsible for maintaining the conveyance of flooding sources to mitigate flood hazards.

If the State in which the Flood Map Project is being performed has established more stringent regulations for the maximum allowable rise in water-surface elevations, through legally enforceable statutes, then these regulations shall take precedence over the NFIP regulatory standard. In the case of streams that form the boundary between two or more States, the 1.0-foot maximum allowable rise criterion shall be used unless the States have previously agreed on a lesser rise criterion. The Mapping Partner that is performing the hydraulic analysis shall obtain the written approval of the RPO, through the Assistance Officer, before computing or mapping a second regulatory floodway based on a criterion established by the community.

When flow is in the supercritical regime for manmade channels, or where velocity conditions are such that normal encroachment analyses are not possible or are inappropriate, the encroachment stations may be computed so that the allowable rise in water-surface elevation may match the target water surface without exceeding the target energy.

Surcharge values must be between zero and the maximum allowable value. Negative surcharge values may be caused by excessive encroachment, errors in bridge modeling, or insufficient encroachment at a downstream section. If attempts to eliminate negative surcharges are unsuccessful, the Mapping Partner that is performing the hydraulic analysis shall contact the RPO and the reviewing Mapping Partner for guidance.

Normally, the Mapping Partner that is performing the hydraulic analysis shall determine the regulatory floodway using equal reduction of conveyance on opposite sides of the stream. If equal reduction of conveyance is not technically appropriate, or where unusual flow patterns are encountered (e.g., interbasin flow, divided flow), the Mapping Partner that is performing the analysis shall coordinate with the RPO in selecting the most appropriate engineering methods. Where the regulatory floodway designation affects contiguous communities on opposite sides of a flooding source, the Mapping Partner that is performing the hydraulic analysis must use equal reduction of conveyance.

The Mapping Partner that is performing the hydraulic analysis shall compute the regulatory floodway on a tributary stream based on the 1-percent-annual-chance flood discharge and elevation of that stream only and normally shall not include consideration of any backwater flooding from the main stream. Therefore, the floodway elevations in the lower reach of a tributary subject to backwater flooding may be lower than those used to plot the Flood Profiles.

The Mapping Partner that is performing the hydraulic analysis shall achieve the maximum allowable surcharge (e.g., 1.0 foot) at the upstream-most cross section in a downstream community that does not have a regulatory floodway, when performing a floodway analysis for upstream communities. This is necessary to avoid excessive increases that would occur if the downstream community decides to establish a floodway. In addition, the Mapping Partner that is performing the hydraulic analysis shall determine the starting water-surface elevation for a floodway analysis at the first cross section using the same friction slope as the 1-percent-annual-chance natural Flood Profile.

The Mapping Partner that is performing the hydraulic analysis shall use an equal conveyance reduction method to establish the regulatory floodway. The total conveyance between the natural Flood Profile and the floodway profile must not differ by more than 1 percent. If they differ, then the Mapping Partner that is performing the hydraulic analysis shall use the encroachment stations obtained from the equal conveyance reduction method and the same starting friction slope of the natural Flood Profile for the floodway profile to determine the starting floodway water-surface elevation and the surcharge value. The computed surcharge value must not be more than the allowable surcharge value of each State.

If a regulatory floodway has been determined for the downstream community, the Mapping Partner that is performing the hydraulic analysis shall use the same flood discharges and corresponding flood elevations for different flood frequencies, floodway water-surface elevation, and the floodway width of the most upstream cross section of the downstream community as the starting conditions for the upstream community.

If storage areas behind structures are accounted for in the flood discharge computations by routing the 1-percent-annual-chance flood hydrograph, and no encroachment is to be allowed, the floodway encroachment stations must be equal to the 1-percent-annual-chance floodplain boundary of the storage area. In this case, the Mapping Partner that is performing the hydraulic analysis shall use the same flood discharge for the unencroached and encroached profiles in the step-backwater analysis to determine the surcharge values. However, if the storage area is to be encroached, then the Mapping Partner must determine the flood discharges for the encroached profile downstream of the structure by routing the 1-percent-annual-chance flood hydrograph through the reduced storage area. In this case, the flood discharge for the encroached profile may be greater than the flood discharge for the unencroached profile in the step-backwater analysis.

Regulatory floodways are not normally delineated in coastal high-hazard areas (Zones V1-30, VE, and V). The Mapping Partner that is performing the hydraulic analysis shall base the computation of regulatory floodways on rivers in coastal floodplains on the 1-percent-annual chance flood discharge and elevations of the rivers only. The Mapping Partner that is performing the hydraulic analysis shall terminate the regulatory floodway at the boundary of the V1-30, VE, or V Zone or where the mean high tide exceeds the 1-percent-annual chance riverine flood elevation, whichever occurs further upstream.

The Mapping Partner that is performing the hydraulic analysis shall begin to coordinate all regulatory floodway determinations with State and community officials and FEMA as early as possible. Where the floodplain is entirely contained within one community, the Mapping Partner that is performing the hydraulic analysis shall coordinate the location of the regulatory floodway with the State NFIP Coordinator, the community, and the FEMA Consultation Coordination Officer through the RPO. This coordination shall not be a reason for delaying the Flood Map Project. If the coordinating parties cannot reach an agreement regarding a floodway determination before the final community coordination meeting, the Mapping Partner that is performing the hydraulic analysis shall determine the regulatory floodway as described earlier in this subsection.

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C.3.3 Restudies

The physical data in the detailed hydraulic analysis for restudies are to be based on the data from the effective study, subsequent revisions, and additional data that are not in the effective study and the revisions. The Mapping Partner that is performing the hydraulic analysis shall recompute flood discharges to reflect the existing condition of the watershed. Detailed guidance on the flood elevation determination and the floodway determination are provided below.

[February 2002]

C.3.3.1 Flood Elevation Determination

Except in cases where errors in measurements or modeling have been found, or where substantial changes in topographic conditions are not reflected in the effective FIS, the Mapping Partner that is performing the hydraulic analysis shall obtain cross-sectional and structural information for the hydraulic model from step-backwater computer models of the effective FIS. In the case of topographic changes, the Mapping Partner that is performing the hydraulic analysis shall revise only the affected cross sections; the remaining data are to come directly from the existing models. The Mapping Partner shall review the existing data for accuracy. If errors in the existing data are detected, the Mapping Partner that is performing the hydraulic analysis shall coordinate a solution with the RPO.

It is important to note that a Flood Map Project may include a detailed study for flooding sources that do not have established BFEs. In these cases, the Mapping Partner that is performing the hydraulic analysis shall consult Subsection C.3.2 for necessary guidance.

To compute the water-surface profiles the Mapping Partner that is performing the hydraulic analysis shall use the existing-conditions 10-percent-annual-chance, 2-percent-annual-chance, 1-percent-annual-chance, and 0.2-percent-annual-chance flood discharges as determined during the hydrologic analysis in the standard step-backwater computer program used to prepare the effective FIS report and FIRM. The Mapping Partner that is performing the hydraulic analysis shall use the most recent version of the effective computer models to reduce the cost in setting up the hydraulic model. The use of alternative computer programs must be approved by the RPO and satisfy the criteria outlined in Subsection C.3.2.1. Roughness coefficients in the model must reflect existing conditions and must be verified by field reconnaissance and backwater studies of observed floods.

