# Westfield Boulevard Alternative

Supplemental Concept-Level Economic Analysis

## 1 - Introduction and Alternative Description

This document presents results of a concept-level[1] incremental analysis of the Westfield Boulevard alternative, intended to assess the feasibility of this alternative relative to the 56th Street alternative (used as the baseline) on the basis of additional costs incurred versus benefits accrued. As an incremental analysis, both costs and benefits considered reflect only the incremental increase in cost/benefits associated with the Westfield Boulevard alternative.

For this analysis incremental benefits of the Westfield Blvd alternative over the 56th St alternative were assessed as reductions in expected annual damages; damages in the without-project condition minus residual damages in the with-project condition. Damages in both the with-project and without-project conditions were estimated for structures and their contents in the Butler Tarkington neighborhood.

The Hydrologic Engineering Center's Flood Damage Analysis (HEC-FDA) model was used to perform a risk-based analysis of damages for both conditions. All dollar values shown are in a 2013 price level. These were indexed from the 2011 price levels of the original analysis for even comparison to the most recent 2013 cost estimates using the ENR CCI. All discounting and amortization was done using the FY13 federal discount rate of 3.75%.

The following sections detail the data gathering, data processing, and modeling (providing a brief overview of the model's function), as well as a summary of analysis results.

## 2 - Structure Inventory

The analysis area was delineated as the area of the Butler Tarkington neighborhood that fall within the leveed area of the approved Westfield Blvd alternative, but that would not fall within the leveed area of the 56th St alternative. This includes the area of Butler Tarkington south of 56th street, and west of N. Meridian Street. The structure inventory is a dataset of properties within the analysis area, including all relevant data to be used as input parameters for the HEC-FDA analysis. Structure data required for HEC-FDA analysis can be subdivided into four primary components; structure counts and locations within the floodplain (stream name and stationing corresponding to that used in the Hydraulic and Hydrologic (H&H) model), structure values and other characteristics, structure elevations, and susceptibility to flooding damages and the magnitude of those damages as represented by a depth-damage curve. The processes for developing these components are detailed below.

[1] "Concept-Level" is used here to describe a level of effort considered to be lower intensity than a reconnaissance level analysis

## 2.1 *Structure Locations and Values*

Structure footprints (as ArcGIS shapefiles) and detailed parcel data were obtained for the structures in the Butler Tarkington area from the Marion County Assessor's Office. Structure footprints provide the geospatial location of individual structures, as well as their first floor square footage. The parcel data was also geospatially referenced, and contains a significant amount of additional data on these structures, including improvement values.

The structure footprints include not only residential, commercial, and public structures, but also all associated out-buildings; garages, car-ports, sheds, etc.. As such, there were often multiple structure footprints in a given parcel, with only one of them being the 'primary' structure (see image at left).

To identify the correct structures within each parcel, in order to correctly associate structure value data from one dataset to structure location in the other, a simple algorithm was used in which the footprint with the largest first floor square footage was assumed the 'primary' structure in each parcel. Structure values from the parcel data were assessed values in 2011 price levels. Typical flood risk management analyses use depreciated structure replacement values, the value to replace the structure new, depreciated by effective age of the structure, rather than assessed values.

## 2.2 *Structure Elevations*

The geospatial location of the identified 'primary' structure footprints are important for the association of individual structures to H&H input data, which is itself associated with stream stationing, and for the assignment of ground elevations to these structures. Ground elevations were assigned by overlaying these footprints over a digital elevation model (DEM) with five-foot grid cells obtained from the Indiana Geologic Survey. This DEM was converted from the NAVD88 to the NGVD29 vertical datum for compatibility with H&H model inputs already in the latter datum. The average of each grid cell of this terrain model (each grid cell representing an elevation) falling within the footprint of a given structure was then assigned to that structure as its ground elevation. The terrain in the area analyzed is fairly flat.

