ECONOMIC STUDIES

The Comprehensive Study performed basin-wide economic evaluations that incorporated a risk-based analysis. The primary tool for the economic studies was the Corps' Flood Damage Analysis Model, or HEC-FDA. This model uses a risk-based analysis to express economic performance in terms of expected annual damages (EAD). This section provides an overview of the development of system-wide economic tools and their use in performing economic analyses. A complete description of the economic studies performed during the Comprehensive Study is included in *Appendix F – Economics Technical Documentation*.

Flood Damage Reduction Analysis

The Corps of Engineers economic analysis is based upon the *Principles and Guidelines* (P&G) published in 1983 by the U.S. Water Resources Council. A primary Corps objective in flood damage reduction studies is to determine the expected annual damage along a river reach, taking into account all possible flood scenarios, and to compare changes in the damage resulting from various alternative plans. The determination of EAD in a flood management study must take into account interrelated hydrologic, hydraulic, geotechnical and economic information and their associated uncertainties. Specifically, EAD is determined by combining the discharge-frequency, stage-discharge (or frequency), and stage-damage functions and integrating the resulting damage-frequency function. Uncertainties are present for each of these functions and are carried forth into the EAD computation. In addition, for the Comprehensive Study most of the rivers being studied have levees on one or both sides for part or all of their studied length. Levees prevent water from breaking out into adjacent floodplain areas. As river stage increases the probability of levee failure also increases. Thus, the derivation of geotechnical levee probability of failure curves, which define relationships between river stage and levee failure probability, becomes very critical to the analysis.

Modeling Tools

The Comprehensive Study used three primary tools to perform the system-wide economic analysis: HEC-FDA, @Risk, and GIS. The GIS component is summarized below, and HEC-FDA and @RISK are described briefly in the previous section and in *Appendix E – Risk Analysis*. The exception is the Upper Sacramento River reach (Vina to Keswick), described later, where a spreadsheet was used to calculate economic damages in lieu of HEC-FDA.

GIS - Although not an economics program, the use of geographic information system software allowed the efficient identification of thousands of structures within the floodplains where digitized parcel maps were available. Where possible, other corresponding data required for flood damage analysis was also developed using GIS.

In addition to these models, critical input into HEC-FDA comes from hydraulic models: UNET (river channel stage-frequency relationships) and FLO-2D (floodplain depths and delineations).

Input Data

Input to the economic analysis models includes composite floodplain delineations, the designation of impact areas, damage categories, land use and structural inventories, structural and content values, and depth-damage relationships.

Floodplains **-** One of the most important steps in a flood damage analysis is the identification of areas subject to flooding. As described previously, the Comprehensive Study's composite floodplains capture a range of potential flood conditions through the use of storm centerings, and the probability of levee failure through identification of a likely failure point. The economic analyses utilize composite floodplains with a 2%, 1%, 0.5%, and 0.2% chance of occurrence in any given year, developed using UNET and FLO-2D. The exception was the use of 2%, 1%, and 0.5% floodplains along the upper Sacramento River (Vina to Keswick Dam) that were developed using HEC-RAS water surface profiles.

Impact Areas **-** Because the Comprehensive Study floodplains cover approximately 2.2 million acres, the floodplains were divided into smaller impact areas to facilitate the analysis. **Figures 11** and **12** in the Risk Analysis section illustrate the 68 impact areas in the Sacramento basin and the 42 impact areas in the San Joaquin basin, respectively.

Damage Categories **-** Damage categories used in the Comprehensive Study economic analysis include: residential, mobile homes, commercial, industrial, public / semi-public, farmsteads, crops, and others (including damage to autos, roads, traffic disruption, and emergency response costs, primarily within urbanized areas).

Land Use/Structural Inventories **-** GIS was used to develop crop and other land use inventories for both basins utilizing DWR digitized land use files. GIS was also used to develop the structural inventories using digitized county parcel map files, geocoding of street addresses, or by physically comparing floodplain maps with county assessor parcel maps.

Structural and Contents Values **-** Parcels were linked to assessor data files to obtain structural improvement values and other information. Adjustments were made to the assessed values to reflect October 2001 prices. Publicly owned parcels, which are not assessed property taxes, are not currently included in the structural inventories but work is underway to assign improvement values by applying construction factors. Contents values were assigned based upon percentages developed by previous Corps studies: residential and mobile homes, 50%; commercial, 100%, industrial, 150%, public/semi-public, 50%; and farmsteads, 65%.