The Mapping Partner that is performing the hydraulic analysis shall obtain RPO approval in choosing the standard step-backwater computer program.

[February 2002]

C.3.3.2 Floodway Determination

The Mapping Partner that is performing the hydraulic analysis shall maintain the effective regulatory floodway configuration wherever possible. If it is not possible to retain the existing configuration, then the Mapping Partner that is performing the hydraulic analysis shall contact the FEMA Lead RPO for guidance. If a revised floodway analysis is deemed necessary, the Mapping Partner that is performing the hydraulic analysis shall consult the information pertaining to regulatory floodways presented in Subsection C.3.2.2.

Because the community has implemented floodplain management decisions based on the effective regulatory floodway, it is important that the Mapping Partner that is performing the hydraulic analysis determine initially whether the effective floodway may be retained given the changes that have occurred along a particular flooding source. However, floodway revisions are justifiable and necessary if data indicate an increase in surcharge above the maximum limit, or if, as a result of improved data, the width or configuration of the regulatory floodway necessitates a change from that shown on the effective FIRM or FBFM. When revisions to the regulatory floodway will necessitate changes to the effective FIRM or FBFM, the Mapping Partner that is performing the hydraulic analysis shall notify the RPO immediately so that the RPO can coordinate with the community as soon as possible.

[February 2002]

C.3.4 General Modeling Methodologies and Guidance

During the course of a Flood Map Project, the Mapping Partner that is performing the hydraulic analysis may encounter unique hydraulic situations that require specialized modeling techniques to determine potential flood hazards accurately. Guidance to be considered in selecting a model to handle these situations is presented below. The complete list of models accepted by FEMA for use in the NFIP is listed on the FEMA Flood Hazard Mapping website at http://www.floodmaps.net/mit/tsd/en_modl.htm.

[February 2002]

C.3.4.1 One-Dimensional Unsteady Flow Models

The Mapping Partner that is performing the hydraulic analysis may use one-dimensional unsteady flow models where appropriate (e.g., floodplains with substantial overbank storage areas; streams where a reversal of flow may occur; complex pipes, channels, ponds, and reservoir systems). To use a one-dimensional unsteady flow model, the Mapping Partner that is performing the hydraulic analysis must first obtain approval from the RPO. Regulatory floodways determined using unsteady flow models must be developed through an interactive trial-and-error procedure and must be based on equal conveyance reduction.

[February 2002]

C.3.4.2 Two-Dimensional Water-Surface Computer Models

Two-dimensional computer models are used to simulate surface-water flow in two directions in a horizontal plane, such as in shallow flooding areas, split-flow situations, and at complex bridge sites. The Mapping Partner that is performing the hydraulic analysis also may use two-dimensional models in areas subject to alluvial fan flooding. This type of model will be used where one-dimensional models, currently accepted techniques, and engineering judgment will not provide satisfactory information for floodplain management and NFIP purposes. Regulatory floodways determined using two-dimensional models must be developed through an interactive trial-and-error procedure and must be based on equal conveyance reduction.

[February 2002]

C.3.4.3 Starting Water-Surface Elevations

In general, the starting water-surface elevations chosen for profile computations are to be based on normal depth (or slope-area), unless known water-surface elevations are available from other sources. When using normal depth on the main channel of any flooding source, the Mapping Partner that is performing the hydraulic analysis shall start the model several cross sections downstream of the corporate limits. For starting conditions on tributaries, the Mapping Partner that is performing the hydraulic analysis shall use normal depth unless a coincident peak situation is assumed, or the tributary flow depths are higher than the corresponding mainstream events.

The assumption of coincident peaks may be appropriate if all of the following are true:

- The ratio of the drainage areas lies between 0.6 and 1.4;
- The times of peak flow are similar for the two combining watersheds; and

- The likelihood of both watersheds being covered by the storm being modeled is high.

If gage records are available for the basins, the Mapping Partner that is performing the hydraulic analysis shall obtain guidance from the RPO on coincidence of peak flows using streamflow records.

[February 2002]

C.3.4.4 Modeling Techniques for Flooding Sources with Supercritical Flow Regimes

Step-backwater analyses are normally performed in a hydraulic model from downstream to upstream as subcritical profile runs for the stream reach studied. Critical depth messages appear in the computer model output of backwater runs at several consecutive cross sections if supercritical flow occurs.

For natural streams, the Mapping Partner that is performing the hydraulic analysis shall use critical depth at all times where supercritical flows occur, including the plotting of water-surface profiles. For concrete-lined channels, the Mapping Partner that is performing the hydraulic analysis shall perform a supercritical run for the project area.

For modified channels, the composite roughness coefficient accounts for the sediment that accumulates on the channel bottom and for the lined surface of the sides of the channel. The hydraulic analysis must extend both upstream and downstream of the project area to have a smooth transition between subcritical and supercritical profiles. The Mapping Partner that is performing the hydraulic analysis shall draw the water-surface elevations from the subcritical run downstream of the project horizontally until they cross the supercritical profiles to eliminate drawdowns. The Mapping Partner that is performing the hydraulic analysis shall check velocities at bends to determine potential erosion. The Mapping Partner must obtain approval to deviate from these procedures from the RPO.

[February 2002]

C.3.4.5 Split-Flow Analyses

The Mapping Partner that is performing the hydraulic analysis is to consider split-flow analyses when a stream overflows its banks and takes a different flow path. The analyses are to address the reduction of flow in the downstream reach with respect to the multiple-Flood Profile and regulatory floodway. Because overbank flood discharges may flow into another stream, the Mapping Partner that is performing the hydraulic analysis shall consider possible increases in flood discharges on the other stream. The Mapping Partner that is performing the hydraulic analysis shall ensure that the overflow segment on the mainstream remains open by determining a separate regulatory floodway for the overflow path, or by a note on the FIRM or FBFM stating that the overflow area remains unencroached until a detailed hydraulic analysis is performed to establish a regulatory floodway. The Mapping Partner that is performing the hydraulic analysis shall inform the RPO when overbank flow paths lead into another jurisdiction where a regulatory floodway has not been computed, thus necessitating that the overflow area remain unencroached.

The RPO may approve, as an alternative, that the Mapping Partner determine the floodway on the mainstream downstream of the overflow area by determining the floodway profile with the total flow (including the flow lost as overflow). The Mapping Partner that is performing the hydraulic analysis shall compare the water-surface elevations from the floodway profile to the water-surface elevations of the 1-percent-annual-chance natural Flood Profile (which has been reduced because of flow lost as overflow) to determine surcharges. If the calculated surcharge is less than or equal to the allowable surcharge, then the Mapping Partner that is performing the hydraulic analysis shall depict the regulatory floodway on the mainstream only. Otherwise, this Mapping Partner shall compute a separate regulatory floodway for the overflow path.