## 2.3 *Structure Characteristics*

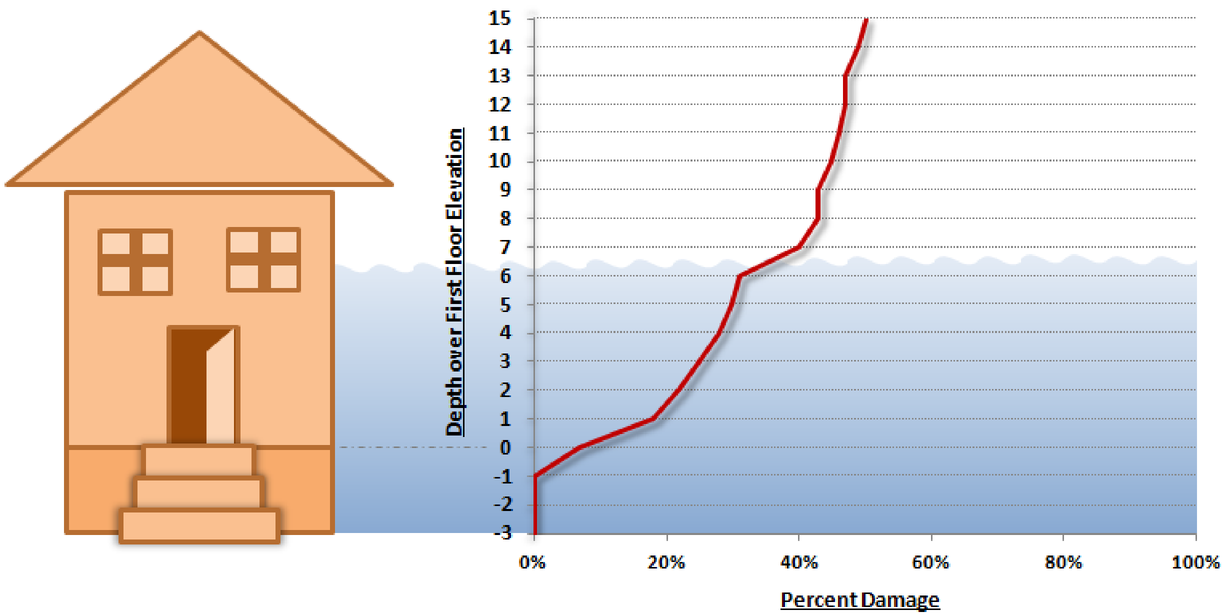
In addition to structure values and elevations, a number of other structure characteristics are critical for accurate estimation of flood damages. These include foundation heights (relative elevation of the structures first or ground floor over the ground elevation described above), structure class (residential/commercial/public), number of stories, and the presence or absence of a basement. Structure class information was available from the parcel data. The remainder of these data were approximated, in the absence of a detailed site survey, as area averages. The average foundation height for all structures was assumed to be approximately 2 feet. Similarly no finished basement was assumed, and all residential structures were assumed single-story.

### 2.4 *Depth-Damage Relationships*

The structure class, presence of a basement, and number of stories estimated above are used to assign each structure a depth-damage relationship, or curve. Standardized generic depth-damage curves developed by the USACE Institute for Water Resources' (IWR) Flood Damage Data Collection Program were used in this analysis[2]. Flood damage data were collected under this program from nationwide flooding events during the period of 1996 through 2001, and these curves and their associated standard deviations of error were developed by IWR via regression analyses on the data collected.

Depth-damage curves essentially relate a flood depth, relative to the first floor elevation of a given structure, to a damage or economic loss represented as a percentage of that structure's value. Standard residential depth-damage curves for single-story, 2-story, and split level homes with and without basements were used in this analysis. Figure 1 below illustrates the concept of a depth-damage relationship for a single-story home without a basement. Two such curves exist for each structure, one describing the relationship between depth and structure damage, and the other depth and content damage –both represented as a percentage of structure value.

**Figure 1 – Depth-Damage Example**




## 3 - Hydraulic and Hydrologic Data

The second key component of flood damage analysis is how the flooding itself is modeled. Hydraulic and Hydrologic (H&H) data is used to estimate flood stages at structures for the eight analyzed probabilistically weighted flood scenarios. This process is summarized below.