Urban Depth-Damage Relationships **-** Damage generally increases as depth of flooding increases. Generic residential depth-damage functions developed by the Corps' Institute for Water Resources were used in the Comprehensive Study. For other urban damage categories, depth-damage functions developed by the Sacramento District and based upon FEMA information were used.

Agricultural Depth-Damage Relationships **-** About 1.9 million acres out of the total 2.2 million acres in the study area is in agricultural production, making crop damage analysis an important element in the Comprehensive Study. Although over 100 different crops are grown within the area, only predominant crop types were evaluated to facilitate the analysis: row crops (corn, beans, wheat, cotton, safflower); fruit crops (almonds, walnuts, peaches, pears, prunes); alfalfa; mixed pasture; rice; truck crops (melons, tomatoes); and vine crops (grapes). The types of agricultural flood damage evaluated included the loss of direct production costs incurred prior to flooding, the loss of net value of crop, the loss of depreciated value of perennial crops, and clean-up and rehabilitation costs, with consideration for the seasonality and duration of flooding.

Existing Condition Expected Annual Damage

Existing condition expected annual damage is over $280 million (October 2001 price levels) for both basins combined. Most of the damage is expected to occur in the Sacramento River basin (about $251 million EAD) compared to the San Joaquin River basin (about $31 million EAD). The distribution of damage within the two basins is significantly different, with urban structural damage representing about 77 percent of total Sacramento River basin EAD compared to about 39 percent within the San Joaquin River basin. **Figure 13** summarizes existing condition EAD estimates by damage category in each basin.

For the Upper Sacramento reach (Vina to Keswick), a different method was used to calculate expected annual damage. The stage-frequency curves required by HEC-FDA were not generated because hydraulic studies for this reach were performed using HEC-RAS rather than UNET. In addition, only three frequency events were evaluated (the 2%, 1% and 0.5% events), rather than the eight events evaluated in UNET. Expected annual damage was based upon simulated flood depths for these three events at individual parcels and economic computations were performed using spreadsheets rather than within HEC-FDA. Damages for these impact areas are included in **Figure 13**. A detailed accounting of EAD by impact area is included in *Appendix F – Economics Technical Documentation*.

As with other Comprehensive Study tools, the HEC-FDA models are a work-in-progress. Potential future work to the existing condition damages analysis includes refinements to damage estimates for the public service sector and other damage categories (autos and roads, traffic disruption and emergency response costs).

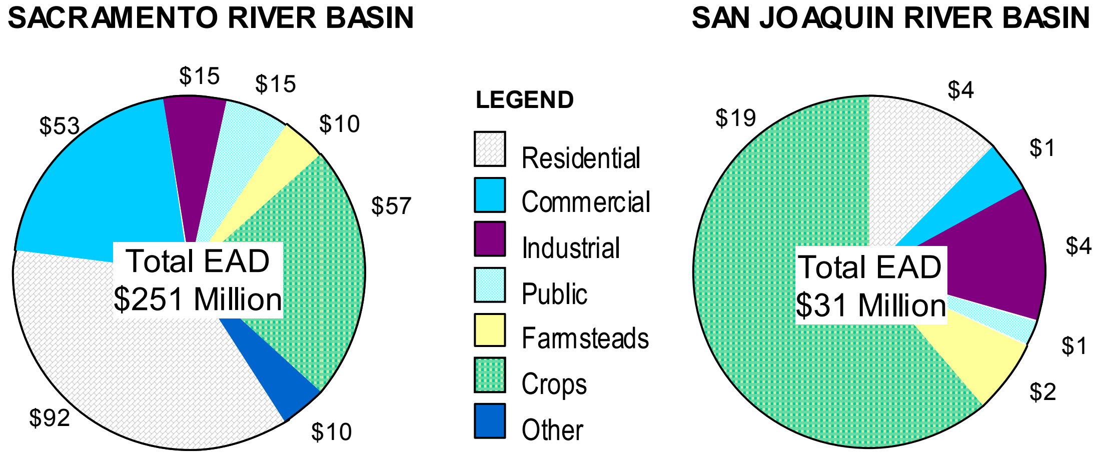


FIGURE 13 –EXISTING CONDITION EXPECTED ANNUAL DAMAGE BY DAMAGE CATEGORY

Future Without-Project and With-Project Conditions

The estimation of existing condition expected annual damage is only part of the "without-project" analysis. A complete analysis would take into account future development likely to occur with and without proposed alternatives. "Future without project" population and economic development levels, and associated flood damage, have not been estimated at this time. It is anticipated that a complete "without project" analysis including future development will be conducted during future studies.