[February 2002]

C.4 Approximate Analyses

Flooding sources that are selected for study by approximate methods will fit into one of the following four categories:

1. Flooding sources for which previously determined approximate 1-percent-annual-chance floodplain boundaries will be adjusted in accordance with updated topographic information;

2. Flooding sources for which new technical information will be used to update approximate 1-percent-annual-chance floodplain boundaries;

3. Flooding sources that were previously unstudied or that have been studied but the previous approximate 1-percent-annual-chance floodplain boundaries are considered unreasonable from an engineering standpoint; for which simplified hydraulic analyses will be performed to delineate the approximate 1-percent-annual-chance floodplain; or

4. Flooding sources that were previously studied by detailed methods, with appropriate floodplain boundaries and BFEs, where the Special Flood Hazard Area is being redesignated as an approximate Zone A because of uncertainty regarding the BFEs. The redesignation of detailed-study area to approximate Zone A must be approved by the RPO.

For those areas for which approximate hydrologic and hydraulic analyses are to be performed, the Mapping Partner that is performing the hydraulic analysis shall select appropriate methods in coordination with the RPO. The most common methods and models are discussed in Subsections C.4.1, C.4.2, and C.4.3. The Mapping Partner that is performing the hydraulic analysis and RPO shall consider the factors of cost, watershed development potential, and existing development when selecting the methods to use. In addition, the Mapping Partner that is performing the hydraulic analysis may recommend or the RPO may specify that the flood elevations be established using the methods discussed below.

[February 2002]

C.4.1 Hydrologic Methods for Determining Approximate Flood Discharges

The Mapping Partner that is performing the hydraulic analysis may select one of the following methods to determine approximate flood discharges for a flooding source:

- Transfer Methods, where peak flows are interpolated from peak flow values upstream and downstream of the area of interest or extrapolated from other sites where frequency curves have been developed;

- Regional regression equations (i.e., USGS regional equations);

- Rational Formula, which is used primarily for drainage areas less than 1 square mile but not to be used for an area larger than 2 square miles; or

- TR-55 urban hydrology procedures (U.S. Soil Conservation Service, 1986).

[February 2002]

C.4.2 Hydraulic Methods for Determining Approximate Base Flood Elevations

The Mapping Partner that is performing the hydraulic analysis may select one of the following methods to determine approximate BFEs for a flooding source:

- Normal-depth calculations using Manning's Equation;

- Highway culvert nomographs from *Hydraulic Design of Highway Culverts* (FHWA, 1985); or

- Computer program Quick-2, which may be used to compute critical depth, and normal depth.

The Mapping Partner that is performing the hydraulic analysis shall obtain all cross sections from existing topographic maps, and shall minimize the number of cross sections for each flooding source (i.e., one or two sections that are representative of the entire flooding source). The Mapping Partner that is performing the hydraulic analysis shall estimate any Manning's "n" values used from field inspection; this effort also shall be minimized by choosing values that are representative of the entire flooding source.

[February 2002]

C.4.3 Limited Hydraulic Modeling for Determining Approximate Base Flood Elevations

The Mapping Partner that is performing the hydraulic analysis may perform limited hydraulic modeling if a Triangular Irregular Network of Light Detection and Ranging (LIDAR) data with the breaklines combined with digital orthophotos is available. The Mapping Partner that is performing the hydraulic analysis may obtain cross sections, road profiles, and openings of structures from these data, and may estimate Manning's "n" values without conducting a field survey. The structures are to be identified from these data as follows:

- The Mapping Partner that is performing the hydraulic analysis may model the structure as a bridge if the width of the water body upstream and downstream of the structure does not change appreciably and no sloping embankment exists upstream and downstream of the road crossing within the stream channel area. The Mapping Partner that is performing the hydraulic analysis may approximate the area of the bridge opening by obtaining the cross section shape at the upstream face of the bridge, assuming that the elevations of the top of the abutments are equal to the low chord elevations, and inserting a pier width of 3 feet for every 50-foot span of the bridge.

- The Mapping Partner that is performing the hydraulic analysis may model the structure as a culvert if the width of the water body upstream and downstream of the structure does not change appreciably, if a sloping embankment exists upstream and downstream of the road crossing within the stream channel area, and if the headwall and the wing walls are at a lower level than the road crossing. The Mapping Partner that is performing the hydraulic analysis may assume that the opening shape of the culvert is a single box culvert. The Mapping Partner that is performing the hydraulic analysis shall measure the width at the upstream face of the culvert between the wing walls as the span and shall measure the difference in elevation between the headwall and the bottom elevation of the stream as the rise of the culvert. The Mapping Partner shall reduce the measured span and rise by 10 percent each to account for the area of the walls between the culverts for multiple openings.

- The Mapping Partner that is performing the hydraulic analysis may model the structure as a weir if the width of the water body upstream and downstream of the structure does not change appreciably, if no sloping embankment exists upstream and downstream of the crossing within the stream channel area, and if no road crosses the stream.

- The Mapping Partner that is performing the hydraulic analysis may model the structure as a dam if the width of the water body upstream and downstream of the structure changes appreciably and a sloping embankment exists upstream and downstream of the crossing within the stream channel area.

The Mapping Partner that is performing the hydraulic analysis may use a Geographic Information System-based tool to create cross-section and structure data for the HEC-RAS program to determine 1-percent-annual-chance water-surface elevations.

Because the 1-percent-annual-chance water-surface elevations are determined using approximate hydrologic and hydrologic methods with topographic and structural data, BFEs will not be shown on the FIRM.

[February 2002]

C.4.4 Map Change Requests Submitted Under Parts 65 and 70 of the National Flood Insurance Program Regulations

In areas designated as approximate Zone A, where BFEs have not been provided by FEMA, communities must ensure that any new development is constructed using methods that will minimize flood damage as outlined in Paragraph 60.3(b) of the NFIP regulations. Subparagraph 60.3(b)(3) of the NFIP regulations requires that all new subdivision proposals and the other proposed development (including proposals for manufactured home parks and subdivisions) greater than 50 lots or 5 acres, whichever is the lesser, must include BFE data.

Community officials, property owners, developers, surveyors, and engineers who need to determine BFEs in special flood hazard areas designated as approximate Zone A may use FEMA 265, *Managing Floodplain Development in Approximate Zone A Areas* (FEMA, 1995). FEMA 265 lists Federal, State, and local agencies that might have information about the BFEs; provides simplified and detailed methods for estimating or developing BFE data; and includes the computer program QUICK-2, which may be used to compute critical depth, normal depth, rating curves, and step-backwater analysis.

One of the primary goals of FEMA 265 is to provide a means of determining BFEs at a minimal cost. The guidance provided in FEMA 265 is primarily intended for use in riverine and lacustrine areas where flow conditions are fairly uniform and do not involve unusual flow regimes, such as rapidly varying flow, two-dimensional flow, supercritical flow, and hydraulic jump.

Property owners and others also may use the detailed methodologies described in FEMA 265 to develop the BFE information necessary to obtain a request for a Letter of Map Amendment or a Letter of Map Revision Based on Fill to remove a legally defined property or structure from a Special Flood Hazard Area. In addition, Physical Map Revision and Letter of Map Revision requesters may use the detailed methods in FEMA 265 to develop the BFE information that must be submitted to FEMA to demonstrate that an area will not be inundated during the 1-percent-annual-chance flood. Detailed information on all of these map change processes and products is provided in Volume 2 of these Guidelines.