[2] Depth-Damage curves published in Economic Guidance Memorandum (EGM) 04-01, dated 10 Oct 2003

### *3.1 Water Surface Profiles*

H&H data was provided in the form of water surface profiles for five cross sections along the White River. These water surface profiles relate stage and discharge to each stream station for a range of eight possible flood events, ranging from those with a nearly 100% chance of exceedance in a given year, to those with 0.2% exceedance chance (commonly referred to as a 500-year flood). Uncertainty around discharge exceedance probability (the chance in a given year of river flow exceeding a set amount, or "discharge") and stage discharge relationships (expected river stages associated with a given discharge) for each cross section are additionally incorporated into the HEC-FDA model. During HEC-FDA model runs, these input parameters are sampled from within the defined uncertainty ranges for each Monte Carlo iteration (this is discussed in greater detail later).

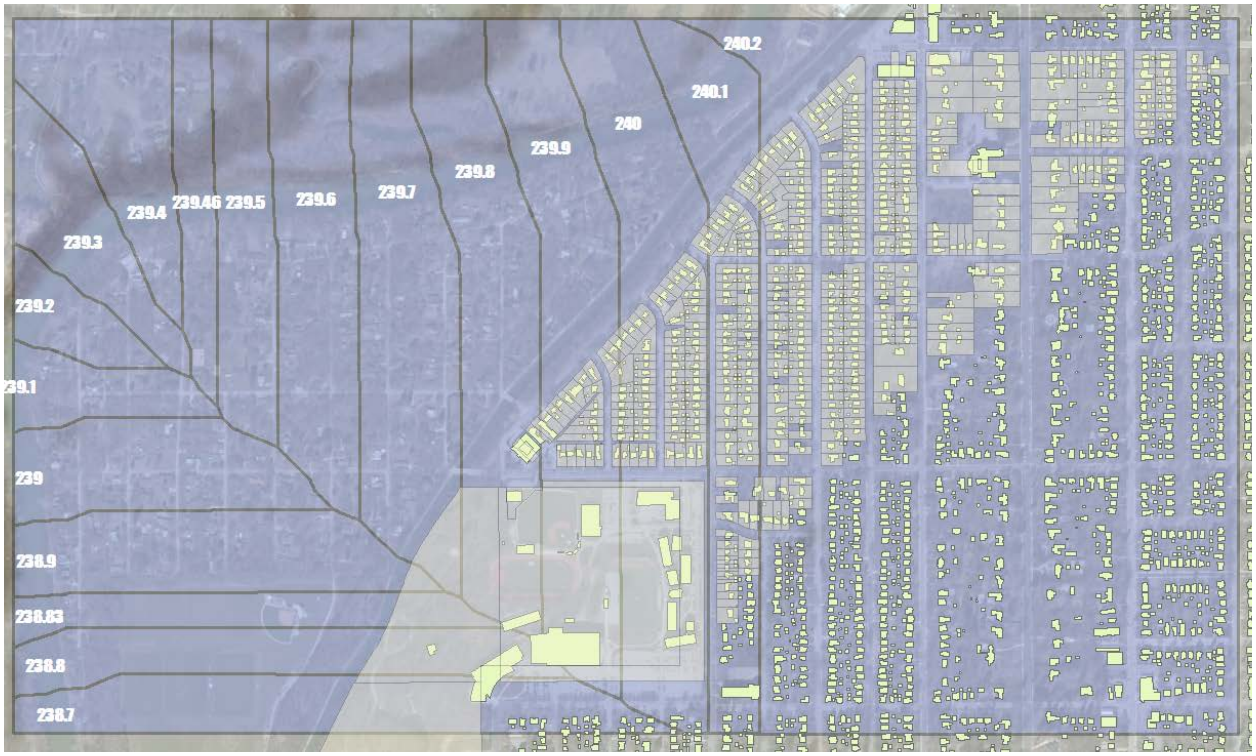
Because HEC-FDA dynamically interpolates water surface profile data between input stream stations, structures can be assigned to these interpolated stream stations to more accurately represent flood stages at their locations. If, for example, a significant variance in stage exists between two stream stations, depth for various flood scenarios at structures somewhere between these two can be either significantly under or overstated unless the structure is more accurately "placed". To accomplish this, stream stations were interpolated at one-tenth mile increments and assigned to structures using the process described below.