Although the Comprehensive study did not develop alternatives, the HEC-FDA model is capable of performing economic analyses for proposed plans in the same manner as described for the existing and future without project conditions. Plan components are simulated using the hydrologic and hydraulic modeling tools and with-project stage-frequency information is passed to HEC-FDA for a determination of EAD. The with-project EAD can be compared with the existing condition and future without-project EAD to estimate the benefits of alternative plans.

EVALUATION PROCESS

This section includes a synopsis of the iterative technical evaluation process that was developed over the course of the study and used to perform preliminary system-wide evaluations. This process was developed for use in reconnaissance-level, basin-wide analyses; future studies using the Comprehensive Study modeling tools should take care in developing assumptions and evaluation procedures appropriate for their needs or level of detail.

The basic flow of information through the Comprehensive Study technical modeling suite involves initial processing of the hydrology through the reservoir operations models, which pass flood flow data to the hydraulic models, which in turn pass stage-frequency information to the risk and economics model. This process used to perform the basin-wide evaluations is outlined in **Figure 14** and described in the following sections.

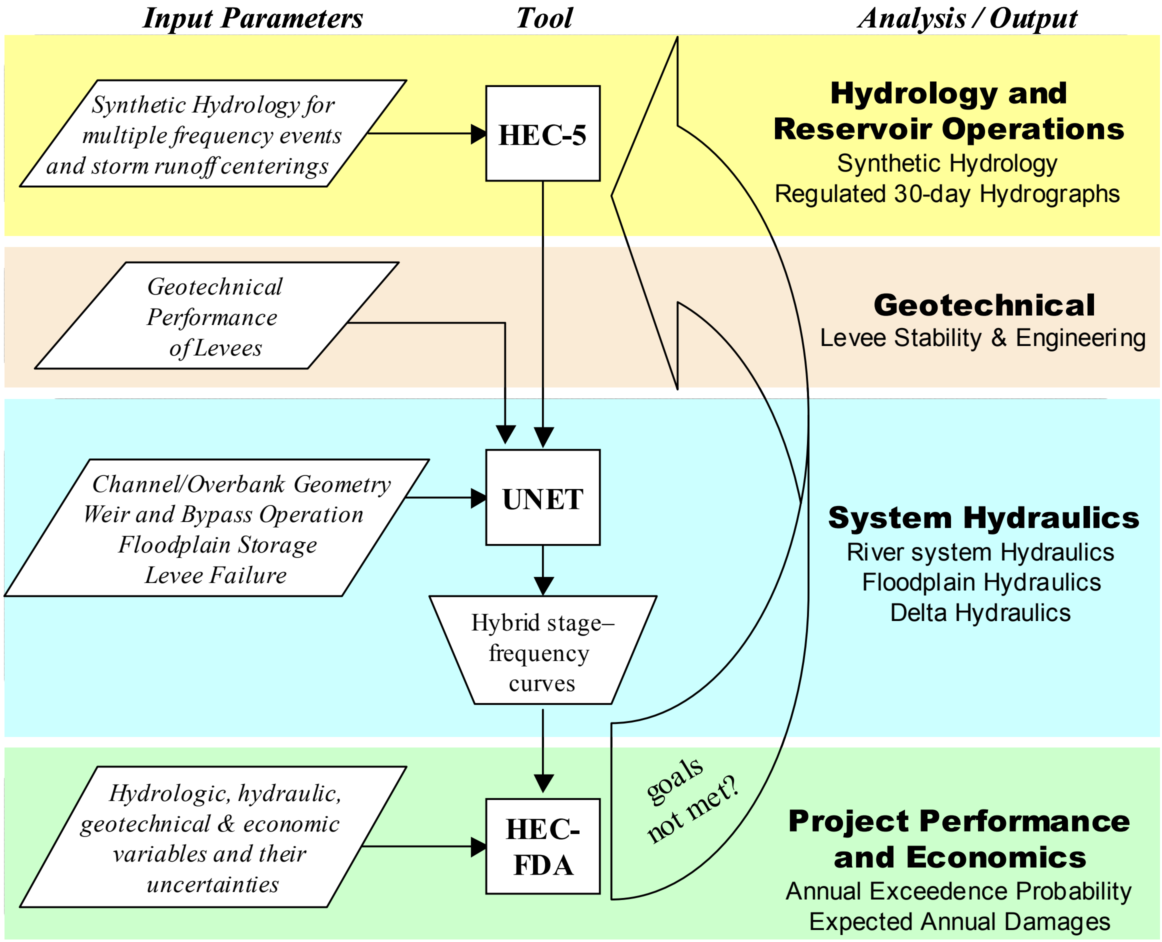


FIGURE 14 – FLOW OF INFORMATION BETWEEN COMPREHENSIVE STUDY TECHNICAL TOOLS

Hydrology and Reservoir Operations

Hydrology, in the form of 30-day unregulated hydrographs, is the starting point for any evaluation. The Comprehensive Study's hydrology was designed for basin-wide and regional analyses, but additional hydrologic evaluations may be required for site-specific projects, feasibility studies, or design. Synthetic hydrographs are fed into the reservoir operations models to simulate the effects of existing storage facilities, and/or to evaluate the benefits of changes to reservoir storage or release operations. For each evaluation, regulated hydrographs below the major flood control reservoirs are developed for each of the flood frequencies and dominant storm centerings.

Geotechnical Performance

As described previously, the chance of levee failure is represented through a geotechnical performance curve that relates river stage to probability of geotechnical failure. For basin-wide evaluations, curves are assigned by reach in the same manner as for the baseline condition but may be modified to reflect proposed levee improvements that would affect the LFP, PFP or PNP. The synopsis describes an evaluation using the Comprehensive Study's