[February 2002]

C.5 Hydraulic Review

This section provides a general discussion of the Hydraulic Review philosophy, the specific procedures for performing Basic and Detailed Reviews, and guidelines for documenting Reviews.

[February 2002]

C.5.1 Review Philosophy

The reviewing Mapping Partner shall ensure that the most appropriate review process is used. A two-tiered review approach consisting of a Basic Review and a Detailed Review is the best way to achieve this goal.

The Basic Review will usually consist of two areas. One area is to satisfy NFIP regulations and FEMA mapping requirements for all analyses, irrespective of the hydraulic models or methods used. The other area is to satisfy engineering standards in determining water-surface elevations. This second area is model- or method-specific, and the requirements set forth in the specific computer model user's manual must be satisfied. The user's manual of each model may also contain other references having requirements that must be satisfied.

A Detailed Review must be performed for a Flood Map Project where the Basic Review reveals errors or inconsistencies in the determination of flood elevations and indicates that a more detailed review is appropriate. In such cases, the reviewing Mapping Partner shall perform a Detailed Review of a limited number of flooding sources. The RPO may also decide to conduct a Detailed Review on additional flooding sources based on the outcome of the Detailed Review of the initial group of flooding sources.

The reviewing Mapping Partner must perform a Detailed Review for all flooding sources for which appeals have been filed or map revisions initiated, where stricter guidelines have to be followed in accordance with Part 67 and Part 65 of the NFIP regulations, respectively.

For the purposes of this discussion, the analyses are broadly categorized as being externally generated or FEMA-generated. Externally generated analyses are those that have been completed by communities or private parties and sent to FEMA with a request to use them to update effective FIS Reports and FIRMs. These analyses shall be given a level of review appropriate to the extent of the requested revision.

FEMA-generated analyses are divided into those that have had a qualified, independent, third-party review and those that have not. The independent review is to follow the guidance for the basic review and the detailed review provided above and for the use of FEMA's automated review tools if applicable. Examples of this situation include those analyses reviewed by a State or Federal agency that was not involved in the preparation of the analyses, or by an outside contractor. A detailed review may be required for FEMA-generated analyses that have not been reviewed independently.

The hydraulic review procedures are results based. During the Detailed Review, the reviewing Mapping Partner shall repeat the analysis and compare the results against those submitted by the Mapping Partner that performed the hydraulic analysis. If differences in 1-percent-annual-chance water-surface elevations, 1-percent-annual-chance floodplain boundary delineations, and/or regulatory floodway boundary delineations are found, the reviewing Mapping Partner shall ensure that these differences are not due to any requirements of the model or method before recommending to FEMA and the Mapping Partner that performed the hydraulic analysis that the model or method be changed.

If the reviewing Mapping Partner and FEMA determine that magnitude of change is insufficient to affect the revised Flood Profiles or floodplain mapping, the model need not be changed or reviewed further. However, in some cases, corrections may be required to meet engineering standards, although the magnitude of change is insignificant, or to meet certain standards established during the scoping process, such as the placement of cross sections and the selection of Manning's roughness coefficients, transition loss coefficients, and loss coefficients at structures. These changes will eliminate the majority of error messages generated by the FEMA automated review tools, CHECK-2 and CHECK-RAS.

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C.5.2 Review Procedures

The specific procedures to be followed by the reviewing Mapping Partner in performing a Basic or Detailed Hydraulic Review are defined below.

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C.5.2.1 Basic Review

A Basic Review consists of basic checks of all studied flooding sources to ensure that NFIP regulations, FEMA mapping requirements, and the requirements of the selected hydraulic model or method are satisfied. These requirements are further described below.

<u>National Flood Insurance Program Regulations Requirements for Modeling Software</u>

The reviewing Mapping Partner shall check that the same model used to prepare the effective FIS Report and FIRM is used in the new analyses and is on FEMA's list of acceptable models (http://www.floodmaps.net/mit/tsd/EN_modl.htm). In checking the model, the reviewing Mapping Partner must note that the USACE has replaced the HEC-2 program with the HEC-RAS program. FEMA's policy for using HEC-RAS in the NFIP (FEMA, 2001) is as follows:

Mapping Partners are encouraged to use HEC-RAS rather than HEC-2 for FISs that have not yet been started and for streams for which there is not an effective detailed study. However, it is important to note that any computer software that appears on the list of acceptable models may also be used.

For revisions or restudies of detailed-studied streams, where the effective model is a HEC-2 model, the conversion to HEC-RAS is encouraged. The following guidelines shall be followed to convert an effective HEC-2 model to HEC-RAS:

- The Mapping Partner that is performing the analysis shall run the effective HEC-2 model in HEC-RAS to create the duplicate effective model. Any differences in water-surface elevation between the effective model and the duplicate effective model shall be fully documented and thoroughly explained. Most differences in water-surface elevation can be attributed to (1) differences in bridge or culvert modeling routines, (2) the method of conveyance calculation, (3) critical depth default, and (4) floodway computations. The Hydraulics Reference Manual of the HEC-RAS User's Manual (USACE, 2001) provides details on computational differences between the two models and guidance on simulating HEC-2 results; this manual shall be consulted to explain the differences between the effective and duplicate effective models.

- Once the duplicate effective model has been established, the corrected effective, existing conditions, and post-project conditions models can be created in HEC-RAS, using the duplicate effective HEC-RAS model as the basis.

- The HEC-RAS models must tie in to the effective water-surface Profile within 0.5 foot at the upstream and downstream ends of the revised reach, in compliance with Subparagraph 65.6(a)(2) of the NFIP regulations.

National Flood Insurance Program Regulations Requirements for Modeling Studies

The reviewing Mapping Partner shall ensure the following requirements are met:

- Elevations in the new model must tie into the elevations of the effective model exactly or within 0.5 foot lower at the upstream end of the new model; and elevations in the new model must tie into the elevations of the effective model exactly at the downstream end of the new model.

- Floodplain widths at the upstream and downstream ends of the studied reach match those shown on the effective FIRM.

- “With floodway” elevations at the downstream end of the new model match those in the effective model.

- “With floodway” elevations at the upstream end of a revised model and beyond do not create surcharge values greater than the allowable limits.

- Regulatory floodway widths at the downstream and upstream end of the new model match the effective model.

- The surcharge throughout the area of study is within acceptable limits.

- The revised 1-percent-annual-chance water-surface elevation is not higher than the effective 1-percent-annual-chance water-surface elevation if the effective regulatory floodway is encroached.
- A floodway run is included in the new model if the effective model included one.
- Construction of all new hydraulic structures reflected in the model has been completed or will be completed within 12 months (only models submitted with requests for Conditional Letters of Map Revision may show proposed structures).

FEMA Requirements for Profile, Map, and Model Agreement

The reviewing Mapping Partner shall ensure the following requirements are met:

- The results of the new model match the work maps and revised Flood Profiles, including the distances between cross sections, water-surface elevations, regulatory floodway widths, and surcharges.
- Any backwater flooding is properly included in the profile.
- All hydraulic structures in the model are reflected on the work maps and vice versa.
- The water-surface profiles of different flood frequencies do not cross one another.
- The water-surface profiles do not show drawdowns (i.e., water-surface elevation at an upstream cross section is not lower than a water-surface elevation at a downstream cross section).