### *3.2 Structure Assignment to Stream Stationing*

Because the HEC-FDA program estimates flood depths at structures by associating these structures with stream stationing, to what stations individual structures are assigned becomes a critical component of damage estimation. Typically this is accomplished by cross-sectioning, with cross-sections drawn perpendicular to the stream centerline and generally following topographic lines. Given the availability of hydrologic data for only five given cross sections along the White River and the geographic character of the area, a cost-distance analysis was performed with ESRI's ArcMap 9.3 software to assign structures to the interpolated cross sections.

The cost-distance analysis determined the least-cost path from each individual structure to the White River; cost being a function of distance and elevation. This was used to create an allocation raster, which associated each grid cell to the interpolated stream station with the minimal cost-weighted distance. The structure footprints were then overlaid on this allocation raster and this was used to assign structures to interpolated stream stations. Figure 1 below illustrates the results of this analysis.

**Figure 2 – Stream Station Assignment**




## 4 - HEC-FDA Analysis

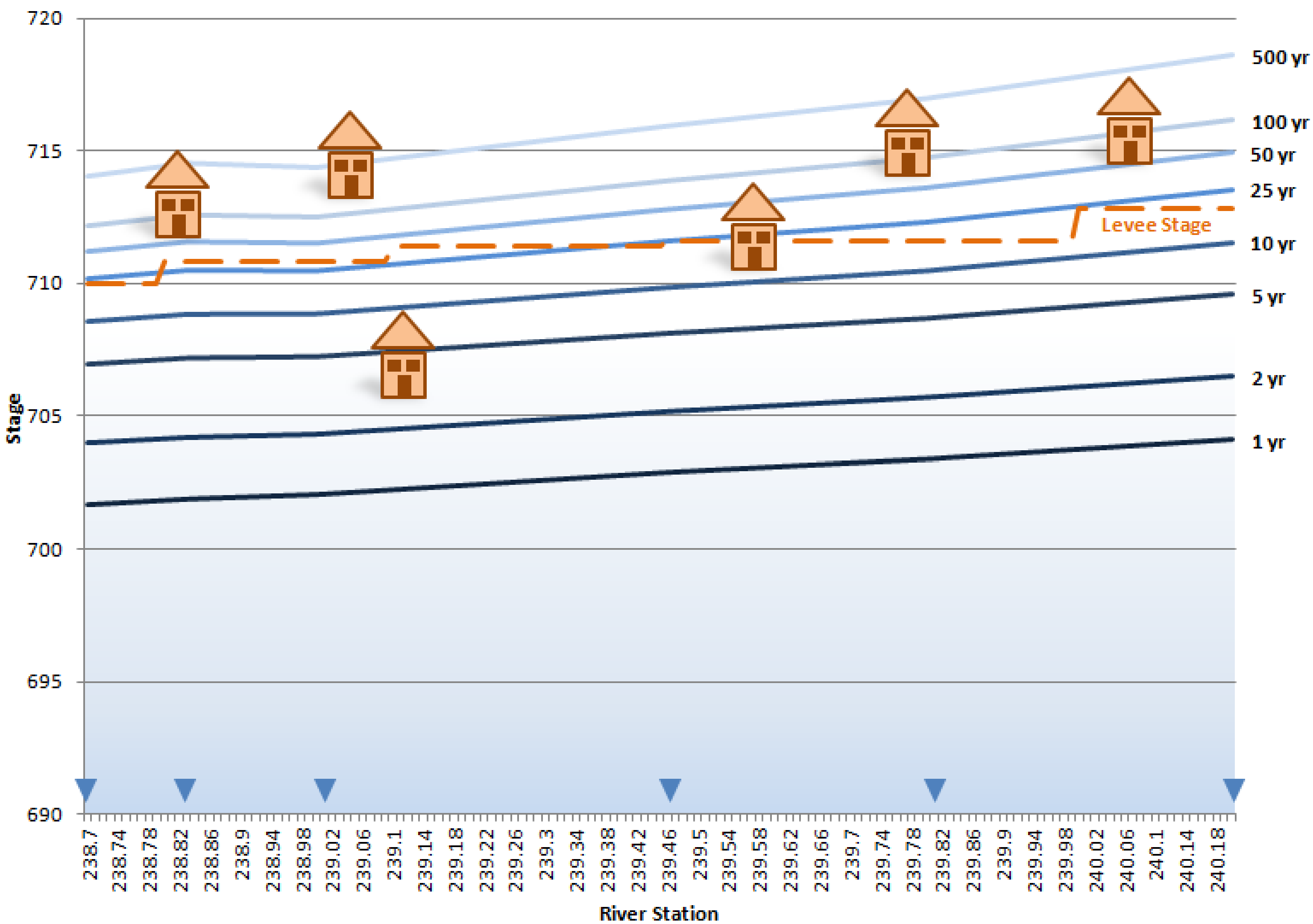
The US Army Corps of Engineers requires the use of risk-based analysis for evaluating flood damages and flood damage reduction measures, as described in ER 1105-2-101, Risk Analysis for Flood Damage Reduction Studies. A risk-based analysis accounts for uncertainty in the stage-flow relationships, discharge -exceedance probability relationships, stage-damage relationships, structure characteristics, and other categories for which uncertainty exists. This procedure further integrates them into an economic analysis for with and without-project conditions and a performance analysis for flood reduction measures. These computations were performed for this analysis using the HEC-FDA software package, version 1.2.4.