LFP (50% probability of failure) approach, which may not be suitable for all model applications.

Hydraulics

Next, the UNET hydraulic models route the regulated flood hydrographs through the system of tributary and mainstem channels in each basin for the various storm events and centerings. UNET modeling results are reported at each index point as a plot of event frequency versus water surface elevation. For example, the peak simulated water surface elevation produced by the various storm centerings for a flood event with a 2% probability of occurring in any year forms one point on the curve, the peak from the event with a 1% probability of occurring forms another point, and so forth. Peak water surface elevations from UNET are plotted for each of the event frequencies and connected to form a stage-frequency curve.

For reaches with levees, the stage-frequency curve flattens or becomes horizontal at the point where the levee in that reach fails (at the LFP elevation), or sometimes when adjacent upstream levees fail. After a levee failure, the water surface elevation remains relatively constant for all higher flow frequencies because flows are escaping into the floodplain through the levee break. The HEC-FDA model needs a complete stage-frequency curve to the top of the levee, so the upper end of the curve is extrapolated above the frequency of levee failure using the infinite-channel UNET run. The infinite channel run assumes that no levee breaks occur (infinitely high failure elevation) and that all water is contained within the main channels. The portion of the infinite channel frequency curve above the frequency of levee failure is translated down to meet the baseline (with-failure) curve where it intersects the LFP and flattens. The resulting hybrid curve, a combination of the with- and without levee failure scenarios, is then entered into HEC-FDA.

Floods with greater than a 50% probability of exceedence were not modeled because more frequent events typically stay within natural channels and do not cause damage. In the Sacramento River basin, the hybrid curve was manually extended to include these frequent events using the slope of the curve between the 50% and 10% exceedence plot points and the adjacent ground elevation. Similarly, stage-frequency curves in the San Joaquin River basin were extended below the 50% flood using the water surface elevation at the time the topographic surveys were performed, which corresponds to nearly a 100% chance of occurring in any year. The development of the hybrid stage-frequency curve is shown graphically in **Figure 15**.