FEMA Requirements for Documentation

The reviewing Mapping Partner shall ensure the following requirements are met:

- All proper documentation is included in the submittal, in the Technical Support Data Notebook format, and appropriate application/certification forms, if applicable.
- The most up-to-date topographic information is used.

FEMA Requirements for Hydraulic Models or Methods

The FEMA requirements for hydraulic models or methods with regard to flood discharges, starting conditions, basic hydraulic modeling, and reality checks are summarize below.

Flood Discharges

The reviewing Mapping Partner shall ensure the following requirements are met:

- Flood discharges used as inputs in the new hydraulic modeling correlate with the hydrologic analysis being used (whether it is new hydrologic analysis or effective hydrologic analysis).
- All frequencies of flood events used to prepare the effective FIS Report and FIRM are included in the new model.

Starting Conditions

The reviewing Mapping Partner shall ensure the following requirements are met:

- Starting water-surface conditions for the 10-, 2-, 1-, and 0.2-percent-annual-chance flood runs are appropriate and follow FEMA guidelines.
- Starting water-surface conditions and encroachment methodology for the floodway run are appropriate and follow FEMA guidelines.

Basic Hydraulic Modeling

The reviewing Mapping Partner shall ensure the following requirements are met:

- Cross sections, Manning's roughness coefficients, transition loss coefficients, and loss coefficients at structures are modeled in accordance with the scoping agreement or the user's manual of the model (for detailed analyses) and/or the standards of the selected approximate-study method.
- The Mapping Partner that performed the hydraulic analysis has coordinated with FEMA to establish basic requirements for unsteady-flow and two-dimensional models.
- The CHECK-2 and CHECK-RAS report files are submitted if HEC-2 and HEC-RAS were used by the Mapping Partner that performed the hydraulic analysis.
- The Mapping Partner that performed the hydraulic analysis has resolved all CHECK-2 and CHECK-RAS error messages or has included explanations why the messages are not applicable.
- The hydraulic parameters for the submitted flooding sources are spot checked against topographic maps.

Reality Checks

The reviewing Mapping Partner shall ensure the following requirements are met:

- The 1-percent-annual-chance water-surface profile has been compared to the bottom slope. For long, straight channels, the water-surface profile shall be parallel to the bottom slope, because open channels tend toward the normal depth, and a problem likely exists if the profile and bottom slope are not parallel.

- The water-surface elevations at bridges or culvert sections have been compared to the top-of-roadway elevations. If a bridge or culvert is not designed to carry the 1-percent-annual-chance flood discharge, yet the 1-percent-annual-chance model shows low flow, a problem likely exists. On the other hand, almost all culverts and bridges are designed to pass the 10-percent-annual-chance flood; if the 10-percent-annual-chance water-surface elevation overtops the bridge or culvert, a problem may exist with the model or profile.

- The elevations in the new model are reasonable relative to high-water marks, where available.

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C.5.2.2 Detailed Review

If the standards of a basic review are not met, or if the items required to conduct a basic review are not included, the reviewing Mapping Partner shall conduct a detailed review using automated review tools such as CHECK-2 or CHECK-RAS, if applicable. If the submitted models are not HEC-2 or HEC-RAS, the reviewing Mapping Partner shall ensure that the model satisfies the requirements in the user's manual or the standards of the selected method.

Where necessary, and with FEMA approval, the reviewing Mapping Partner shall conduct detailed sensitivity tests to verify questionable modeling parameters and approaches. The reviewing Mapping Partner shall ensure that models have been calibrated against all available high-water marks and/or post-flood hazard verification data, if included in the scope of the hydraulic analysis. All concerns shall be resolved by coordination between FEMA and the community, the Mapping Partner, the model developer (if necessary), the revision requester, or the appellant.

For FEMA-contracted studies and restudies involving numerous flooding sources, a limited number of flooding sources will be selected for the Detailed Review. If technical concerns are uncovered, FEMA and the reviewing Mapping Partner shall determine whether a Detailed Review of additional flooding sources is necessary.

Mapping Partners typically will perform analyses for a selected subset of streams, submit them for review, and await the completion of the review before performing additional analyses. If technical concerns are uncovered, Mapping Partners will resolve those issues before analyzing the remainder of the streams.

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C.5.3 Hydraulic Review Documentation

The reviewing Mapping Partner shall provide review comments to the Mapping Partner that performed the hydraulic analysis if there are concerns with any aspect of the review. Concerns may be related to the following:

- Acceptability of the model used in the analysis;
- Water-surface elevation and floodway width tie-ins at the downstream and upstream end of the studied area;
- Increase in BFE if the effective regulatory floodway is encroached;
- Agreement of structures, distances, water-surface elevations, and regulatory floodway widths among the map, profile, and model;
- Acceptability of surcharge values;
- Water-surface profiles crossing each another;
- Proper documentation of the study and application/certification forms;
- Agreement in discharges between hydrologic and hydraulic analysis;
- Selection of starting water-surface elevation options;
- Deviation of hydraulic parameters from recommended values; and
- Messages and comments in the CHECK-2 and CHECK-RAS reports.

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C.6 Floodplain Mapping

Upon completion of the hydrologic and hydraulic analyses and review, the Mapping Partner that performed the analyses shall determine the boundaries of the new or revised floodplains as well as the floodplain boundaries and the regulatory floodway that are being revised to reflect new topographic data and/or a new base map. The Mapping Partner also shall plot BFEs to reflect the results of the hydraulic analyses.

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C.6.1 Floodplain Boundaries

The Mapping Partner that performed the hydraulic analysis shall delineate the floodplain boundaries resulting from the hydraulic analyses on a work map. This Mapping Partner shall present the 1-percent-annual-chance and 0.2-percent-annual-chance floodplain boundaries using the standard symbologies and map screens detailed in Appendix K of these Guidelines.

The Mapping Partner that performed the hydraulic analysis shall submit a work map delineating the 1-percent-annual-chance floodplain, which shall be designated as Zone A. The work map also shall include any hydraulic information generated on water-surface elevations or water depths. The Mapping Partner that performed the hydraulic analysis shall submit all backup data and calculations used to obtain the 1-percent-annual-chance floodplain delineation.

The plotting of floodplain boundaries may be separated into three distinct action classifications:

1. New or revised floodplains;

2. Floodplains that are being redelineated to reflect updated topographic data, but are not otherwise reflecting new analyses; and

3. Floodplains that are being "fitted" to new base maps (including new streamline locations) without using new topographic date and are not otherwise reflecting new analyses.

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C.6.1.1 New or Revised Floodplains

The Mapping Partner that performed the hydraulic analysis shall determine the boundaries of the 1- and 0.2-percent-annual-chance floods using the topographic data that was identified during the Project Scoping phase of the Flood Map Project. (See Volume 1, Section 1.3 of these Guidelines for further detail.)