All of the data previously described are integrated within the HEC-FDA program, along with associated uncertainty distributions. FDA performs a 'Monte Carlo' analysis using these distributions to model uncertainty in model inputs. This Monte Carlo analysis will be explained below.

### *4.1 Model Overview*

FDA can be thought of as a 2-dimensional model; it doesn't know where a structure is geospatially, only to what set of water surface profile data it is assigned (as well as elevation and other characteristics). It can be thought of best in linear terms, with the stream or river (in this case the White River) along the x-axis, as represented in Figure 3. This is somewhat of a simplification, but helps illustrate how the model functions.

**Figure 3 – HEC-FDA Illustration**




For each river station, a series of river stages are associated with a range of flood events ranging in exceedance probability from 99% (1 year flood) to 0.2% (500 year flood). Structures are associated with these stations (both those input from H&H data – identified with the blue triangles in the Figure, and those interpolated within the model), and are essentially placed along the y-axis at their ground elevation. It is important to point out that nearly all of these input parameters have defined uncertainty distributions, so the 5 year flood stage curve illustrated in the Figure above for example will in fact have a distribution around it, within which actual stages could fall. As a further example, each structure shown in the Figure will have a stage-damage curve associated with it, assigning a percentage loss of the structure and contents to the depth of flooding at that structure. This curve too will have a uncertainty distribution around it, so for example the five year flood depth could be a foot higher (or lower) than that shown, and damages associated with that depth could be 6% higher (or lower) than shown on that structure's depth-damage curve.

The area between each pair of river cross sections (the blue triangles in Figure 3) was configured as a "reach" in the HEC-FDA model. Within each reach is an identified station called the "index location" (typically near the midpoint). Within this framework, FDA is essentially aggregating and analyzing a series of probabilistic curves defining relationships between flood stage and frequency of occurrence, and flood stage and damages. These are used ultimately to generate a curve relating probability of occurrence and total damages (called a "damage frequency curve"), the integration of which provides expected annual damages (EAD – this concept will be discussed later). Stage-exceedance probability functions for each reach are used to generate a range of stages and probabilities at each index location that will be used in the creation of an aggregated stage damage function for that reach. This aggregated stage damage function represents the total stage-damage relationship of that reach, including damages to all structures and contents within it, for a series of probability ordinates.

The HEC-FDA software is essentially generating a reach-wide depth-damage function similar to those input for each structure as described above (and similarly with uncertainty). To generate these aggregated damages, total damages must be estimated for all structures and contents within that reach for a given stage at the index location. To do this, accounting for the variation in stage throughout the reach, the water surface profiles are used to translate the index stage to corresponding stage at the stream station of each structure. These stages are then compared to that structure's ground elevation + foundation height, the difference applied the structure's individual depth-damage functions (content and structure), and percent damages computed using these functions. Dollar damages are computed by simply multiplying the percent damage by the total structure value.