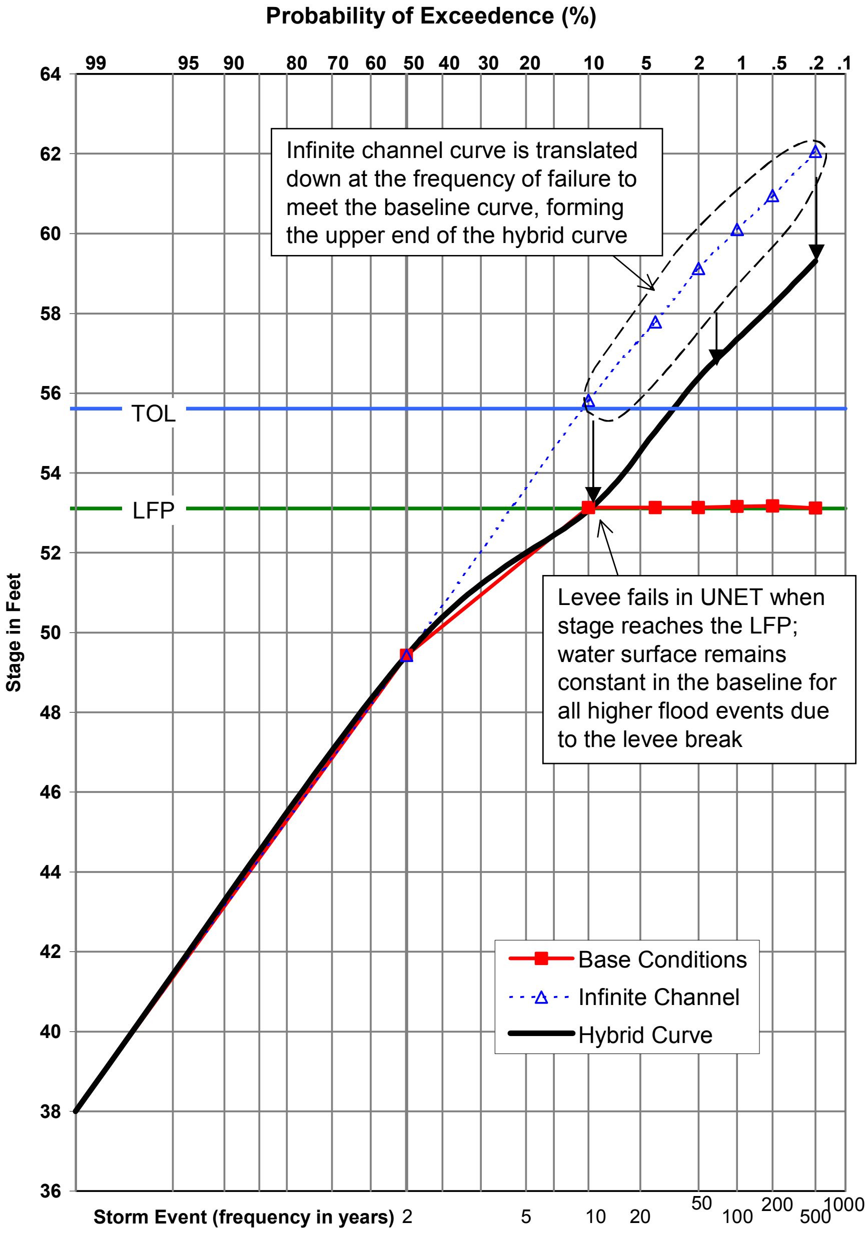


FIGURE 15 – CONSTRUCTION OF THE HYBRID STAGE-FREQUENCY CURVE

Project Performance and Economics

HEC-FDA integrates input from the hydrologic, geotechnical and hydraulic technical tools in a risk-based analysis. Input data includes information relating to the uncertainty of the hydrologic data, levee performance curves, stage-frequency curves from UNET, and economic data. As described previously in the Risk Analysis section, the primary outputs of HEC-FDA that are used in project formulation and evaluation are project performance (flood risk statistics) and economic damages.

Iteration Process

Iterations are performed within each model and between analysis steps until all of the planning goals or objectives of an evaluation are met. For example, successive iterations might be performed within UNET until a target water surface is achieved only to find that the desired flood risk, calculated in HEC-FDA, was not achieved. In this case, additional iterations between UNET and HEC-FDA may be required until the risk target is also achieved. The number of iterations performed both within the models and between the models is largely dependent upon the type and number of planning objectives set for a particular plan, and the level of detail desired. Initial simulations may be performed that examine only a few representative index points or risk statistics to quickly narrow in on the targets, followed by final simulations examining all index points to refine the plan. In this manner, an expedited analysis process was developed to decrease the amount of time required to arrive at desired targets or objectives.