The Mapping Partner that performed the hydraulic analysis shall ensure that floodplain boundaries are normalized to (in agreement with) the best available topographic information. In addition, the Mapping Partner shall ensure that the regulatory floodway boundary does not lie outside of the 1-percent-annual-chance floodplain, and the 1-percent-annual-chance floodplain boundary does not lie outside of the 0.2-percent-annual-chance floodplain. The Mapping Partner that performed the hydraulic analysis also shall "smooth" floodplain boundaries derived from a digital output file to ensure that rectilinear floodplain boundaries are not shown on the final FIRM.

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C.6.1.2 Effective Floodplain Boundaries

During the course of the flood hazard analyses and floodplain mapping preparation, the Mapping Partner that performed the hydraulic analysis shall ensure that effective (unrevised) floodplain boundaries are redelineated using updated topographic data and/or new base map data, when available.

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C.6.1.3 Effective Floodplain Boundaries Adjusted to New Topographic Data

The Mapping Partner that performed the hydraulic analysis will often be required to normalize otherwise unrevised floodplain boundaries to new or updated topographic data. The process will require that the Mapping Partner superimpose the unrevised floodplain boundaries onto the new topographic data and adjust the boundaries to reflect the new or updated topographic data.

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C.6.1.4 Effective Floodplain Boundaries Adjusted to New Base Map Data

When new/updated topographic data are being used to redelineate the effective floodplain boundaries, a Mapping Partner selected by FEMA (usually, the reviewing Mapping Partner) shall superimpose the adjusted floodplain boundaries onto the new/updated base map source and assess the impact of using new base map data with unrevised floodplains. The floodplain/road relationships are to be maintained whenever possible; however, the application of new topographic data is to take precedence over these relationships.

If new/updated topographic data are not provided by the Mapping Partner that performed the hydraulic analysis, the reviewing Mapping Partner shall ensure that the effective floodplain boundaries being transferred to new base maps fit the new base map features. Issues that could affect a flood insurance determination are to be given special consideration. Effective floodplain boundaries may need to be adjusted to fit new base maps to ensure that relationships with base map features (roads, streamlines, etc.) are maintained as closely as possible.

Where modeled hydraulic structures (i.e., structures appearing on the Flood Profiles) cross streams that were studied by detailed methods and were not revised as a result of the revised flood hazard analyses, the reviewing Mapping Partner shall adjust the unrevised floodplain boundaries so that the subject structures fall at or near the crossing as indicated in the hydraulic model to within a tolerance of 25 feet. Because the mapped regulatory floodway boundary configurations, cross sections, and BFEs have a direct relationship to hydraulic structures, the reviewing Mapping Partner shall maintain these relationships as closely as possible.

If significant unmodeled hydraulic structures are identified during the adjusting of unrevised floodplain boundaries to new topographic information or new base map information, the reviewing Mapping Partner shall contact the FEMA RPO, PO, and/or their designees to assess the possible need for floodplain analyses to account for new structures.

[February 2002]

C.6.1.5 Effective Floodplain Boundaries Adjusted to New Streamlines

In cases where the stream has moved significantly, causing the unrevised floodplain boundary configuration to no longer fit the new stream location, the reviewing Mapping Partner shall adjust the floodplain boundaries to fit the new stream, ensuring that the regulatory floodway boundary configuration relative to the new stream data is maintained. The effective regulatory floodway boundaries were delineated with a relationship between the left and right floodway boundaries and the stream. Whenever possible, the reviewing Mapping Partner shall maintain that relationship.

At a minimum, the regulatory floodway shall contain the new stream. In addition, the floodway fringe areas (i.e., the portion of the 1-percent-annual-chance floodplain considered encroachable) have a direct relationship to the regulatory floodway boundary. The reviewing Mapping Partner shall ensure that this relationship is also maintained to whatever degree is reasonably possible. In other words, it is important that the relationship of the regulatory floodway to the entire floodplain is maintained as closely as possible.

The process of fitting unrevised floodplain boundaries to new streamlines likely will result in changes in stream channel distances from the unrevised hydraulic model to the new FIRM. These changes shall be addressed by placing a note in the FIRM legend on a case-by-case basis. The decision on which note to use is based on the number of occurrences of effective floodplain boundaries being superimposed on new stream data. See Appendix K for examples of this note.

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C.6.2 Regulatory Floodway Boundaries

The Mapping Partner that performed the hydraulic analysis shall develop regulatory floodway boundaries to reflect the results of the floodway analysis and delineate them on a work map. The Mapping Partner that performed the hydraulic analysis shall connect the regulatory floodway boundaries computed at the cross-section locations of the floodway model to form a hydraulically smooth flow path, which shall be shown as the floodway boundary configuration for the flooding source.

The floodway boundary is to be shown by long dashed lines as indicated in Appendix K. The floodway boundary must be plotted to within a maximum tolerance of 5 percent of the map scale. The location and the width of the floodway shown on the FIRM shall be consistent with the locations and widths computed by the floodway model and those tabulated for the lettered cross sections in the Floodway Data table of the FIS Report. In cases where the regulatory floodway and the 1-percent-annual-chance floodplain boundaries cannot be shown separately due to the map scale, only the floodway boundary is to be shown. When a floodway boundary follows an existing feature, such as a levee or a road, the floodway boundary is to be clearly indicated.

Separate regulatory floodway analyses are to be computed for a split flow path considered in a hydraulic analysis. The provision of a regulatory floodway will assure that the overland flow section remain open to convey flow. If storage areas behind structures were accounted for in the hydrologic analysis by routing the 1-percent-annual-chance hydrograph, the regulatory floodway boundary is to encompass the storage area. Regulatory floodways are not normally delineated for coastal high hazard areas.

Revisions to regulatory floodway boundaries are justified when a revised area within the effective regulatory floodway boundary configuration indicate surcharges above the maximum limit, or if, as a result of improved data, the regulatory floodway boundary configuration necessitates a change from that shown on the effective FIRM or FBFM.

[February 2002]

C.6.3 Base Flood Elevations

Whole-foot, rounded BFEs are to be located on the work map for all detailed study flooding sources. The basic intent of plotting BFEs on a FIRM is to represent the Flood Profile to within 0.5 foot of elevation tolerance. If BFEs are plotted correctly, the FIRM can be used to recreate the Flood Profiles within 0.5 foot.

BFEs are to be plotted at significant Profile inflection points (Profile breaks), or as close to them as possible. These points are critical to the accuracy of the FIRM, because the Flood Profiles could not be reproduced accurately without them.

Intermediate BFEs are to be plotted between inflection points and required BFEs. Intermediate BFEs are to be placed at whole-foot elevations whenever possible. The main factor in determining the proper interval at which intermediate BFEs are to be plotted is the Profile slope (gradient). The general guidelines below are to be followed, keeping in mind that the profile slope should be relatively constant between inflection points.