### *4.2 Monte Carlo Analysis*

HEC-FDA uses Monte Carlo simulation to account for uncertainty and to make estimates that don't reflect the single most likely outcome (i.e. flood damages of a certain dollar value), but rather the *average* of all possible outcomes, known as an 'expected value'. This approach is also useful in that it provides a distribution of results, translating uncertainties around input parameters into an uncertainty distribution around model outputs.

This Monte Carlo analysis is a random sampling approach in which uncertain input parameters are randomly sampled from associated uncertainty distributions, the model is run and results saved, and then these distributions re-sampled, the model re-run, and this process continued for hundreds of thousands of iterations until results "converge" on an expected value. This convergence is similar to if you were to average the roles of a die in a similar iterative fashion: rolling the die once, computing the average (whatever number you rolled), rolling again, re-averaging etc.. The cumulative average with each iteration would change dramatically, but as you performed more and more iterations, the averages would become closer and closer, eventually converging on 3.5. You could easily cheat in this example, and simply take the average on each possible outcome, one through six, as each outcome in the die rolling example has the exact same probability of occurrence. Monte Carlo analysis is used in FDA to extract this average for a complex model in which there are a vast multitude of possible outcomes, each with a different probability of occurrence. For this analysis, 500,000 iterations were performed for each of the 5 reaches analyzed.

## 5 - Analysis Results

HEC-FDA model results are presented as "expected annual damages" or EAD. These do not represent the damages expected to occur in a given year, but rather the probability weighted damages of the range of analyzed flood events. For this analysis a 50 year analysis period was used. The previous discussions of FDA methodology described the process of creating an aggregated damage-frequency curve, a curve which relates property damages in the area with probabilities of occurrence. Expected annual damages result from the integration of this curve performed by Monte Carlo simulation in risk-based analysis.

### *5.1 Without-Project Condition*

Without-project condition EAD for this analysis represents the annualized value of the range of potential flood damages given the 56th Street alternative. These damages are only those that would occur to structures that would be protected in the with-project (Westfield Blvd) condition, but are not protected by the 56th St alternative.

Expected annual flood damages are shown for each of the five reaches analyzed in the following screen capture from HEC-FDA. In this table it can be seen that structure damages occur in reaches 4 and 5, and that the primary damage category is single-family residential structures. Note that all dollar values are in 1,000's. The final row represents the totals by category.

**Figure 4 – Without-Project EAD by Reach[3]**

Expected Annual Damage by Damage Categories and Damage Reaches
for the Without (Without project condition) Plan and Analysis Year 2011
(Damage in $1,000's)
Plan was calculated with Uncertainty

| Damage Reach Name | Damage Categories | | | | | Total |
|---|---|---|---|---|---|---|
| | Commercial | Mobile Home | Multifamily | Public | Single Family | |
| RR Section 1 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| RR Section 2 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| RR Section 3 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| RR Section 4 | 0.69 | 0.00 | 0.03 | 4.45 | 35.73 | 40.89 |
| RR Section 5 | 0.42 | 0.00 | 0.01 | 0.12 | 76.64 | 77.18 |
| | 1.11 | 0.00 | 0.03 | 4.57 | 112.37 | 118.07 |

[3] Values shown are in 2011 price levels from the initial model runs. These have been indexed to 2013 price levels using the ENR-CCI

## *5.2 With-Project Condition*

With-project condition EAD represents annualized flood damages to structures given the Westfield Blvd alternative. Damages reduced in the with-project condition are illustrated for reaches 4 and 5 in the following screen captures from FDA. The green curves represent damages (y-axis) in the without-project condition; the red curves represent damages in the with-project condition. The x-axis is exceedance probability (the probability that damages will equal or exceed those shown on the y-axis in a given year). The incremental damage reductions (benefits) of the Westfield Blvd alternative would, conceptually speaking, be the area between these without-project curves and the with-project curves (the integration of these curves does not produce EAD – these curves are approximate and do not account for uncertainty).