Expedited Basin-wide Analysis

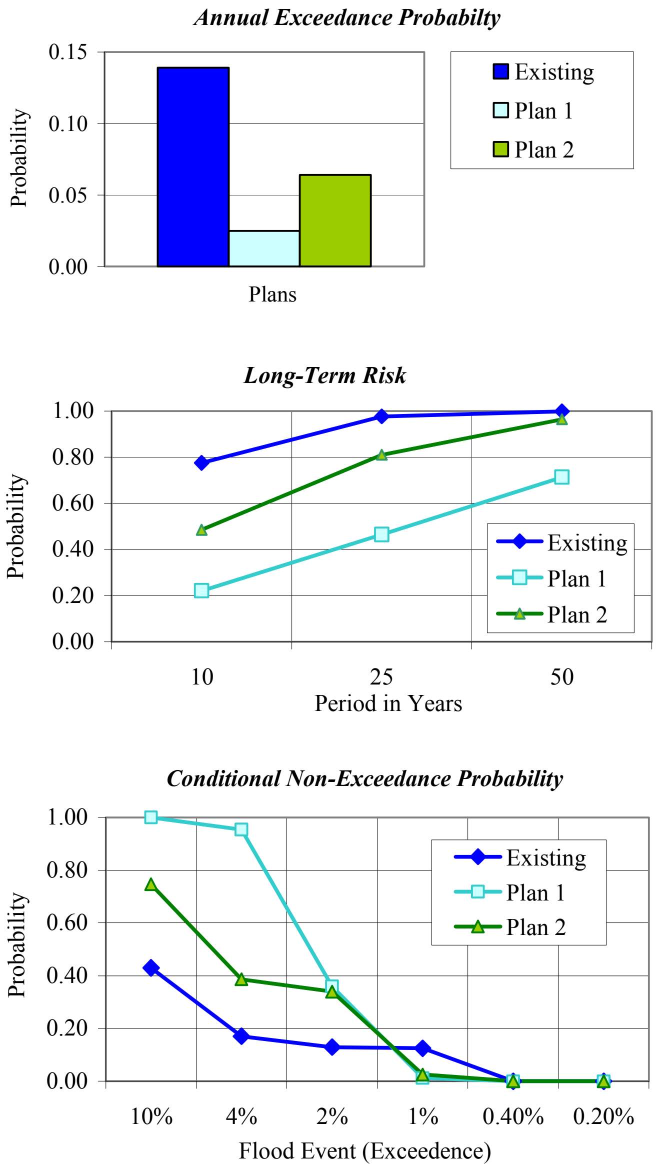
Generating hybrid stage-frequency curves from the hydraulic models and passing this data to HEC-FDA is one of the most time-consuming steps in the basin-wide evaluation process. During conceptual planning stages, it may not be necessary or time-efficient to examine all of the index points and damage areas. Instead, the study developed a procedure in which the index points and damage areas were grouped into larger, “bubble” areas for quick, initial analysis. Nine of these bubble areas were delineated in the Sacramento River basin and seven in the San Joaquin River basin. One index point was chosen to represent all damage areas within a given bubble area. The index point was chosen based on several factors including stage conditions, topography, initial breakout, and significance of damages caused. The hydrology and reservoir operation steps of the evaluation process do not change, and hydrographs from all frequency events are still run through UNET. However, fewer stage-frequency curves are developed and iterations are stopped when the HEC-FDA risk results are within an acceptable margin of the desired targets. Because not all index points are evaluated in the expedited analysis, there is a potential to over- or underestimate the success of an evaluation in meeting its goals. Thus, the expedited analysis process is limited to conceptual planning.

Interpreting Evaluation Results

Figure 16 provides an example comparison of project performance statistics in a representative impact area. The top panel compares annual exceedance probabilities for existing conditions with two hypothetical alternative evaluations. Both alternative evaluations have lower annual exceedance than for existing conditions, thus both plans represent an improvement. Similarly, the middle panel indicates that long-term risk is lower for both of the hypothetical evaluations compared to existing conditions. In the bottom panel, both plans show improved non-exceedance values (the ability to pass specific events) for the 10%, 4%, and 2% flood events, but values for the 1% event are slightly less than existing conditions.

When evaluating results between UNET and HEC-FDA, it is important to remember that HEC-FDA applies uncertainty to all aspects of a plan. For example, safely conveying a 1% flood flow in UNET may not be sufficient to achieve a 1% AEP in HEC-FDA. This is because UNET does not consider the possibility that the computed hydrology or water surface for the 1% event could be inaccurate.

Consider the hypothetical evaluation of a levee that is intended to provide a CNE of at least 0.90 for the 2% flood event (a 90% chance of passing the 2% flood). UNET modeling is performed to determine the peak water surface elevation for the 2% flood and the LFP of the new levee is set to this elevation. A stage-frequency curve is prepared for the index point in this reach and passed to HEC-FDA. However, the calculated CNE reflects only a 65% probability of passing the 2% flood because the hydrology for this reach is based on only 15-years of gage record, introducing uncertainty. Fine-tuning of the stage-frequency curve indicates that an additional 1.5 feet will need to be added to the top of the levee in order for the project to achieve the CNE target of at least 0.90 for the 2% flood.


Annual Exceedance Probabilty

Long-Term Risk

Conditional Non-Exceedance Probability

FIGURE 16 – SAMPLE COMPARISON OF PROJECT PERFORMANCE RESULTS