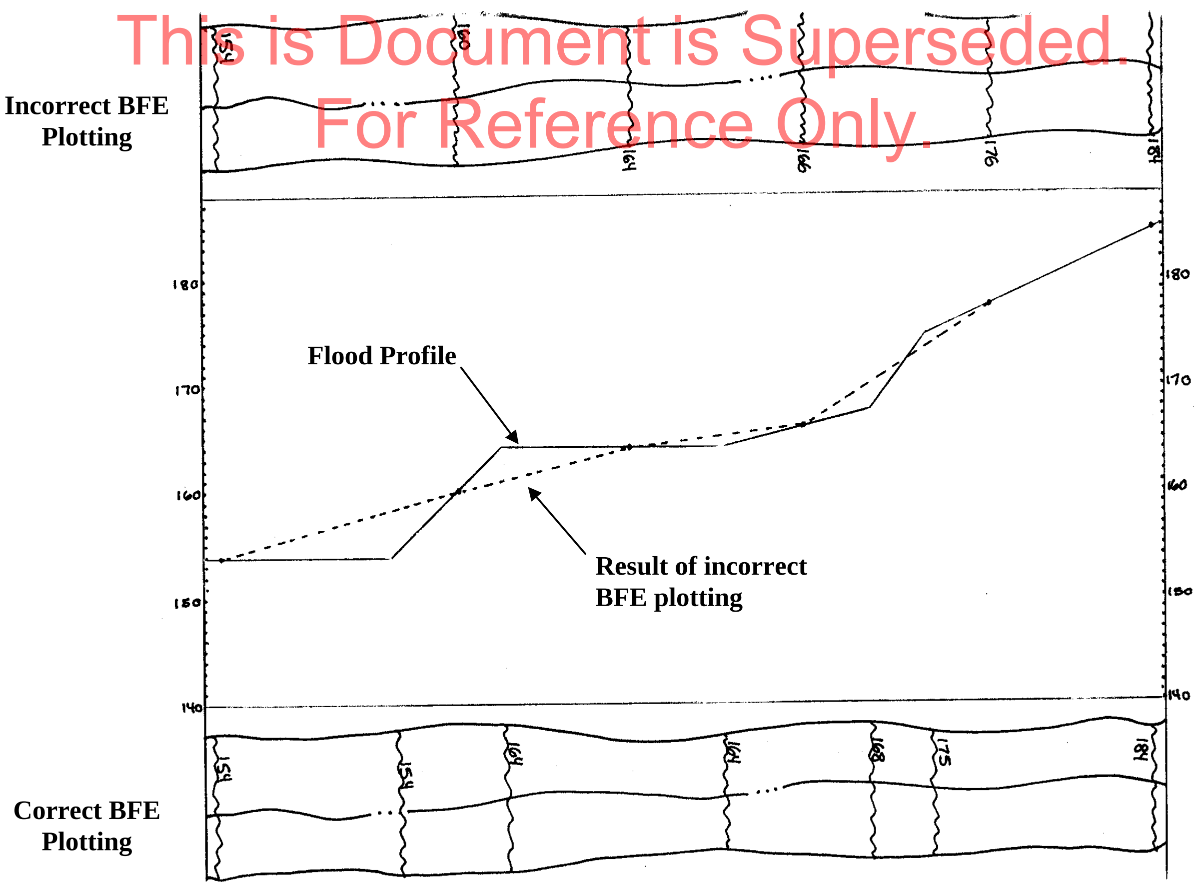
- Gentle Gradient – If BFEs rise less than 1 foot per 1 inch of map distance, the BFEs shall be plotted at every whole foot of elevation rise.

- Moderate Gradient – If BFEs rise more than 1 foot, but less than 5 feet per 1 inch of map distance, the BFEs shall be plotted at approximately 1-inch intervals.

- Steep Gradient – If BFEs rise 5 feet or more per 1 inch of map distance, the BFEs shall be plotted at 0.5-inch intervals of map distance or at 5-foot intervals, whichever is greater (i.e., whichever results in a wider BFE spacing).

To determine the proper method for the intermediate BFE interval, the amount of BFE rise is divided by the map distance over which it rises. For example, 10 inches of map distance with a 30-foot BFE rise equals a 3-foot BFE rise per inch, and BFEs shall be plotted at 3-foot intervals.

Once all BFEs have been plotted, the Mapping Partner that performed the hydraulic analysis shall test whether all significant inflection points have been plotted. It is critical that the FIRM reflect the BFEs shown on the Flood Profile to within a 0.5-foot tolerance. The diagram shown below demonstrates how the FIRM could show accurate BFEs, but still not reflect the BFEs shown on the Flood Profile to within the required tolerance. As demonstrated in the diagram, the difference between the line drawn to reflect the FIRM and the actual 1-percent-annual-chance flood elevation could be significantly skewed if BFEs are not plotted at significant inflection points, even if the BFE values shown on the FIRM are correct where they are plotted.



The following general rules are to be applied to the plotting of BFEs on work maps and FIRMs:

- BFEs must not rise more than 1 foot across panel edges (unless the stream gradient is very steep at the panel edge).
- The maximum rise between plotted BFEs must not exceed 10 feet.
- Extreme BFEs at corporate limits and Limits of Detailed Study do not have to be shown if graphically impossible (e.g., when the elevation is 65.5 at the corporate limits, BFE 65 may be plotted within 0.5 inch of the corporate limits).
- In a static 1-percent-annual-chance flood insurance risk zone (tidal or lacustrine flooding), elevation numbers under zone labels must be used in lieu of BFE lines. For tidal flooding only, a zone break (or gutter) must be placed at the point where the static zone becomes a rising elevation zone, and a BFE line of the same elevation as the static zone must be placed immediately upstream of the gutter.
- BFEs must be shown as wavy lines perpendicular to the flow of the 1-percent-annual-chance flood.
- All BFEs must be labeled with an elevation value that is located above, below, or at the end of the line (i.e., where it meets the 1-percent-annual-chance floodplain boundary).
- If the BFE value cannot be placed within 0.1 inch of the BFE line, a leader line must be used to connect the BFE value to the BFE line.

[February 2002]

C.7 Hydrologic and Hydraulic Analyses of Lake Levels for Closed Basins

Conventional floodflow-frequency analysis, such as that described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982), is based on the assumption that the data are stationary and independent. These conditions are usually satisfied when analyzing annual maximum peak discharges on a river. However, some notable exceptions do occur. For example, annual maximum lake levels or lake volumes are usually significantly correlated with time (autocorrelated) and hence violate the independence requirement.

In the presence of autocorrelation, flood-frequency analysis takes on a new meaning. The floodflow-frequency curve depends on an initial condition and evolves over time to a steady-state or equilibrium distribution. As a consequence, when conventional flood-frequency analysis is applied to autocorrelated lake data, the results must be interpreted as the long-term or steady-state distribution of annual maximum lake levels. This is in marked contrast to a conventional analysis of independent riverine data where a single flood-frequency distribution applies at all times. This fundamental difference between conventional flood-frequency analyses for lakes and rivers has important ramifications in developing sound floodplain management strategies for lakeshore communities.

A closed-basin lake, as defined by FEMA, is a natural lake from which water exits primarily through evaporation and whose surface area exceeds or has exceeded 1 square mile at any time in the recorded past. Most of the nation's closed-basin lakes are in the western half of the United States, where annual evaporation exceeds annual precipitation and where lake levels and surface areas are subject to considerable fluctuation due to wide variations in the climate. These lakes may overtop their basins on rare occasions. (See Section 61.17 Appendices A(1), A(2), and A(3) of the NFIP regulations.) Because of the unique type of flooding, special policy and procedural considerations are warranted.