**Figure 5 – Reach 4 Mean Damage Reduction Plot**

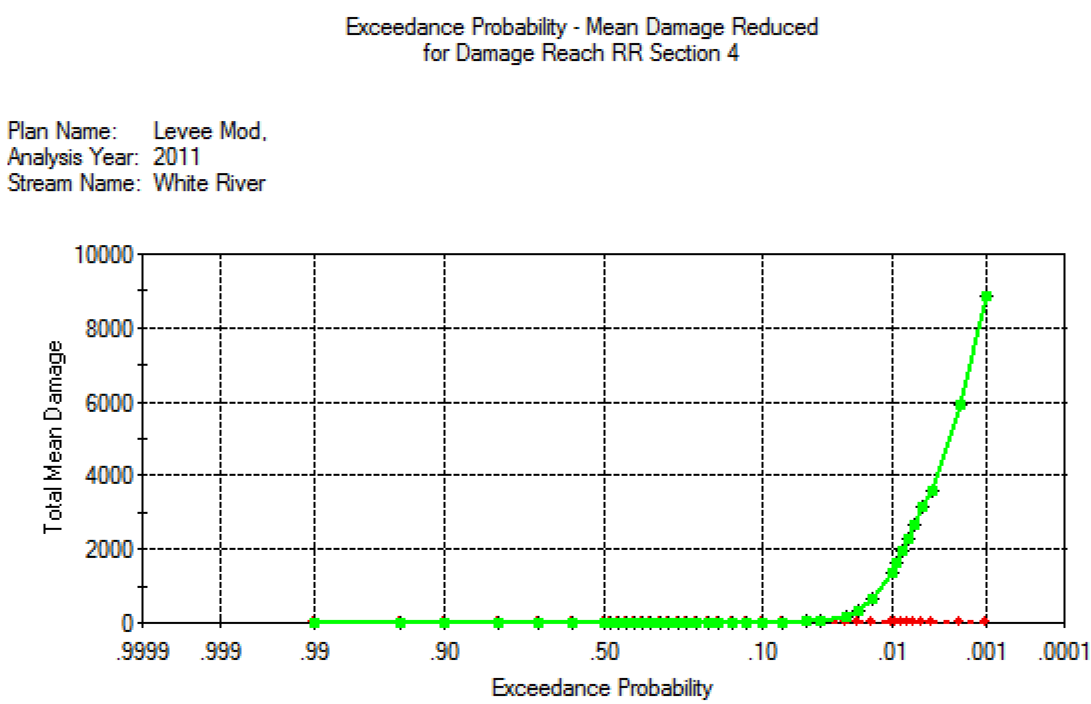
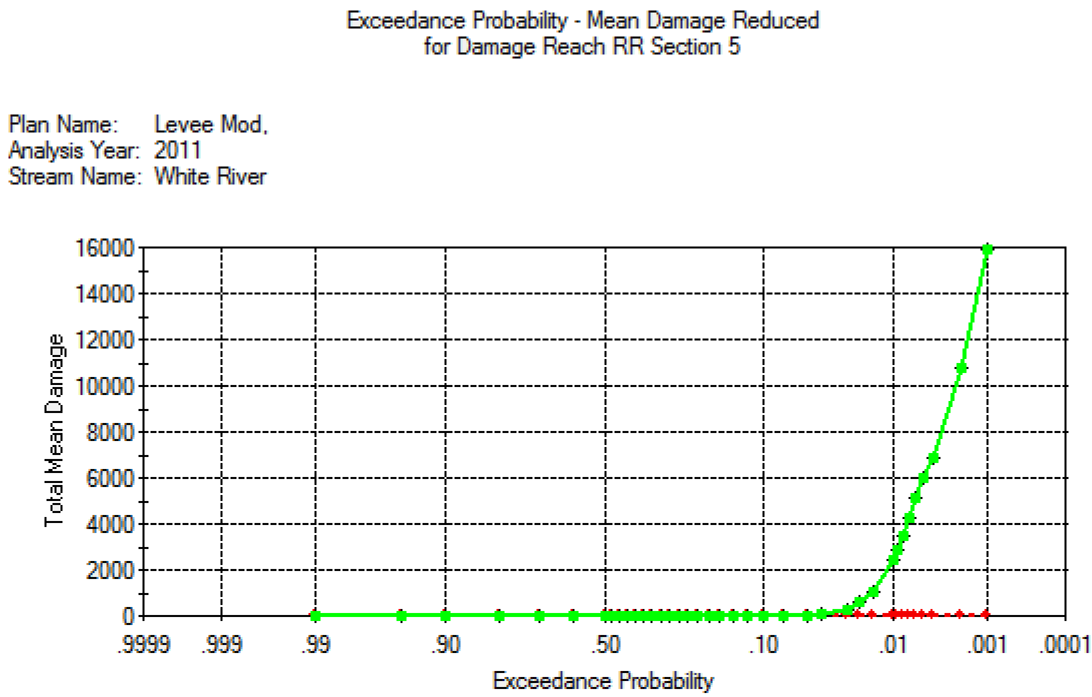


**Figure 6 – Reach 5 Mean Damage Reduction Plot**




## *5.3 Expected Annual Damages*

Table 1 and Table 2 below display the HEC-FDA model results as expected annual damages in the without-project and with-project conditions, as well as project benefits (without-project EAD minus with-project EAD), and the uncertainty around these benefits.

**Table 1 – Expected Annual Damages**

| | |
|---|---|
| Without-Project Condition | $124,088 |
| With- Project Condition | $399 |
| **Damage Reduction (Benefits)** | **$123,689** |

Given the uncertainty around input parameters, this benefit estimate is likewise uncertain. To best capture the likelihood of project feasibility, the uncertainty of benefit estimates should be illustrated. Table 2 below roughly approximates this uncertainty; each value in the right-hand column indicates the damage reductions, or benefits, which have the probability of being exceeded shown in the left-hand column. So for example there is a 25% chance that the Westfield Blvd alternative could provide annualized incremental benefits greater than $165,287 in value (and likewise a 75% chance that it will provide benefits less than this value).

**Table 2 – Percent Chance Damage Reductions Exceed Indicated Values**

| | |
|---|---|
| 75% | $26,253 |
| 50% | $76,406 |
| 25% | $165,287 |

### 5.4 *Annualized Implementation Costs*

As stated earlier, the costs used in this analysis reflect only the incremental costs necessary to implement the Westfield Blvd alternative over the 56th St alternative.  These incremental costs, including interest during construction (IDC), were annualized over the 50 year analysis period (at a discount rate of 3.75%) for comparison to expected annual benefits.  Total costs, interest during construction, and the annualized value of these costs are shown in Table 3 below.

**Table 3 – Implementation Costs**

| | |
|---|---|
| Total Cost | $364,000 |
| Interest During Construction | $40,403 |
| Total Cost w/ IDC | $386,403 |
| **Annualized Costs** | **$17,224** |

### 5.5 *Benefit-Cost Ratios*

The results of a benefit-cost analysis can be displayed in two ways: as a single net benefits number (benefits minus costs) and as a benefit-cost ratio (BCR).  Net benefits are typically used to select and scale a recommended course of action from an array of alternatives within the context of a single study or analysis.  Benefit-cost ratios are used as a metric to test the viability of a proposed course of action; a benefit-cost ratio greater than one indicates that every dollar invested will yield in excess of 1 dollar of benefit to the nation.  A benefit-cost ratio less than one indicates that every dollar invested will yield less than one dollar in benefit.

Benefit-cost ratios are computed using the annualized costs and annualized damage reductions associated with the alternative or plan analyzed. The (concept-level) incremental benefit-cost ratio for the Westfield Blvd alternative *over* the 56th St alternative then would be:

$$\frac{\$123{,}689}{\$17{,}224} = 7.18$$

Using the uncertainty parameters shown in Table 2 above, we can extrapolate the *range* of possible benefit-cost ratios given uncertainty around project benefits (note this does not incorporate cost uncertainty, essentially assuming costs are certain). This is shown in Table 4 below:

**Table 4 – Percent Chance BCR's Exceed Indicated Values**

| | | |
|---|---|---|
| 75% | $\frac{\$26{,}253}{\$17{,}224}$ | = 1.52 |
| 50% | $\frac{\$76{,}406}{\$17{,}224}$ | = 4.44 |
| 25% | $\frac{\$165{,}287}{\$17{,}224}$ | = 9.6 |

It should be noted that the uncertainty represented by these ranges does not fully encompass the uncertainty around model results and thus benefit-cost ratios or net benefits, especially in the case of a concept level analysis such as this one. These benefit-cost ratios are intended only to depict a *likely range* of outcomes.