[February 2002]

C.7.1 Insurance and Ordinance Issues

FEMA has amended the Standard Flood Insurance Policy to address the closed-basin lake continuous flooding circumstance. FEMA has added an endorsement to all policies allowing policyholders to file a total loss claim for an insured building that is actually damaged or under imminent threat of flooding, without the requirement for the building to be continuously inundated for 90 days. Policyholders must use claim payments, less salvage value, relocate their structures to a site outside the area subject to flooding. This special floodprone area around closed basin lakes is referred to in this Appendix and on the affected FIRM panels as an Area of Special Consideration (ASC). The insurance claim provision provides the means for homeowners and commercial business interests to relocate outside the ASC, thereby affording the community and its residents a permanent means of eliminating future flood losses in these areas.

The special endorsement for closed-lake basins is established in Paragraph 61.13(d) of the NFIP regulations. The insurance claim provisions are described in Appendices A(1), A(2), and A(3) of Section 61.17 of the NFIP regulations. Local and State governments must establish ordinances and building restrictions as described in Section 61.17 to be eligible for the special insurance claim provisions.

[February 2002]

C.7.2 Mapping Protocol

As mentioned earlier, FEMA established the ASC to accommodate the unique type of flooding around closed-basin lakes. The ASC may include the 1- and 0.2-percent-annual-chance floodplains and additional areas to account for the continuous and often uncertain fluctuations in the water-surface elevation due to the closed-basin lake phenomenon. An ASC is an area subject to flooding, but the percent chance of being flooding in any given year is not defined. For example, the elevation shown within the ASC may be determined by using the natural spill elevation of the closed lake, the historical (or geological) elevation of record, and other criteria. The FEMA RO shall determine whether closed-basin lake flooding conditions exist and shall implement the closed-basin lake policy accordingly.

FEMA shall exclude those areas that are landward of certified levees that provide protection from flooding from the ASC. FEMA and its Mapping Partners shall not take into account all flood hazards that may exist from other flooding sources, such as local streams or other floodwaters that are not hydraulically connected to the closed-basin lake, in determining the ASC.

[February 2002]

C.7.3 Technical Methodologies

For large closed-basin lakes, such as Devils Lake in North Dakota and the Great Salt Lake in Utah, historical water level data and other data are available to estimate the 1-percent-annual-chance lake level. If the data are available, autoregressive moving average models can be used to model annual lake levels and volumes.

In North Dakota, Wiche and Vecchia developed a stochastic water balance model to estimate the 1-percent annual chance lake elevation (USGS, 1995). Wiche and Vecchia used long-term seasonal precipitation, evaporation, and inflow to Devils Lake to develop a stochastic water balance model for generating possible future lake-level elevations, namely 10,000 traces of 50 years in length. Wiche and Vecchia determined the chance that a given lake level will be exceeded in any given year by evaluating the proportion of the generated annual maximum lake levels that exceeded the given level.

The chance that a given lake level will be exceeded in any given year is dependent on the current or existing water level on the lake. The equilibrium level corresponding to a given percent chance of exceedance is reached when the current lake level has no effect on the given percent chance of exceedance. The equilibrium level for the 1- and 0.2-percent-annual-chance floods are mapped on the FIRM.

[February 2002]

C.7.4 Future Actions

Special considerations are needed to define the potential flooding in and around closed-basin lakes. FEMA has amended the Standard Flood Insurance Policy to address insurance and relocation issues relative to this phenomenon. FEMA is finalizing and adopting methodologies for determining the frequency of water-surface elevations for closed-basin lakes. These methodologies will be provided in future updates to these Guidelines.

[February 2002]

C.8 Future-Conditions Flood Mapping

Communities experiencing urban growth and other changes often use future-conditions hydrology in regulating watershed development. While some communities regulate based on future development, others are hesitant to enforce more restrictive standards without FEMA support. To assist community officials, FEMA has decided to include future-conditions flood hazard data on FIRMs and in FIS reports for informational purposes on a case-by-case basis. This decision was documented in a Final Rule published in the *Federal Register* on November 27, 2001. (The Final Rule may be downloaded from the FEMA website at http://www.fema.gov/mit/tsd/frm_fchy.pdf.)

Because multiple options exist for presenting future-conditions floodplains and related data on the FIRM and in the FIS report, interested community officials should contact the appropriate RO to discuss the available options and agree on the approach to be taken. For information on these options, FEMA encourages interested community officials to review the November 27, 2001, Final Rule and the FEMA report entitled "Modernizing FEMA's Flood Hazard Mapping Program: Recommendations for Using Future-Conditions Hydrology for the National Flood Insurance Program" (FEMA, 2001). That report contains one possible scenario/example of depicting future-conditions flood hazard information on a FIRM and in an FIS report and may be downloaded from the FEMA website at http://www.fema.gov/mit/tsd/ft_futur.htm.

At the request of a community and with the approval of FEMA, FIRMs and FIS reports may include, for informational purposes, flood hazard areas based on projected- or future conditions hydrologic and hydraulic analyses. If community officials request that FEMA show the future-conditions 1-percent-annual-chance floodplain on the FIRM, the future-conditions floodplains and flood insurance risk zone shall be shown on the FIRM and referenced in the accompanying FIS report. Although graphic specifications are flexible for the mapping of this flood insurance risk zone, the zone label will be "Zone X (Future Base Flood)."

The future-conditions flood insurance risk zone shall be defined in the FIRM legend and in the FIS report as follows:

> Zone X (Future Base Flood) is the flood insurance risk zone that corresponds to the 1-percent-annual-chance floodplains that are determined based on future-conditions hydrology. No BFEs or base flood depths are shown within this zone.

FEMA opted to use the Zone X (shaded) screen, in lieu of a new flood hazard zone designation, to depict the future-conditions 1-percent-annual-chance (100-year) floodplain to minimize confusion by users of the FIRM that make determinations regarding Federal mandatory flood insurance purchase requirements. Those users now recognize that areas designated as Zone X (shaded) are floodprone, but that the mandatory flood insurance purchase requirement does not apply. Because the risk premium rates for buildings located in the future-conditions 1-percent-annual-chance

(100-year) floodplain will be the rate comparable to other areas outside the SFHA, FEMA believes designating these areas as "Zone X (Future Base Flood)" will be sufficient distinction.

FEMA may develop graphic specifications for the presentation of future-conditions flood hazard data on the FIRM and specifications and guidelines for the inclusion of support information in the accompanying FIS report. However, it is FEMA's intent, as indicated in the previously referenced Final Rule, to have flexibility in the implementation of this community-requested mapping option. Because multiple options for presenting the future-conditions flood hazard data exist, FEMA intends to work closely with each community to develop the presentation format that best meets community and FEMA needs. For the time being, FEMA, in coordination with the affected community(ies) and the Mapping Partner that is preparing the Preliminary FIRM and FIS report, shall establish the presentation specifications on a case-by-case basis.

Once future-conditions flood hazard data have been included on the FIRM and in the FIS report for a community, all revision submittals shall incorporate the future-conditions data developed by the community. The community is entirely responsible for developing and maintaining this data layer on a digital FIRM.

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